

# Minimizing Impediments to Design for Construction Safety (DFCS) Implementation on Capital Projects

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## Dissertation

PhD AECM (Architecture-Engineering-Construction-Management)

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Date Submitted: April 30, 2012

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This dissertation document is submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Architecture-Engineering-Construction-Management.

## Abstract

The construction industry is notorious for having one of the worst safety records among all industries in the private sector (Bentil, 1990; and Behm, 2005). In the United States, the industry accounts for up to 18% of work-related deaths and 15% of all worker compensation cases with approximately 1,000 construction workers killed annually (BLS, 2000-2009).

Towards minimizing safety hazards and incidents, construction companies employ several strategies including safety planning, staffing and training among many others (CII, 2003). Different strategies apply to different project phases. However, as the early identification and elimination of potential safety hazards is not only more effective but cheaper (Behm 2005; and Anumba, 1999), those strategies applicable to the earlier project phases are likely to have a more significant impact in improving construction worker safety. One of such strategies, Design for Construction Safety (DFCS), has the ability to function effectively in the current Architecture/Engineering/Construction (AEC) industry environment without requiring any major changes in procedure or contractual structure. DFCS is the explicit consideration of construction worker safety in the design of a project (Toole and Gambatese, 2008). Besides the ultimate benefit of decreasing site safety hazards, DFCS, through the proactive identification and elimination of hazards is safer and more cost effective than reactive management of the same hazards (Toole and Gambatese, 2008).

The most critical impediments to DFCS include designers' concern about increased liability, increased cost, and designers' lack of safety expertise. Others include concerns about schedule problems, diminished design creativity, and designers' lack of interest (Gambatese et al, 2005). To assist designers in DFCS implementation, safety researchers sponsored by the Construction Industry Institute (CII) developed over 400 design suggestions to minimize or eliminate certain construction safety hazards (Gambatese et al, 1997). These suggestions were incorporated in a computer program, the DFCS Toolbox. Besides this, other research has been conducted and guidelines developed to aid DFCS implementation.

However, as DFCS is still experiencing limited application (Toole and Gambatese, 2008), this research presented a different paradigm. This paradigm considered that the guidelines and tools provided to enable and aid DFCS implementation were incomplete, inaccurate and/or inadequate to serve their intended purpose. Through this research, some of the available guidelines and tools were fine-tuned and detailed to better enable DFCS implementation. Hence, the research produced certain deliverables.

Firstly, the research identified DFCS measures that meet all the criteria for being situated in the capital project design phase. Secondly, the research identified impediments to implementing each of these design-phase DFCS measures where applicable. Thirdly, the research obtained revisions of certain design-phase DFCS measures based on their identified impediments to make them more viable, both for implementation and for improving construction safety. Additionally, the safety benefits of implementing each of the design-phase DFCS measures were identified through the publicly accessible Occupational Safety and Health Administration (OSHA) database. These benefits refer to the construction hazard incidents that could have been prevented by implementing the DFCS measures. Lastly, a relational database application was developed to assist designers in making safety a consideration in the early phases of the capital project delivery process. This desktop software application was developed to have the functionality to provide the design-phase DFCS measures, their preventable safety incidents, their potential impediments, potential solutions to their impediments, and their tier of feasibility, based on project characteristics, design profession, and the stage of the design phase. The application also allows for the addition of new DFCS measures and accompanying data. It therefore incorporates the other research deliverables and thus, encapsulates the research findings to serve as a vehicle for utilizing the data to enhance DFCS implementation. In producing and validating these deliverables, a number of research tasks were executed including survey administration to AEC design professionals. Also, over 30 interviews were conducted with design professionals.

Besides the deliverables, there were a number of findings from the research results. Firstly, the results emphasized a key shortcoming of the DFCS concept. This is the effectiveness of DFCS depends on construction sequence. Secondly, it was determined that DFCS measures or modifications that not only improve construction worker safety but occupant and maintenance worker safety are more likely to be implemented by AEC design professionals and more likely to be accommodated by project owners as well. On this basis, a new dimension was identified towards increasing and improving DFCS implementation. Thirdly, this research further emphasized that the design-build project delivery method offers more opportunity and fewer barriers for DFCS implementation.

This research made a number of contributions. Firstly, the research characterized the design suggestions for construction worker safety yielded from earlier research. This research also brought focus to individual DFCS measures and their feasibility for implementation, as opposed to for the DFCS concept as a whole. Secondly, this research, through its deliverables, serves in fulfilling several earlier recommendations for DFCS research and some earlier identified information gaps. These research contributions are collectively intended to enhance and increase DFCS implementation on projects towards improving construction safety. There are a number of motivating factors for this. Firstly, professional, ethical and moral obligations require the safety of others to be protected. Secondly, the improvement of safety could potentially benefit every project stakeholder and participant by minimizing or eliminating the numerous costs associated with injuries to construction workers. Thirdly, all project participants may also benefit in that reducing the number of construction accidents and injuries could avoid disruption to work and avert delays in project completion and as a result, improve productivity (Huang, 2003). Additionally, poor safety performance and its resulting consequences such as court cases and lawsuits expose all project participants to bad publicity which could have such adverse impacts as preventing job awards or causing even more lawsuits from prior projects (Huang, 2003). These reasons collectively highlight the importance of improving construction worker safety and towards this goal, this research emphasized and enhanced DFCS as a strategy for reducing or eliminating construction hazard risks on capital projects.

## Acknowledgements

I owe an incalculable debt of gratitude to Prof. Omer Akin for chairing my advisory committee and guiding me through this research. His insight and perspectives demonstrated experience and wisdom which I someday wish to have. His time and tireless efforts are forever appreciated. I would also like to thank Prof. Burcu Akinci for her input in the research design and execution. Her questions continuously exposed critical issues in the research. I must also thank Prof. Chimay Anumba, not only for his constructive comments and contributions, but for his effort in traveling several hours for multiple research meetings. All three advisors have earned my unending thanks.

I gratefully acknowledge the participation of exactly 100 AEC design professionals in this research. This includes those who completed surveys and those with whom I conducted interviews, along with those that participated in the pilots. I greatly appreciate their time, effort, and input. To them, I give many thanks. I especially wish to thank those that either referenced or provided me with documents that supported their remarks and responses. The documents were all of much value. I am also thankful to two DFCS researchers, Prof. John Gambatese and Prof. Michael Behm, for providing me with useful sources of information through correspondence and through research literature. I also wish to thank the entire Graduate Programs Committee of the School of Architecture. I particularly acknowledge Prof. Vivian Loftness, with whom I worked on different research projects. Her breadth of knowledge is impressive to say the least. I also wish to acknowledge my colleagues in the AECM PhD program. They gave vibrancy to an otherwise quiet research atmosphere.

Special thanks go to my father, Adamu Bello. He not only influenced me to enroll in the PhD program but provided multi-dimensional support towards its completion. For emphasizing the value of education, setting high standards, and for everything else, he has my everlasting thanks and unquestionable loyalty. I would particularly like to thank my mother, Lubabatu, for helping me develop a work ethic that has made my progress to date possible. Whether through hereditary or through effort, I always strive towards meeting the high bar she set for attention to detail. For all she has done for me, I am eternally grateful.

I would also like to thank my five siblings. Without them, my life would not be half as interesting as it has been, even during this period of study. To my friends and well-wishers, though without naming names, I say thanks for their high expectations of me and for their constant supply of useful and entertaining stories that brightened up my days. I am also thankful to everyone that contributed to my development academically, professionally, and as a person. For those that contributed to this research or to my development, who were not identified, my failure in acknowledgement is in no way a measure of the importance of the role they have played. My gratitude is assured.

## Abbreviations and Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ABET	Accreditation Board for Engineering and Technology
ADA	Americans with Disabilities Act
AEC	Architecture/Engineering/Construction
AHMCT	Advanced Highway Maintenance and Construction Technology
AHP	Analytic Hierarchy Process
AIA	American Institute of Architects
AIS	Accident Investigation Search
AOD	Associated Owners and Developers
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASSE	American Society of Safety Engineers
BIM	Building Information Modeling
BLS	U.S. Bureau Of Labor Statistics
BOCA	Building Officials Code Administrators
BVB	Best Value Bid
CABO	Council of American Building Officials
CAT	Comparative Analysis Table
CDM	Construction Design and Management
CE	Concurrent Engineering
CFR	Code of Federal Regulations
CHAIR	Construction Hazard Assessment and Implication Review
CHPTD	Construction Hazard Prevention Through Design
CII	Construction Industry Institute
CPDP	Capital Project Delivery Process
CPWR	Center to Protect Workers' Rights
CURT	Construction Users Roundtable
DBIA	Design-Build Institute of America
DBMS	Database Management System
DFCS	Design For Construction Safety
DFS	Design For Safety
DFSP	Design-for-Safety-Process
DOT	Department of Transportation
EJCDC	Engineers Joint Construction Documents Committee
FACE	NIOSH Fatality Assessment Control and Evaluation
GUI	Graphical User Interface
HVAC	Heating, Ventilation and Air Conditioning
IBC	International Building Code
ICBO	International Conference of Building Officials
ICC	International Code Council
IEEE	Institute of Electrical and Electronics Engineers
IPD	Integrated Project Delivery

IRB	Institutional Review Board
LEED	Leadership in the Energy and Environmental Design
MEP	Mechanical/Electrical/Plumbing
MLCM	Modified Loss Causation Model
NAICS	North American Industry Classification System
NEC	National Electrical Code
NETA	Inter-National Electrical Testing Association
NFPA	National Fire Protection Association
NIOSH	National Institute For Occupational Safety And Health
NIST	National Institute of Standards and Technology
NORA	NIOSH National Research Agenda
NSC	National Safety Council
NSPE	National Society of Professional Engineers
OSHA	U.S. Occupational Safety and Health Administration
PC	Personal Computer
PPE	Personal Protective Equipment
RDBMS	Relational Database Management System
SBCCI	Southern Building Code Congress
SIC	Standard Industry Classification
SMS	Safety Management System
SQL	Standard Querying Language
SRS	Software Requirements Specification
SWA	Safe Work Australia
TIPS	Tool for Implementation on Projects and Systems
USGBC	United States Green Building Council
VBA	Visual Basic for Application

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# **1.0 Introduction**

## **1.1 Motivation**

### **1.1.1 The Poor Safety Record of the Construction Industry**

The construction industry is notorious for having one of the worst safety records among all industries in the private sector (Bentil, 1990; and Behm, 2005). In the United States, the industry accounts for up to 18% of work-related deaths and 15% of all worker compensation cases with approximately 1,000 construction workers killed annually (BLS, 2000-2009). Construction has about 8% of U.S. workers, but 22% of the fatalities (NIOSH, 2009).

Between 2000 and 2009, the U.S construction industry had the highest number of fatalities among all industry sectors (BLS, 2000-2009). However, with regards to the fatality rate of workers, the construction sector stood behind the agriculture, fishery, forestry & hunting sector; the mining sector; and the transportation & warehousing sector. During this same period, the injury incidence rate for the construction industry was the third highest standing behind transportation & warehousing and manufacturing (BLS, 2000-2009).

The industries on par with the construction industry in possessing the highest rates of fatalities and injuries highlight the major reason for the high level of safety hazards; the nature of the work (Helander, 1991). This work includes many inherently hazardous tasks and conditions (NIOSH, 2009). All the industries with the highest incidences have certain common features such as the involvement of heavy equipment, machinery and materials. They also have high exposure to risky natural conditions such as uncertain subterranean conditions and adverse weather.

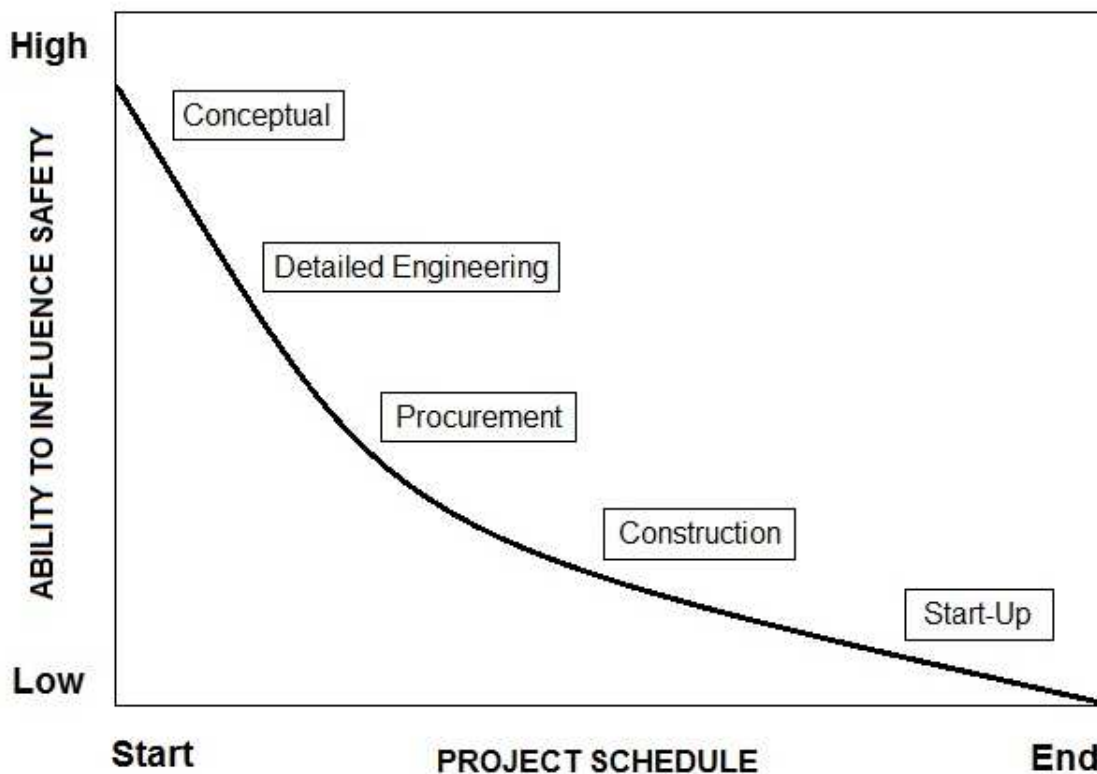
Over the past decades, concern for safety has intensified due to the increasing costs of workers' compensation insurance, the increasing number of liability lawsuits and the intensification of safety regulations (Gambatese et al, 1997). Largely as a result, the construction industry has been experiencing a steady decline in the incident rates of fatalities and disabling injuries (Gambatese et al, 1997; and BLS, 2000-2009). This decline, though encouraging, has however not been significant enough to diminish the industry's prominence in poor safety.

### **1.1.2 Early Strategies for Safety on Construction Projects**

Towards minimizing safety hazards and incidents, construction companies employ several strategies including safety planning, staffing and training among many others (CII, 2003). Different strategies apply to different project phases.

Those strategies applicable to the earlier project phases are likely to have a more significant impact in improving construction worker safety. This is for a number of reasons.

Firstly, safety risk is best mitigated in the early phases of a capital project. According to Stephenson (1991), the safety of an operation is determined long before the people, procedures, and equipment come together at the work site to perform a given task. A 1991 report by the European Foundation for the Improvement of Living and Working Conditions (Eurofound) concluded that approximately 60 percent of fatal accidents in construction are as a result of decisions made before site work begins. As such, it is more effective to address safety in the conceptual, design and procurement phases of a capital project. The time/safety influence curve by Szymburski (1997) illustrates this. Seen in *Figure 1*, the graph shows that the ability to influence safety declines as a project advances through its phases.



**Figure 1:** Time/Safety Influence Curve (Source: Szymburski, 1997)

Additionally, there are economic advantages to addressing safety in the earlier project phases. It is less costly to combat risks at source than to contain problems when they occur at a later phase (Anumba, 1999). Therefore, the early identification and elimination of potential safety hazards is a more cost-effective approach to addressing construction worker safety.

Another advantage of addressing safety in the earlier phases is it may place emphasis on safety throughout the construction project by demonstrating management and stakeholder commitment to safety. Companies that demonstrate management commitment to safety have been shown to have fewer incidences of injury than companies that do not (CII, 2003). This may largely be due to the fact that implementing safety strategies in the early project phases positively influences the implementation of strategies applicable to the later phases.

A number of strategies were identified as applicable to the pre-construction project phases. They include project safety assessment, design for construction safety (DFCS), best value bid approach, and collaborative project procurement approaches. These strategies utilize different approaches to addressing construction worker safety. A comparative analysis was conducted to highlight their features and differences. This is seen in *Table 1*.

All the safety strategies applicable to the early project phases have the potential to improve construction worker safety and research can be geared towards tackling their impediments to implementation. However, among all the strategies, DFCS currently has the most potential to make an immediate contribution in decreasing construction site safety incidents. As stated in *Table 1*, DFCS has the ability to function effectively in the current construction environment without requiring any major changes in procedure or contractual structure.

DFCS is essentially an active safety hazard risk mitigation strategy for designers and a passive one for contractors. A contractor is obligated to complete a project even when unaware of the motivation behind certain design features. As such, an architect or engineer can implement DFCS measures in the design phase without any implication on the contractor's responsibilities and obligations. However, if an architect or engineer specifies a design measure for a temporary construction structure such as a scaffold; he or she will be exposed to liability in the event of a site safety incident involving the scaffold. This is because such a measure is applicable to the construction phase of the project. In the interest of avoiding liability, DFCS measures must remain restricted to the design phase. This specification by itself addresses that impediment to DFCS implementation. The other impediments, seen in *Table 1*, can also be avoided through the establishment of appropriate specifications, and the development and/or selection of measures that meet the specifications.

<b>Early Strategies for Construction Worker Safety</b>	<b><u>Project Safety Assessment</u></b>	<b><u>Design for Construction Safety (DFCS)</u></b>	<b><u>Best Value Bid Approach</u></b>	<b><u>Collaborative Project Procurement Approaches</u></b>
<b>Definition</b>	The comprehensive evaluation of potential safety concerns that are present or could occur on a project (Hislop, 1999).	The explicit consideration of construction worker safety in the design of a project (Toole and Gambatese, 2008).	The evaluation of bid proposals and determination of winning bids on the basis of price and a specified set of technical criteria.	A project delivery method that integrates people, systems, and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases from design, to construction (AIA, 2010).
<b>Applicable Project Phase</b>	Concept and Feasibility Studies	Design and Engineering	Procurement	Procurement
<b>Approach</b>	Identifying potential hazards and developing strategies and/or modifying project requirements to minimize or eliminate their risk of occurrence.	Identifying design features that are potentially hazardous and then adding elements to minimize/eliminate the safety risks. The features themselves may be modified or eliminated to address the safety risks they pose.	Evaluation of bid proposals on basis of price and several technical criteria including safety among many others. The bid with the highest value to the project owner secures the contract. By assigning scores/priorities to safety planning and/or record, contractors are motivated to develop and adhere to safety plans and safe practices. Contractors are also able to make cost provisions for safety with less risk of losing out on a contract.	Identification and mitigation of safety hazard risks that may exist throughout the lifecycle of a project. This is done through the collaboration of all project participants early on in the project.
<b>Implementation</b>	Project stakeholders either implement this safety strategy by themselves or engage an analysis and planning team to conduct the comprehensive evaluation. This team is to include both project designers and contractors (Hislop, 1999).	Project designers which typically include the architects and engineers evaluate their designs for potentially hazardous features. Once identified, they develop or implement design measures to decrease or eliminate the safety risk associated with the features.	Project owner and/or stakeholders determine a set of technical criteria for the bid proposal evaluation and then assign scores/priorities to each criterion including that of safety. Both the bid approach and evaluation criteria are then publicized in the solicitation for bids. When the bids are received, mathematical and subjective evaluations are used to determine the value of each.	Key project participants are convened to form an integrated or multi-functional matrix team during the pre-construction project phases. The team then evaluates how project features and decisions impact each project phase. On this basis, changes are made to optimize project results with regards to cost, time and other factors including safety (AIA, 2010).

<b>Early Strategies for Construction Worker Safety</b>		<u>Project Safety Assessment</u>	<u>Design for Construction Safety (DFCS)</u>	<u>Best Value Bid Approach</u>	<u>Collaborative Project Procurement Approaches</u>
<b>Impediments to Implementation</b>	Schedule and Time Constraints	The comprehensive evaluation may prove too time-intensive to be implemented. Time is one of the project triple-constraints.	There may be increased schedule needs resulting from implementing the DFCS measures (Gambatese et al, 2005). This may be particularly true for measures that introduce additional building features.	Best value bid evaluation is more time and resource intensive than competitive tendering where the lowest bidder secures the contract.	There are increased logistics and time needs for collaborative project procurement as compared to the traditional procurement process. As such, ensuring adequate collaboration may prove difficult.
	Liability for Construction Worker Safety	There are liability implications in cases where a site safety procedure is defined for a contractor. In the event of an injury, the contractor will not indemnify the owner and designers. This is in accordance with the indemnification clause that is commonplace in traditional construction contracts (Bockrath, 2000).	There are liability implications in cases where a DFCS measure specifies construction site safety approaches and/or procedures for the contractor. This by itself will nullify the indemnification clause in traditional construction contracts.	There may be stiff opposition to best value bidding from contractors and unions particularly on public capital projects (Scott et al, 2006). And considering that some of the evaluations may be subjective, there is risk of increased legal action against project owners and stakeholders.	There are liability implications in cases where a site safety procedure is defined for a contractor by other project participants. In the event of an injury, the contractor will not indemnify the project participants.
	Other Impediments	<ul style="list-style-type: none"> <li>- Project owners and stakeholders may lack the expertise to conduct the comprehensive assessment of their projects with regards to safety. They may also lack the expertise to effectively modify project requirements to minimize or eliminate identified safety risks.</li> <li>- The strategy may not be productive because many key project participants are yet to be engaged during the conceptual phase.</li> </ul>	<ul style="list-style-type: none"> <li>- Designers may lack the expertise to implement DFCS (Toole, 2007). Designers with limited construction experience may lack the prerequisite knowledge to determine effective design measures for improving worker safety.</li> <li>- There may be increased cost associated with DFCS implementation. The addition or modification of building features will likely have implications on both direct and overhead costs (Toole, 2007).</li> <li>- Diminished design creativity may result with DFCS implementation as aesthetic features that pose hazards are designed out of a project (Gambatese et al, 2005).</li> </ul>	<ul style="list-style-type: none"> <li>- Some jurisdictions have legislation, laws or regulations requiring competitive bidding for the award of contracts (Scott et al, 2006). In such settings, best value bidding is not an option.</li> </ul>	

<b>Early Strategies for Construction Worker Safety</b>	<u>Project Safety Assessment</u>	<u>Design for Construction Safety (DFCS)</u>	<u>Best Value Bid Approach</u>	<u>Collaborative Project Procurement Approaches</u>
<b>Functionality in the current U.S construction and contractual environment</b>	With regards to modifying project requirements on the basis of improving construction worker safety, project safety assessment can function in the current construction environment. However, the restructuring of current contractual formats and agreements will be required to allow the involvement of other project participants in site safety planning without their assumption of liability.	DFCS will not require any major changes in project procedure and/or contractual structure to function effectively in the current construction/contractual environment. However, to avoid liability implications, the implementation of DFCS must remain restricted to the project design phase.	Best value bidding has limited functionality in the current construction environment. For functionality and general adoption, changes in regulation and/or legislation will be required.	For functionality, collaborative project procurement approaches will require an overhaul of the current system where contractors are responsible and liable for construction site safety. As any input from other project participants presents possible liability, current contractual structures and obligations will have to be modified.

**Table 1:** Comparative Analysis Table of Early Strategies for Construction Worker Safety

### 1.1.3 Design for Construction Safety (DFCS)

This approach to construction safety involves the consideration of worker safety in the design of a project. There are two terms used for the approach, “Design for Construction Safety (DFCS)” and “Construction Hazard Prevention through Design (CHPtD)”. The more widely accepted term is DFCS as noted from its more prevalent use in literature.

A number of definitions have been used for DFCS. Behm (2005) defined DFCS as the consideration of construction site safety in the design of a project. Toole (2007) meanwhile, defined DFCS as safety constructability. Also, Toole and Gambatese (2008) defined DFCS as a process in which engineers and architects explicitly consider the safety of construction workers during the design process.

DFCS is the extension of the “Safety through Design” or “Design for Safety” concept to construction projects (Mroszczyk, 2006). The “Design for Safety (DFS)” concept had been presented as early as 1955 in the National Safety Council’s (NSC) Accident Prevention Manual. DFS is defined as integrating hazard analysis and risk assessment methods early in the design and redesign processes, and taking the actions necessary so that the risks of injury or damage are at an acceptable level (Hagan et al, 2009). The DFS model places emphasis on moving the considerations of hazards and risks upstream to the conceptual and design phases of facilities, products and processes. During these phases, integrating safety is easier and less costly. Hagan et al (2009) also presented benefits of DFS which include decreases in injuries, illnesses, environmental damage and their attendant costs. Others are improved productivity, reduction of operating costs and avoidance of possible retrofitting costs.

In the past, application of DFS to construction has been limited. This is largely because worker safety consideration has traditionally not been part of the project designers' role (Gambatese et al, 2005).

#### **1.1.3.1      DFCS Approaches to Worker Safety**

DFCS entails addressing construction worker safety in the design of permanent project features (Gambatese et al, 2005). It also involves the inclusion of worker safety considerations in the constructability review process. DFCS utilizes a number of mechanisms.

DFCS addresses safety by minimizing the number of safety decisions that have to be made by contractors and construction workers on the work site. By eliminating a hazard at the design phase, a decision will no longer have to be made on site with regards to preventing or minimizing the hazard. This results in fewer opportunities for poor safety decisions made on site, leading to accidents (Mroszczyk, 2006). For example, consider an upper story window designed with a sill height of 0.5 m (20 in.). Prior to the installation of glazing, the low sill height will add to the chance of falling through the window opening during construction work. As such, a temporary fall protection system will be required to prevent this hazard. Decisions will then have to be made by the contractor and construction workers as to the type and characteristics of the fall protection system. Should the decisions be inadequate or poor, the hazard risk will remain imminent. OSHA standards (1926.502(b)) specify the use of guardrail systems for such window openings. However, if the window sill height is designed to be at least 1.0m (39 in.) above the floor level, the guardrail system will not be required as the modification will inadvertently reduce the risk of falls through the window opening (Gambatese et al, 2003). This is an example of a DFCS measure that eliminates the need for adherence to specific OSHA regulations.

The approach of DFCS to safety is similar to that of Design for Safety (DFS). There are a number of protocols used in DFS. The most common of which is the "Safety Hierarchy" (Green, 2009). The simplest version of the safety hierarchy lists approaches to safety in this order of effectiveness:

1. Design
2. Guard
3. Warn

The safety hierarchy is not a scientific principle but a widely recognized rule of thumb (Green, 2009). Organizations such as the National Society of Professional Engineers (NSPE) and the International Ergonomics Association consider its application a core competency for professionals. The safety hierarchy has been adapted by a number of authors including Manuele (1997), Andres (2002), Stephans (2004) and Bauer (2006). All their adapted versions are similar. The

most widely cited version in DFCS research, Manuele (1997), has approaches listed in the following order of decreasing priority and effectiveness:

1. Eliminate hazards and risks through system design and redesign
2. Reduce risks by substituting less hazardous methods or materials
3. Incorporate safety devices (fixed guards, interlocks)
4. Provide warning systems
5. Apply administrative controls (work methods, training, etc.)
6. Provide personal protective equipment.

Eliminating the hazard is recognized as a far more effective way to improve safety than reducing the hazard or providing personal protective equipment to workers (Gambatese et al, 2005).

### **1.1.3.2      Cases for DFCS**

Significant attention has been drawn to DFCS as a viable approach towards improving the construction industry's poor safety record (Hecker et al 2004). In recent years, the Construction Industry Institute (CII), the National Institute for Occupational Safety and Health (NIOSH) and the Center to Protect Workers' Rights (CPWR) sponsored research towards characterizing the use of DFCS and its implementation. This highlighted the need to determine how DFCS demonstrably improves construction worker safety. Some research work had been done in this regard.

Weinstein et al (2005) conducted an analysis of a full-scale DFCS initiative during the design and construction of a \$1.5 billion semiconductor fabrication and research facility in the Pacific Northwest of the United States. In the project, DFCS was found to have been successful in eliminating or mitigating significant safety and health hazards during construction. 26 design changes were considered for addressing specific hazards and among them, 16 were implemented.

An approach for determining how DFCS can improve safety is through the identification of specific safety incidents that would have been prevented by implementing DFCS measures. Behm (2005) investigated 224 construction fatality investigation reports from the NIOSH FACE (Fatality Assessment Control and Evaluation) program. The study found that, for 42% of fatalities reviewed, the associated risk that contributed to the incident would have either been reduced or eliminated had the DFCS concept been utilized.

Using the same model as Behm (2005), I selected design suggestions from two earlier DFCS studies, Gambatese (2000) and Gambatese et al, (2003). I then used the OSHA database to identify specific safety incidents that would have been prevented by implementing the design suggestions. The results of this database investigation, seen in *Table 2*, further makes the case for DFCS as it is apparent design modifications may prevent certain construction site hazards.

	Design Suggestions	Preventable Safety Incidents from Implementation of the Design Suggestions	
		OSHA Inspection [Number]	Accident Details and Mechanism of Failure
1.	Window sills and roof parapets designed to be 107cm above the floor/roof level.	309256444	Employee #1 was walking in a room, when he tripped and fell through an unguarded window. The window was located on the second floor of a building. He fell approximately 18 ft upon an adjacent concrete patio and died from traumatic brain injuries that included a fractured skull.
2.	Stairways and ramps designed to run parallel and immediately adjacent to structure.	307014282	Employee #1 was working on a stairway landing measuring four feet by seven feet, eight and one-half inches. Employee #1 fell 22 feet from an open side of the landing to a lower stair rail and then to the ground floor. Employee #1 was not using fall protection. Employee #1 died.
3.	Dimensions similar from story-to-story to facilitate the reuse of concrete forms.	304479132	Employee #1 was erecting 16-ft-tall formwork for a concrete placement. The foreman and a coworker were aligning the formwork while Employee #1 and another coworker were tied off to the top of the formwork. As they were working, the formwork collapsed and Employee #1 and his coworker fell. Employee #1 was killed and two of his coworkers sustained injuries.
4.	Attachment points designed on the roof for connection of safety lines.	123398331	Employee #1 was positioning bundles of roofing material on the roof of a residence as other members of the crew were located elsewhere on the roof. The pitch of the roof was 12-in-12 (vertical to horizontal). Employee #1 fell approximately 23 feet (7 meters) from the roof onto a concrete driveway. Although a lifeline was tied to an anchor point at the ridge of the roof and a body belt (not a body harness) was attached at the other end, he was not wearing the body belt. Employee #1 died later in a hospital.
5.	Permanent guardrails designed to be installed around skylights.	306176231	A construction employee was working on the sixth story of a building. He was securing a lifeline on a concrete beam when he stepped back and fell through a skylight, approximately 60 feet to the ground. The employee was hospitalized with a concussion and died three days later from his injuries.

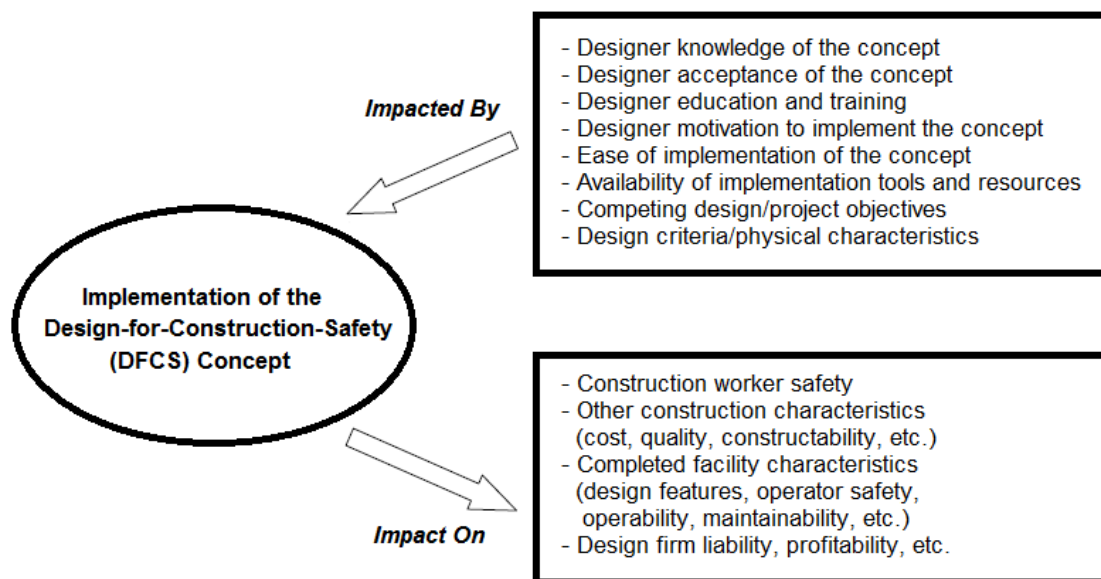
	Design Suggestions	Preventable Safety Incidents from Implementation of the Design Suggestions	
		OSHA Inspection [Number]	Accident Details and Mechanism of Failure
6.	Beam-to-column connections designed to have full support for the beams during the erection process.	303642359	Employee #1 died when he was struck in his head by an I-beam. He was standing within six feet on the back side of an I-beam they were in the process of bolting in place to replace a support column. The I-beam was raised earlier that day. The beam was in place waiting for Employee #1 to come up in a scissor lift to mark the hole. The beam was in place for several minutes when the fork lift operator saw a flash and heard a popping sound and saw the beam start coming down. Employee #1 dove forward to get out of the way as the beam came down. The beam hit him in the back of his head and landed on his ankles. Employee #1 was taken by ambulance to a local hospital where he later died.
7.	Single or distinguishable size of bolts, nails, and screws to be used.	120321484	Employee #1, a worker at a steel construction company, was assisting in the setting of a steel column. The column had been bolted with anchor bolts and raised into position, using a forklift. Employee #1 climbed a nearby ladder and got onto the column to unlock the lifting line. For some reason, the anchor bolts pulled out of the footing and the column fell over, causing Employee #1 to jump off the column and land on top of the forklift. He was transported to a local hospital and diagnosed with a cracked sternum, for which no treatment exists.
8.	Closely spaced reinforcing steel designed for mat foundations and slabs.	300840980	Employee #1 was working in an area where rebar did not have protective caps. As he moved through the rebar, he slipped and fell right onto one of them. That rebar impaled him in the stomach, and he was hospitalized with this serious injury.
9.	Design the geotechnical structure to minimize safety risks. Use drilled piles as opposed to driven piles for deep foundations.	125639252	An employee, employed as a pile driver apprentice, sustained a serious injury to his right foot, middle toe, when his foot was caught by a concrete pile being driven. The employee was in the process of removing the choker from a pile that was being driven, when the soil at the base of the pile sunk. The employee's foot was caught by the moving pile and he was pinned between the pile and earth wall. The employee as a result of the injury suffered a secondary infection to his middle toe which resulted in amputation.

	Design Suggestions	Preventable Safety Incidents from Implementation of the Design Suggestions	
		OSHA Inspection [Number]	Accident Details and Mechanism of Failure
10.	Design components designed to facilitate prefabrication in the shop or on the ground.	303721203	Employee #1 was assembling scaffolding directly beneath a concrete block on-loading/staging area when two 8-inch concrete blocks dislodged from a partial cube and fell three stories (32 feet), striking and killing Employee #1.
11.	Underground utilities and other below-grade features located in areas easily accessible for excavation.	308384775	Three electricians entered an excavation that previously collapsed to clean dirt off electrical conduits. The excavation collapsed a second time and engulfed one electrician up to his waist. This employee suffered multiple fractures to his head, chest, and pelvis and was hospitalized.
12.	Rooftop mechanical equipment located away from skylights and roof edges.	307931600	An employee was on a roof cutting a hole in concrete, for the installation of an HVAC system. He was approximately 16 ft high when he fell and was killed.

**Table 2:** Design Suggestions and Preventable Safety Incidents  
(Sources: Gambatese (2000); Gambatese et al (2003); and OSHA)

### 1.1.3.3 Potential Implications of DFCS Implementation

There are several potential implications of Design for Construction Safety (DFCS) implementation. Gambatese et al (2005) identify project characteristics or issues that DFCS implementation could potentially impact along with those that could potentially impact DFCS implementation. These are seen in *Figure 2*.



**Figure 2:** Factors affecting Implementation of Design for Construction Safety (Source: Gambatese et al, 2005)

As seen in *Figure 2*, designer knowledge of the concept, designer acceptance of the concept, design education and training, designer motivation to implement the concept, ease of implementation of the concept, availability of implementation tools and resources, competing design/project objectives, and design criteria/physical characteristics are the factors that impact DFCS implementation. Meanwhile, construction worker safety, other construction characteristics, completed facility characteristics, and design firm liability/profitability, are the factors that are impacted or have implications through DFCS implementation.

Construction worker safety is the main positive implication of DFCS implementation. The prevention of injuries and fatalities of construction workers alongside decreasing near misses and accidents on the construction site constitute the ultimate benefit of DFCS implementation. DFCS is after all, aimed at decreasing site safety hazards (Toole and Gambatese, 2008). To ensure that DFCS implementation has no negative implications on construction worker safety, the design professional should have the design modification or measure assessed to determine/confirm whether it could favorably impact construction safety in that particular project case.

Another positive potential implication of DFCS implementation is cost-savings. DFCS, through the proactive identification and elimination of hazards is safer and more cost effective than reactive management of the same hazards (Toole and Gambatese, 2008). Eliminating the need to install temporary safety measures during construction may result in overall construction cost savings (Gambatese et al, 1997). Also, where DFCS eliminates certain permanent project features, its implementation might decrease project cost. Additionally, certain DFCS modifications may not only enhance construction worker safety but have lesser costs than the typical features. On the other hand, there may be negative potential cost implications. The addition of permanent protective elements to otherwise ordinary project features comes at a cost. For example, the placement of permanent guardrails around skylights would cost more than not placing guardrails at all. This would thus be a negative implication on project cost.

Improved constructability is another potential implication of DFCS implementation. Toole (2007) defined DFCS as safety constructability. This is the ability of construction workers to safely construct a project. With added safety elements on the project, the construction workers should be able to better fulfill their duties. This means a positive implication on project quality as well. On the other hand, quality with regards to such matters as aesthetics may be negatively impacted by DFCS implementation. DFCS implementation may suggest or require the elimination of certain aesthetic but “risky” features. Eliminating these features will reduce the aesthetic quality of the project thereby impacting the completed facility characteristics.

Another positive potential implication of DFCS implementation is in operator safety, operability, and maintainability. DFCS measures or modifications can be

implemented and not only improve construction workers safety but occupant and maintenance worker safety. For example, considering permanent guardrails surrounding skylights, these would minimize the safety risk of maintenance workers falling through the skylight when they are performing maintenance tasks on the roof during the project operations phase. And, where occupants also have access to the roof, this decreased safety risk will apply to them as well. An example of an actual scenario where the safety of construction workers may have cascaded to the safety of occupants is the case of the Kansas City Hyatt Regency Hotel walkway collapse.

On July 17, 1981 at approximately 7.05pm; two walkways collapsed killing 114 people and injuring over 200. This occurred during a tea dance attended by more than 2,000. The elevated walkways were situated in the atrium of the hotel which became the site of one of the deadliest structural collapses in the United States. During construction, workers carrying loaded wheel barrows across the walkways complained about excess vibration and swaying. The excessive swaying of the elevated walkways was so much that they were temporarily shut down. However, when the visible swaying stopped, the bridges were reopened for use in the interest of expedience (Marshall et al, 1982). Perhaps if construction worker safety had been addressed by rectifying the design to prevent the swaying and instability of the walkways, then the lives of 114 occupants could have been preserved while injuries to 200 avoided. It must be noted that the initially approved structural design had called for a continuous rod arrangement for supporting the walkways but was changed to an interrupted rod arrangement by reason of installation practicality. The new arrangement was found to have doubled the load on the fourth floor box beam-hanger rod connections; this was found to be the cause of the failure under the load at the time of collapse. To make the change, the contractor submitted shop drawings with the modification for approval by both the architect and structural engineer. Ultimately, the particular drawing with the detail was stamped by both the architect and the engineer. This highlights the need to take note of change orders even when implementing DFCS. Change orders may omit or eliminate design features intended to collectively enhance construction worker, occupant, and maintenance worker safety.

DFCS implementation may have negative potential implications on design firm liability. It may offer an additional avenue for liability exposure in the event of a safety incident connected to a DFCS feature. In a lawsuit, the objective of the feature may be revealed to the contractor and the judge/jury and if the incident occurred when the feature was properly installed and used, the designer may be found liable. This scenario is expected to be rare if the design professional does not prescribe means, methods or sequences but only designs features to enhance the safety of the contractor or construction workers with/without their knowledge. This is adherence to the defined approach of DFCS implementation.

Even where there are negative implications on design firm liability, it may not be much given that legal and litigation costs are commonplace for design firms. In event of any notable injury incident, there is typically buck-passing among all project participants where each attempts to avoid liability. Expectedly, all parties incur some legal costs. The only sure way of reducing potential liability of all parties for worker injuries is by reducing the frequency and severity of construction injuries (Levitt and Samelson, 1993). And, this is the goal of DFCS implementation. Thus, legal and litigations costs alongside the cost of insurance programs may potentially become lower (Toole et al, 2006). DFCS implementation could then have positive potential implications on design firm profitability.

Design firm profitability may also be positively impacted in that reducing the number of construction accidents and injuries could avoid disruption to work and avert delays in project completion and as a result, improve productivity (Huang, 2003). The design firm may benefit by proceeding to other jobs sooner. On the other hand, besides the fact that design firm profitability could be negatively impacted by additional legal costs, it may also be impacted by the schedule needs of DFCS implementation particularly where high detailing is required.

Conclusively, based on the discussed potential implications, the positive seem to outweigh the negative implications. Also, earlier research by Gambatese et al (1997) found that different project participants believe improving construction safety by any means will result in benefits to other project characteristics in addition to safety. This further supports the implementation of DFCS on projects by design professionals and design firms.

#### **1.1.3.4      Impediments to DFCS Implementation**

There are a number of impediments to DFCS implementation and they mainly stem from designer perceptions and concerns. The most critical impediments include designers' concern about increased liability, increased cost and designers' lack of safety expertise (Toole, 2007). Others include concerns about schedule problems, diminished design creativity and designers' lack of interest (Gambatese et al, 2005).

The impediments are mostly situated in the factors that impact DFCS implementation as indicated by Gambatese et al (2005). This is as seen in *Figure 2*. Designers' lack of safety expertise alludes to the absence of designer knowledge of the DFCS concept, the absence of DFCS education and training, difficulty of implementation of the DFCS concept, and inadequacy/unavailability of DFCS implementation tools and resources. Meanwhile, designers' lack of interest alludes to the absence of designer acceptance of the DFCS concept, and absence of designer motivation to implement the DFCS concept. Lastly, increased cost, schedule problems, and diminished design creativity allude to the presence of competing design/project objectives and set design criteria/physical characteristics.

## **Exposure to Liability**

The fear of liability constitutes a uniquely strong barrier to DFCS in the litigious United States (Toole, 2005). A study by Gambatese et al (2005) found most designers believe DFCS will increase their liability exposure.

Avoiding liability for construction worker safety underlies the paragraphs in most model contracts that explicitly state the design professional as not being responsible for construction site safety methods or programs. Architects in the United States use the American Institute of Architects (AIA) A201 contract document. The issue of architects' involvement in construction safety is addressed in Sections 3.3.1, 4.2.2, 4.2.7, 5.3.1, 10.1, 10.2 and 10.6. The most relevant to DFCS are Sections 3.3.1 and 4.2.7 which are presented.

- 3.3.1 The Contractor shall supervise and direct the Work, using the Contractor's best skill and attention. The Contractor shall be solely responsible for and have control over construction means, methods, techniques, sequences and procedures and for coordinating all portions of the Work under the Contract, unless the Contract Documents give other specific instructions concerning these matters. If the Contract Documents give specific instructions concerning construction means, methods, techniques, sequences or procedures, the Contractor shall evaluate the jobsite safety thereof and, except as stated below, shall be fully and solely responsible for the jobsite safety of such means, methods, techniques, sequences or procedures. If the Contractor determines that such means, methods, techniques, sequences or procedures may not be safe, the Contractor shall give timely written notice to the Owner and Architect and shall not proceed with that portion of the Work without further written instructions from the Architect. If the Contractor is then instructed to proceed with the required means, methods, techniques, sequences or procedures without acceptance of changes proposed by the Contractor, the Owner shall be solely responsible for any resulting loss or damage.
- 4.2.2 The Architect, as a representative of the Owner, will visit the site at intervals appropriate to the stage of the Contractor's operations (1) to become generally familiar with and to keep the Owner informed about the progress and quality of the portion of the Work completed, (2) to endeavor to guard the Owner against defects and deficiencies in the Work, and (3) to determine in general if the Work is being performed in a manner indicating that the Work, when fully completed, will be in accordance with the Contract Documents. However, the Architect will not be required to make exhaustive or continuous on-site inspections to check the quality or quantity of the Work. The Architect will neither have control over or charge of, nor be responsible for, the construction means, methods, techniques, sequences or procedures, or for the safety precautions and programs in connection with the Work, since these are solely the Contractor's rights and responsibilities under the Contract Documents, except as provided in Subparagraph 3.3.1.

Engineers in the United States meanwhile utilize the Engineers Joint Construction Documents Committee (EJCDC) E-500 contract document. The issue of construction safety is addressed in Sections 6.01, A.1.05, A.2.02 and D1.01. The most relevant to DFCS are 6.01.H and A1.05.C which are both presented.

6.01.H. Engineer shall not at any time supervise, direct, or have control over Contractor's work, nor shall Engineer have authority over or responsibility for the means, methods, techniques, sequences, or procedures of construction selected or used by Contractor, for security or safety at the Site, for safety precautions and programs incident to the Contractor's work in progress, nor for any failure of Contractor to comply with Laws and Regulations applicable to Contractor's furnishing and performing the Work.

A1.05.C Limitation of Responsibilities: Engineer shall not be responsible for the acts or omissions of any Contractor, Subcontractor or Supplier, or other individuals or entities performing or furnishing any of the Work, for safety or security at the Site, or for safety precautions and programs incident to Contractor's Work, during the Construction Phase or otherwise. Engineer shall not be responsible for the failure of any Contractor to perform or furnish the Work in accordance with the Contract Documents.

One could argue that the model contracts for both architects and engineers preclude both parties from making design decisions in the interest of construction worker safety. However, one can also infer that so long as the designer does not prescribe means, methods, techniques, sequences or procedures, the designer can be involved in construction worker safety although the designer is not responsible for site safety. Nevertheless, some designers believe DFCS will interfere with the contractor's means and methods and this, they feel, is a major barrier to DFCS (Gambatese et al, 2005).

### **Designers' Lack of Safety Expertise**

To effectively contribute to construction worker safety, it is imperative designers possess some degree of expertise in construction safety and some knowledge of construction processes (Toole, 2005). In a study by Gambatese et al (2005), designers indicated lack of construction experience and knowledge as a barrier to DFCS.

Designers will require some knowledge of how individual construction tasks are performed. They will also require knowledge on the sequencing between the tasks, and how different trades coordinate their work (Toole, 2005). Designers should also possess some knowledge of safety standards and programs. For example, they should be familiar with OSHA standards.

A significant majority of design professionals have had limited or no academic exposure to construction safety management (Toole, 2005). An investigation of 36 civil and construction engineering programs in the United States by Gambatese (2003) found no course solely devoted to construction safety exists in their curricula. A number of programs however indicated they offered courses that include some amount of construction safety content.

Furthermore, the traditional design-bid-build project does not allow the contractor to provide the designer with safety constructability input during the design phase. During this phase, the contractor is typically yet to be engaged. Also, if the contractor bears witness to the designer's involvement in construction safety, the contractor may present this as a basis for shifting liability to designer if and when a safety incident occurs.

### **Increased Cost**

Another impediment to DFCS is increased cost. Performing DFCS may increase direct and indirect costs for projects, design firms and designers. In a study by Gambatese et al (2005), 74% of designers stated that DFCS would result in increased cost. This includes design and/or construction cost.

Project costs may increase due to additional protective features incorporated into the design. It is however important to note that, in cases where DFCS eliminates a feature, decreased project costs may result. While increased cost is a valid impediment, it is dependent on the DFCS approach utilized.

Additionally, eliminating the need to install temporary protection systems during construction may result in overall construction cost savings (Gambatese and Hinze, 1999). In the traditional design-bid-build project, construction cost may have no bearing on the designer. However, in design-build projects where a single firm is charged with both design and construction, net project cost savings will increase their project margins (Toole, 2005).

With regards to increased cost for design firms, this may result from training all its designers to design for safety and review submittals for safety (Toole, 2005). Time that could have otherwise been billable will be used for this training. Designers meanwhile may experience increased costs in the form of insurance premiums. If designers begin explicitly attempting to contribute to worker safety, plaintiff lawyers may claim designers are at least partially responsible for preventing worker injuries (Toole, 2005). Insurance carriers providing designers with liability insurance could legitimately increase their premiums to cover increased costs associated with defending lawsuits against the designers. Cost increases associated with DFCS implementation may ultimately require design firms and designers to increase their professional fees. This would in turn make them less competitive with those still utilizing the traditional design process without DFCS implementation (Toole, 2005).

## **Schedule Problems and Time Constraints**

Implementing DFCS may impact project schedule. As in the case of project cost, the incorporation of protective features into the design may result in increased time requirements to install or construct additional features. However, where DFCS eliminates a feature, decreased time needs may result. As such, this impediment is also dependent on the DFCS approach utilized.

DFCS may also result in increased schedule needs for the project design phase as safety will be yet another criterion for design and analysis (Toole, 2005). Additionally, concern for liability may lead to excessive reviewing by designers. With DFCS implementation, design and review may thus require considerably more time.

In a study by Gambatese et al (2005), roughly half of the designers surveyed stated that DFCS would lead to schedule delays. In the same study, designers identified time constraints as a significant barrier to DFCS.

## **Decreased Project Quality and Diminished Design Creativity**

Eliminating elaborate project features in the interest of construction worker safety can diminish design creativity and possibly, project quality. This is particularly considering the fact that functional features that are aesthetic and creative add value to projects. As an example, consider the Sydney Opera House in Australia. If the precast concrete shells that form the distinctive roof are eliminated in the interest of construction safety, the value of the design will be substantially diminished. In light of such implications, a number of designers surveyed by Gambatese et al (2005) stated that DFCS would lead to decrease in project quality by limiting design creativity. Also in the same study, increased project complexity and reduction in quality of design concepts were identified as barriers to DFCS.

## **Absence of Designer Interest and Motivation**

DFCS implementation at least in part, depends on the interest and motivation of the individual designer since it is not a standard practice and also since it is not typically mandated in U.S. design contracts (Gambatese et al, 2005).

Gambatese et al, (2005) found only 37% of designers surveyed were interested and willing to implement DFCS. This figure indicates the absence of designer interest and motivation as a DFCS impediment. Further to this, the surveys assessed work priorities and found the designers ranked construction worker safety as their lowest priority.

Additionally, it is important to note that this absence of interest and motivation may be due to the other impediments to DFCS implementation.

### 1.1.3.5 Addressing the Impediments to Implementation

Earlier research proposed ways through which the impediments to DFCS implementation could be addressed. The potential solutions are provided in *Table 3*.

	<b>Impediments to DFCS Implementation</b>	<b>Potential and Possible Solutions</b>
1.	Exposure to liability	Engage legal experts to revise model contract language and legislation to facilitate DFCS without shifting liability to designers (Toole, 2005). Engage insurance experts to assist in developing insurance policies that protect designers from excessive legal liability for incorporating safety features in their designs (Gambatese et al, 2005).
2.	Designers' lack of safety expertise	Engage outside safety experts such as experienced contractors and construction managers to review designs and help train designers in DFCS (Toole, 2005). Provision of designers with formal training on the federal or state OSHA standards (Toole, 2005). Expansion of professional licensure examinations to include construction safety (Toole, 2005). Inclusion of construction safety in undergraduate engineering curricula through courses, internships and projects (Gambatese, 2003). Use of design for safety tools which include computer-based databases, checklists, and graphics, to help designers identify design decisions that have a high potential for improving worker safety, to guide designers toward decisions that result in an acceptable level of worker safety, and suggest details or other documents to include in the construction documents to maximize worker safety (Gambatese et al, 1997; and Toole, 2005). Provision of practical guidelines for addressing safety amid the complex array of design processes and regulations designers encounter in their work (Gambatese et al, 2005).
3.	Increased cost	Identification, selection and implementation of DFCS measures that can improve construction safety with minimal or no increase in cost.
4.	Schedule problems and time constraints	Identification, selection and implementation of DFCS measures that can improve construction safety with minimal or no increase in schedule needs.
5.	Decreased project quality and diminished design creativity	Identification, selection and implementation of DFCS measures that can improve construction safety without compromising architectural form or function (Toole, 2005).
6.	Absence of designer interest and motivation	Changing the mindset of designers by making them cognizant of how their work can directly affect the safety and health of construction workers (Gambatese et al, 2005). Motivating designers and providing them with incentives from sources that may include the design contract, market forces, knowledge of potential cost savings, professional codes of ethics, building codes, standard design practice, and legislative actions such as regulations that clearly recognize a safety role for designers (Gambatese et al, 2005).

**Table 3:** Impediments to DFCS Implementation and Potential Solutions

A separate strategy that could address perhaps all the impediments to DFCS implementation is a change in project delivery type from design-bid-build to design-build (Coble and Blatter, 1999). The Design-Build Institute of America (DBIA) defines design-build as a method of project delivery in which one entity works under a single contract with the project owner to provide design and construction services. DBIA identifies benefits of design-build for practitioners to include higher profit margin, decreased administrative burden, reduced litigation and increased market share.

As the designer and contractor are one entity, liability for site safety incidents during construction rests with the entity, the design-build firm. The issue of increased liability exposure due to DFCS implementation becomes inapplicable. Also, the designers' lack of expertise will be diminished as an impediment to DFCS. Since the designers and contractors are engaged at the same time, the contractor can provide input in the project design phase. The contractor's safety knowledge can thus be utilized in DFCS.

With a design-build firm, cost and schedule issues can be approached differently. The net benefits or costs due to DFCS can be considered over the design and construction phases. Thus, design-build firms should be able to capture the overall economic and other benefits resulting from designing for safety (Toole, 2005).

With regards to possible decreased project quality and diminished design creativity, the design-build firm will have to utilize the typical approach of implementing DFCS measures that improve safety without compromising form or function (Toole, 2005).

In design-build firms, designers tend to have more interest and motivation in implementing DFCS. In a study by Gambatese and Hinze (1999), designers from design-build firms were found to be very knowledgeable of design measures that may impact worker safety. This was because many of the designers already addressed construction worker safety in their designs. As designers work together with their colleagues, the contractors, they begin to appreciate each other's concerns (Gambatese and Hinze, 1999). Construction personnel for example, may alert the designer of how a particular connection presents worker safety concerns and the designer may then substitute it for a safer connection.

DFCS is not a rigid concept. It utilizes different measures and approaches towards eliminating or minimizing construction hazard risks. DFCS measures can thus be devised or selected to avoid the impediments. A designer should weigh the merits of implementing DFCS measures based on project characteristics, constraints and features and then decide which to implement without compromising criticalities (Gambatese, 2000). For example, many designers believe DFCS leads to increased project costs, schedule problems, and diminished design creativity (Gambatese et al, 2005). However, the analysis of a

full-scale DFCS initiative by Weinstein et al (2005) did not reveal such results. 16 of the 26 design changes considered were implemented for addressing specific hazards. This project illustrated how DFCS measures can be selectively implemented to adhere to project constraints while eliminating or mitigating significant construction safety and health hazard risks.

## **1.2 The Case for Research**

### **1.2.1 Research Gaps and Recommendations from Earlier Research**

DFCS as a practice is considered to be in its infancy (Gambatese et al, 2005). As such, there are significant research gaps to address and numerous recommendations for research geared towards characterizing and enhancing DFCS implementation towards the improvement of construction safety.

#### **1.2.1.1 CPWR Recommendations for DFCS Research**

The Center to Protect Workers' Rights (CPWR) sponsored two main studies for DFCS, Gambatese et al (2005) and Behm (2006). The studies concluded with recommendations for research to demonstrate the effectiveness of DFCS in improving construction worker safety. Research was also recommended towards gaining widespread acceptance for DFCS among design professionals. The recommendations have been consolidated. They are presented.

1. Accumulate demonstrable evidence on the effectiveness of DFCS.
  - a. Investigate actual on-site deaths and disabling injuries with a special focus on the role of the project design.
  - b. Test the feasibility of implementing individual DFCS suggestions using specific design-related information.
2. Develop case studies on the negative consequences of ignoring worker safety in building designs.
3. Determine economic benefits of design modifications for construction worker safety.
  - a. Evaluate the economic benefit of implementing the design-for-safety concept to all construction entities (designer, owner, and constructor).
  - b. Create a database of cost-effective design modifications using cost-benefit modeling.
  - c. Demonstrate the effectiveness of designing for safety in reducing costs associated with workers' compensation insurance premiums.
4. Research project delivery methods, design and construction contracts, and errors and omissions insurance to develop design review and assessment tools that will assist designers in addressing safety.

- a. Investigate how DFCS can be incorporated into building codes and standards, sustainability models, and OSHA construction standards (29 CFR 1926).
  - b. Investigate the incorporation of design for safety within owner-controlled insurance programs (OCIPs) as a method to reduce overall project risk.
- 5. Evaluate how academic design coursework should be revised to include design-for-safety content and also how professional designers, owners, and constructors can be trained regarding the principles and applications of designing for safety.

#### **1.2.1.2      NIOSH NORA Research Gaps**

Through the National Research Agenda (NORA), the National Institute for Occupational Safety and Health (NIOSH) identified a number of DFCS information gaps that could address the barriers to the diffusion of DFCS in the United States. The NIOSH NORA Construction Sector Council named DFCS as one of its top 10 priority areas. The identified research gaps are stated.

##### *NIOSH NORA Construction Sector Strategic Goals*

Main Goal: Increase the use of DFCS approaches to prevent or reduce safety and health hazards in construction.

- 1. Characterize the current use of DFCS and coordinate efforts to promote its use and to fill key information gaps.
  - a. Establish a baseline on the current use of DFCS.
  - b. Collect basic materials, case studies, and business case models needed for effective demonstration of concepts and strategies. Evaluate materials and identify gaps where additional information products are needed.
  - c. Evaluate key gaps related to engineering and /or effectiveness of DFCS approaches.
  - d. Identify other groups working on these issues and coordinate efforts to facilitate understanding of challenges and possible solutions.
  - e. Create a repository of existing programs, checklists, best practices, etc. which can be adapted according to type of construction and firm size.
  - f. Collaborate with and educate key professional organizations to promote the use of DFCS.
- 2. Evaluate, clarify, and address the most prevalent obstacles to acceptance and implementation of DFCS:
  - \* Fear of liability
  - \* Lack of expertise in safety and in designing for safety
  - \* Uncertainty about costs associated with DFCS

- a. Explore and characterize the issue of liability concerns for designers. Research real versus perceived liability. Develop potential solutions such as model contract language, design specifications, and legal protection that allow designers to incorporate DFCS concepts without exposing themselves to inappropriate liability.
  - b. Develop a recommended/suggested minimum level of adequate safety and health training for design students and determine the number of schools providing an acceptable baseline level of safety training.
  - c. Characterize economic aspects associated with implementing DFCS concepts.
    - Will inclusion of safe design concepts increase direct costs for designers?
    - Will there be costs associated with higher insurance premiums and associated legal defense with potential changes in liability?
    - Will increased design fees associated with DFCS be offset by reduced construction cost, potential lawsuits, and costly injuries in the total design and construction of the project?
    - Will improved design result in reduce costs over the lifecycle of a building or structure by lowering safety and health costs (e.g., installing temporary fall protection) associated with maintenance, renovation, and eventual demolition?
    - What costs and benefits should be included in DFCS business case studies?
3. Evaluate opportunities to develop potential incentives for encouraging architects and engineers to embrace DFCS.
    - a. Explore potential opportunities for integrating DFCS into newly emerging design tools and practice trends such as use of building information models (BIM) and Integrated Project Delivery (IPD).
    - b. Evaluate how DFCS approaches can provide secondary benefits such as improved safety and health for other groups such as: the general public (from construction-related bystander incidents), maintenance workers, and building occupants, or improved work efficiency and constructability.
    - c. Explore how emerging “Model Client” and best practice procurement approaches provide mechanisms for encouraging owners to engage in DFCS activities.
    - d. Develop methods to utilize the U.S. Green Building Council’s (USGBC) Leadership in the Energy and Environmental Design (LEED) rating system and the sustainability movement to implement DFCS.
  4. Develop tangible products and methods to address identified DFCS obstacles and challenges.
    - a. Develop a website repository to house tangible DFCS products and methods.

- b. Develop DFCS training modules for practicing design professionals that could earn them continuing education credits.
  - c. Develop business case studies of owner organizations who have implemented DFCS.
  - d. Develop a targeted white paper for engineering and architectural professionals, educators, and owners that define and describe the DFCS process.
  - e. Develop presentation materials tailored for engineering and architectural designers, educators, and owners for use at professional conferences, such as ASCE, ASSE, AIA, CII, CURT, AOD, DOT, National Safety Congress, etc.
  - f. Develop model contracts and general conditions text to allow designers to perform DFCS without shifting responsibility for means, methods and site safety from contractors.
  - g. Develop and provide associations such as ASCE, AIA, ASME, IEEE and ASSE with model language they can use for policy statements that support implementation of DFCS.
  - h. Develop a customized DFCS “OSHA 10-hour” course for design professionals and educators.
  - i. Develop tools such as educational documents, checklists, databases and interactive software to enable designers to perform DFCS.
  - j. Develop three general and discipline-specific case studies of design professionals or design builders implementing DFCS, emphasizing the business case for DFCS.
  - k. Develop modules for engineering and architectural courses that include specific DFCS applications.
5. Expand the use and evaluation of DFCS practices.
- a. Partner with interested and influential owners, clients, investors, professional groups, contractors, and other stakeholders to develop innovative DFCS demonstration projects.
  - b. Partner with stakeholders to widely disseminate outputs.
  - c. Publicize practitioner success stories and use to make larger policy, institutional, and organizational changes.
  - d. Implement social marketing approaches, awards, and other campaigns to increase awareness of DFCS concepts.

### **1.2.2 Scope of Research and Deliverables**

This research considered a different paradigm towards increasing DFCS implementation. The new paradigm considers that several tools have been provided to enable and aid DFCS implementation. These tools are however incomplete, inaccurate and/or inadequate to serve their intended purpose. This is particularly since most of the tools have been available for over a decade but, are

still experiencing limited use with the diffusion of DFCS relatively minimal in the United States (Toole and Gambatese, 2008). Research literature had not addressed technical principles underlying DFCS to help designers better perform DFCS, and to facilitate the development of additional DFCS tools (Toole and Gambatese, 2008).

To better enable DFCS implementation, available tools could be fine-tuned through research. They could be improved to address or avoid the impediments to DFCS implementation. On this basis and with consideration given to feasibility, I decided on a number of research deliverables.

1. DFCS measures applicable to the design phase of a capital project.
2. Impediments to successful implementation of DFCS measures that apply in the CPDP (Capital Project Delivery Process) design phase.
3. Revised DFCS measures based on 1 and 2.
4. Preventable construction site hazard incidents for 1 and 3.
5. Computer tool/application to aid the implementation of design phase DFCS measures through use of 1, 2, 3 and 4.

#### **1.2.2.1      Applicable DFCS Measures to the Project Design Phase**

To assist designers in DFCS implementation, safety researchers sponsored by the Construction Industry Institute (CII) accumulated design suggestions for minimizing or eliminating certain construction safety hazards (CII, 1996; and Gambatese et al, 1997). Applicable DFCS measures to the project design phase were to be determined from these design suggestions. I selected this source for a number of reasons. Firstly, it provided a very extensive list of design measures for construction worker safety. 430 design suggestions were presented. Secondly, the design suggestions from the CII study were the most cited in DFCS research. Lastly, the design suggestions were developed or identified from sources in the United States AEC industry. The suggestions were thus more likely applicable to the U.S. DFCS measures from other sources and countries could have been considered if available or different. The Construction, Design and Management (CDM) regulations of the United Kingdom require the involvement of all major project participants including designers in addressing construction worker safety. The performance-based regulations specified the hazards to be addressed but not the measures to utilize. This was also the case in some other European countries such as France (Gibb, 2004). In Australia, DFCS is encouraged but not required by Safe Work Australia (SWA), the statutory agency for improving work health and safety. SWA presented a few examples of design suggestions for construction worker safety, all of which were already included in the 430 suggestions from the CII study.

The design suggestions were identified and developed from a number of sources. The sources are specified in *Table 4*.

	Source	Number of Suggestions	Percent (%)
1.	Safety design manuals and checklists	140	32.6
2.	Authors and safety task force members	123	28.6
3.	Interviews	81	18.8
	- Constructors and design-builders	(50)	
	- Academics	(17)	
	- Local/state/federal public agency personnel	(7)	
	- Owners	(5)	
	- Designers	(2)	
4.	OSHA (CFR, publications, data)	34	7.9
5.	Journal articles	19	4.4
6.	Periodicals	14	3.3
7.	Public safety courses	8	1.9
8.	Other (NIOSH, HBR Constructability Plan)	11	2.6
	[Total]	430	100
<u>Note:</u> CFR = Code of Federal Regulations; NIOSH = National Institute of Occupational Safety and Health; HBR = Houston Business Roundtable			

**Table 4:** Design Suggestion Sources (Sources: CII, 1996; and Gambatese et al, 1997)

The design suggestions pertain to different design disciplines including architectural, civil, structural, MEP (mechanical-electrical-plumbing) and construction management. The suggestions address numerous construction site hazards applicable to a multitude of project systems and components. Also, they are mostly building construction related.

In the CII research study, none of the 430 design suggestions were discarded based on cost, schedule, relative risk reduction, or any other design or construction performance criteria (Gambatese et al, 1997). As a result, many of the suggestions are not applicable to the project design phase. Consider these two examples.

- Limit the lift height of concrete pours to minimize the load on formwork and the risk of collapse of fresh concrete during pouring operations.
- Provide a procedure for placing and holding initial loads on post-tensioned concrete. This procedure should include the safe positioning of workers.

The two suggestions prescribe means, methods, techniques, sequences or procedures for the contractor. Thus, they expose the designer to liability. Additionally, since they are applicable to the construction phase and do not pertain to permanent project features, they do not fit the criteria for DFCS measures. Design suggestions that do not meet the criteria are considered infeasible for implementation.

The 430 design suggestions were to be individually analyzed to identify those applicable to designers and the project design phase. They were also to be assessed to identify those that address or avoid the impediments to DFCS

implementation. As hundreds of design suggestions were yet to be individually evaluated, the development of additional DFCS measures was not within the scope of this research.

The need for safety expertise in the DFCS implementation process is minimized with the provision of viable DFCS measures. These measures must be design guidelines applicable to the project design phase that do not expose the designer to additional liability. This is the justification for this research deliverable.

#### **1.2.2.2      Impediments to Implementing DFCS Measures Applicable to the Design Phase**

Identifying impediments to successful implementation of DFCS measures that are applicable to the project design phase, serve to achieve three functions. Firstly, it provides a means for evaluating the DFCS measures for feasibility of implementation. DFCS measures derived from the CII study's 430 design suggestions were to be utilized. As stated earlier, none were discarded based on any criteria (Gambatese et al, 1997). Several studies identified impediments to implementing DFCS. However, only a limited number considered individual DFCS measures (Gambatese et al, 2005; and Behm, 2006). Gambatese et al (2005) considered the feasibility of implementing certain design-for-safety modifications. The study collected responses and comments from designers with regards to 6 modifications. The scope of this research was to be broader, to include all DFCS measures from the 430 suggestions that were applicable to the project design phase.

Secondly, this deliverable presents the issues that must be surmounted to enhance the feasibility of implementing individual design-phase DFCS measures, thus providing a basis for yielding specific potential solutions to the impediments. Thirdly, this deliverable provides a basis for revising the DFCS measures to better enable their implementation. The yielded impediments to be avoided or addressed are essentially to serve as a specification for making the DFCS measures more feasible for implementation.

#### **1.2.2.3      Revised DFCS Measures based on Impediments to Implementation**

Design guidelines that avoid or address the impediments to DFCS are more likely to be implemented on projects. Even those design suggestions from the CII study that are applicable to the project design phase, could be poorly specified. They could be inaccurate and/or incomplete.

Some DFCS measures could be revised to be more specific and applicable to the particular project feature they address. This could make the measures more viable for implementation and/or more viable for improving construction safety.

Also, some of the DFCS measures could be found not to be revisable for improving implementation. Others meanwhile, could be revised to avoid perceived impediments to their implementation or to provide their individual basis for implementation. Incorporating the purpose or goal of certain DFCS measures might motivate designers to implement them. For example, those DFCS measures that eliminate the need for adherence to certain OSHA regulations could be indicated accordingly.

The scope of this research includes the revision of DFCS measures to be both more viable for implementation and for improving construction safety. This research deliverable is to be an addition to the accumulated design-phase DFCS measures and to further serve in minimizing the need for safety expertise in the DFCS implementation process.

#### **1.2.2.4      Preventable Construction Hazard Incidents from Applicable DFCS Measures**

For a majority of DFCS measures, potential benefits of their implementation were neither determined nor provided. However, a number of studies conducted research in this direction. Behm (2005) reviewed 224 fatality investigation reports to establish a link between DFCS and fatalities. The study results found that the risk associated with 42% of the fatalities would have been reduced or eliminated had DFCS been utilized. A successive study by Gambatese et al (2008) validated 71% of the cases reviewed.

In the same vein, Behm (2006) analyzed 450 reports of construction workers' deaths and disabling injuries to determine whether addressing safety in the project designs could have prevented the incidents. The study results found that in 151 cases, the hazard that contributed to the incident could have been eliminated or reduced if DFCS measures had been implemented. This was perhaps the most comprehensive of the studies with regards to evaluating the potential benefits of individual DFCS measures.

For this research, a similar model to that of Behm (2006) was to be utilized. The study used design suggestions from CII (1996) and Gambatese et al (1997). This also included suggestions that are not applicable to the project design phase and designers. This research was to only identify preventable construction hazard incidents for design-phase DFCS measures.

Behm (2006) randomly selected 224 NIOSH FACE (Fatality Assessment Control and Evaluation) reports along with 226 OSHA inspection reports from the States of Oregon, Washington and California. From these reports, the number of construction safety incidents that could have been prevented through implementation of 73 design suggestions was tallied.

In this research, preventable construction hazard incidents were to be identified for each design-phase DFCS measure, to serve as illustrative cases for the implementation of the measures. For this, the OSHA database was to be used. OSHA, as the authority charged with safety regulatory oversight, collects and compiles data on occupational safety hazards. For each hazard, OSHA records the details of the accident, the degree of injury, the worker's occupation, the worker's establishment name, and the date of accident. Additionally, keywords are specified for each hazard. This eases the identification of relevant hazards in the publicly accessible database. The database is fairly comprehensive in documenting the accidents that led to fatalities and serious injuries. However, many minor injuries go unreported and undocumented (Leigh et al, 2004). All construction fatalities investigated in the NIOSH FACE program are included in the OSHA database. Fatalities investigated in the FACE program were those voluntarily notified by participating states, and the 9 State health or labor departments that have cooperative agreements with NIOSH for conducting surveillance, targeted investigations, and prevention activities at the state level. OSHA reports provide less detail than NIOSH FACE reports. However, the OSHA database provides a larger repository of data as it accounts for practically all fatalities and a significant percentage of recordable injuries in the past 2-3 decades throughout the United States construction industry. The OSHA database was therefore considered very appropriate for this research.

Demonstrable evidence of the effectiveness of the DFCS measures show the benefit of their implementation, injuries prevented and lives saved. This could increase designers' motivation towards DFCS by justifying its implementation. This deliverable strives towards addressing lack of interest as an impediment to DFCS implementation.

#### **1.2.2.5      Computer Application to aid implementation of design phase DFCS Measures**

As DFCS is still an emerging practice in the United States, tools are needed to assist designers in making safety a consideration in the early phases of the capital project delivery process (Gambatese, 2008). This is particularly considering designers' lack of safety expertise and also lack of motivation for DFCS (Gambatese et al, 2005). DFCS tools have the potential to support and improve designers' safety knowledge and skills of hazard recognition (Ku and Mills, 2010). They can also facilitate communication between designers and contractors in the project design phase (Ku and Mills, 2010). Without regulations requiring the involvement of designers in construction worker safety, it is imperative that tools not only aid in the DFCS process but increase the participation of designers in safety (Ku and Mills, 2010).

The use of computer tools is currently an integral aspect of the capital project delivery process. Computer tools are thus most likely to have an impact on DFCS

implementation. A number of such tools have been developed. A comparative analysis was conducted to highlight their features and differences. This is seen in *Table 5*.

<i>Tools</i>	<b>Design-for-Construction-Safety (DFCS) Toolbox</b>	<b>ToolSHed</b>	<b>Construction Hazard Assessment and Implication Review (CHAIR)</b>	<b>Design-for-Safety-Process (DFSP) Tool</b>
<i>Function</i>	DFCS ToolBox provides design suggestions for improving construction worker safety. These suggestions are classified based on specific activities, design features and project systems. The tool enables user access of the DFCS database through a checklist system. (CII, 1996; and Gambatese et al 1997)	ToolSHed deploys argument trees to enable the evaluation of hazards associated with specific design options and also, the proposition of mitigation strategies. The tool provides interactive risk assessment through an online survey interface that generates the risk level of specific activities or materials. (Cooke et al, 2008)	The CHAIR tool provides a framework for the detailed and systematic examination of construction, maintenance, repair, and demolition safety issues associated with design. It utilizes prompts to incorporate reviews in a structured process. (Workcover NSW, 2001; and Ku and Mills, 2010)	The DFSP tool virtually simulates construction processes to detect interferences between building systems and spatial-temporal workspace conflicts during construction. The tool utilizes 3D/4D building information models (BIM) and a DFSP database. Its four virtual reality functions include collision detection, terrain following, geometry picking, and 3D tape measurement. (Hadikusumo and Rowlinson, 2002; and Ku and Mills, 2010)
<i>Adaptability to Project Characteristics</i>	Yes	Yes	Yes	Yes
<i>Provision of DFCS Measures</i>	Yes	No	No	No
<i>Exclusive Provision of Design-Phase DFCS Measures</i>	No	No	No	No
<i>Indication of Implementation Benefits</i>	No	No	No	No
<i>Indication of Implementation Costs and Impediments</i>	No	No	No	No

**Table 5:** Comparative Analysis Table of Design-for-Construction-Safety (DFCS) Tools

Based on the comparative analysis in *Table 5*, there is need for a more effective DFCS tool. For a tool to increase or improve DFCS implementation in the United

States AEC industry, it must function effectively in the current contractual environment by not providing a means for increased exposure to liability. It must therefore exclusively provide design-phase DFCS measures. Considering regulations and current contractual structures do not require designer involvement in construction safety, implementation benefits should be provided to motivate DFCS implementation. For this same reason, providing a means or framework for implementing DFCS without providing actual DFCS measures is inadequate. Additionally, such details as the costs or impediments of implementing the DFCS measures may also serve to aid designers' decision-making process. These were also not provided by any of the DFCS tools.

A new computer tool was to be developed to provide design-phase DFCS measures, their potential impediments, and their preventable safety incidents based on project characteristics. The design-phase DFCS measures were to include both those that were revised and those that were not revised. The tool was thus to incorporate the other research deliverables. The product of using the tool is to be a guideline that includes selected DFCS measures that are applicable to the features of the project on which DFCS is being implemented.

In determining the type of computer tool to be developed, the most widely used tools in the AEC industry were considered. Autodesk currently holds 85% of the market share for design software. Autodesk products such as AutoCAD and REVIT are the market standard for architectural and engineering designs. They are mostly desktop applications. In line with this, the DFCS tool is to be a desktop application.

This research is to produce a structured collection of DFCS data. The DFCS tool is to encapsulate the research findings and to serve as a vehicle for utilizing the research data to enhance DFCS implementation. The DFCS tool is to enable users to retrieve the data based on project characteristics and other entered criteria. Relational database applications enable users to sort and retrieve specific information from stored data based on field entries (Chays et al, 2004). They also enable users to generate reports containing only certain fields from each record. Based on the expected function of the tool, it was to be a relational database application.

Relational database applications can be developed using such existing software as Microsoft Access, Visual FoxPro, Oracle, Siebel and MySQL among others. However, my familiarity with using Microsoft Access made it my preferred choice for developing the tool.

This research aims to increase DFCS implementation through the development of a computer application without the inadequacies of existing DFCS tools. As a result, DFCS implementation could be more convenient and significantly less likely to increase liability exposure.

### 1.2.3 Value of Research

The value of this research lies in its objective to aid, improve and increase DFCS implementation on projects. This is the avenue through which the research aims to enhance construction worker safety. The means through which the research offers such value is discussed in this section.

#### 1.2.3.1 Improving DFCS Implementation

This research is to serve in aiding and improving DFCS implementation through its deliverables. Through earlier research, guidelines and tools were developed to enable and/or aid DFCS implementation but these have been incomplete, inaccurate and/or inadequate to serve their intended purpose (Toole and Gambatese, 2008). Through this research, these guidelines and tools were to be fine-tuned. Furthermore, additional data was to be collected to serve towards documenting and addressing, minimizing or avoiding the impediments to DFCS implementation. Mainly stemming from designer perceptions and concerns on implementation outcomes, the impediments include increased liability exposure, designers' lack of safety expertise, increased cost, schedule problems, diminished design creativity and designers' lack of interest (Toole, 2007; and Gambatese et al, 2005). These impediments were discussed in detail in *Section 1.1.3.4*. Each of the research deliverables are to serve in addressing the DFCS implementation impediments through distinct approaches.

By determining and documenting the applicable DFCS measures to the project design phase from the 430 design suggestions included in the CII's DFCS Toolbox, the need for safety expertise to effectively implement DFCS is minimized. Furthermore, by being situated in the design phase, the DFCS measures will not expose the designer to additional liability in case of related safety incidents.

By identifying impediments to successful implementation of the design-phase DFCS measures, this research provides a means for determining DFCS measures that are feasible for implementation, providing a basis for determining specific solutions to the impediments, and also providing a basis for revising the DFCS measures to better enable their implementation. This deliverable thus indicates the impediments that should be addressed, minimized or avoided for each of the DFCS measures in order to make them more feasible for implementation.

The DFCS measures themselves, where applicable, were to be revised in order to address or avoid the impediments to DFCS implementation. This is important as some of the DFCS measures were poorly specified and this in itself served as an impediment to their implementation. Documentation of a revised set of DFCS measures in addition to the other design-phase measures will serve in further

minimizing the need for safety expertise in implementing DFCS while avoiding other impediments.

By identifying the preventable construction hazard incidents that could be realized from implementation of each design-phase DFCS measure, the benefits of their implementation are provided. These are injuries prevented and lives saved. This deliverable will serve to increase designers' motivation towards DFCS and thereby address their lack of interest as an impediment to DFCS implementation.

In *Section 1.2.2.5*, it was determined that a computer application that could function effectively in the current contractual environment of the United States AEC industry was necessary to aid DFCS implementation. A DFCS application that exclusively provides design-phase DFCS measures, their potential impediments, and their preventable safety incidents based on project characteristics will serve to address designers' lack of safety expertise and lack of motivation as impediments to DFCS implementation while also not providing a means for increased exposure to liability. As the final research deliverable, this desktop relational database application will incorporate the other research deliverables. As such, the DFCS tool is to enable the convenient use of the research results and to potentially have a more immediate effect in aiding DFCS implementation on capital projects.

DFCS has been identified as a viable strategy for improving construction safety (Hecker et al 2004). This is for a number of reasons. Firstly, the proactive identification and elimination of hazards through DFCS is safer and more cost effective than the reactive management of the same hazards (Toole and Gambatese, 2008).

Secondly, DFCS has the ability to function effectively in the current construction environment without requiring any major changes in procedure or contractual structure. By eliminating a hazard at the design phase, DFCS can passively address safety by minimizing the number of safety decisions to be made by contractors and construction workers on the work site. This means fewer opportunities for poor safety decisions made on site, leading to accidents (Mroszczyk, 2006). Furthermore, eliminating the hazard is recognized as a far more effective way to improve safety than reducing the hazard or providing personal protective equipment to workers (Gambatese et al, 2005).

Thirdly, while many construction craftspeople have a tacit understanding of forces and motions associated with their trade, design professionals have had formal schooling in physics and engineering and may thus better consider site safety as they make their design decisions (Toole and Gambatese, 2008). Additionally, the involvement of other project participants including designers in construction worker safety is important for both symbolic and substantive reasons as safety is more likely to be affirmed as a project priority for all entities (Toole and Gambatese, 2008).

Another reason for the viability of DFCS is the possibility of improving safety for other project phases beyond that of construction. DFCS may improve operations, utilization, maintenance and even demolition safety. This would improve occupant, user and maintenance worker safety in addition to that of construction workers all from the project design phase. Also, Toole (2007) identified a strong link between DFCS and the social equity dimension of sustainability as another reason for the viability of DFCS as a construction safety strategy.

AEC design professionals can also consider DFCS a viable strategy as it may provide a marketing advantage. Design professionals who choose to implement DFCS could market themselves as progressive, team-oriented professionals (Toole et al, 2006). They may also benefit financially if engaged in design-build projects as reduced construction accident and injury rates will minimize the impact of compensatory and other related costs on the bottom-line of the projects.

Additionally, contractors can also consider DFCS a viable strategy as the influence of design professionals on such construction issues as safety can have favorable cost implications for projects (Huang, 2003). This is an additional benefit besides improving the safety of their workers and thereby minimizing costs and other consequences associated with construction accidents and injuries.

As DFCS is to be implemented by AEC design professionals in the project design phase, they are the intended users of the results of this research. This includes architects, civil engineers, MEP engineers and possibly other project participants such as project managers, owners and even contractors. The research beneficiaries meanwhile, are the construction workers that stand to benefit from fewer fatal and non-fatal injuries on the project site. However, where certain design professionals already implement DFCS, they will be research beneficiaries since the deliverables will serve to aid and/or improve their implementation process. This is since the research deliverables will serve to address, minimize or avoid the implementation impediments so as to increase the use of DFCS as a strategy for improving construction worker safety on capital projects.

### **1.2.3.2      Improving Construction Worker Safety**

The ultimate value of this research lies in its goal of improving construction safety. There are a number of reasons why this is important. Firstly, professional, ethical and moral obligations require the safety of others be protected. It is thus every AEC design professional's responsibility to preserve and protect human life including that of construction workers (Toole et al, 2006). This is indicated in the design professionals' respective code of ethics. The code of ethics of the American Institute of Architects (AIA) requires architects to protect the safety of

the public. The National Society of Professional Engineers (NSPE) state in their “Code of Ethics for Engineers” that engineers shall hold paramount the safety, health, and welfare of the public. Additionally, the American Society of Civil Engineers (ASCE) state in their code of ethics that “ Engineers shall recognize that the lives, safety, health and welfare of the general public are dependent upon engineering judgments, decisions and practices incorporated into structures, machines, products, processes and devices”. While many design professionals traditionally do not include construction workers in their definition of “the public”, it is still the designers’ moral duty to prevent injuries to the workers whenever and wherever possible. Injuries, non-fatal and fatal, adversely impact the quality of construction workers’ lives and/or negatively impact their loved ones. For humanitarian reasons, such an outcome should be prevented (Jaselskis et al, 1996).

Secondly, the improvement of safety could potentially benefit every project stakeholder and participant by minimizing or eliminating the costs associated with injuries to construction workers. The importance of this reason is further emphasized by the fact that all the costs are continually escalating (Gambatese et al, 1997). The owner, architect, engineers and contractors could all potentially benefit financially.

Injury and fatality compensation can significantly dent the bottom line of projects (Jaselskis et al, 1996). To account for this, contractors raise their bid prices and this in turn makes it more expensive for owners to execute projects. Owners realize the costs of injuries are ultimately reflected in the cost of construction (Gambatese, 2000). And with higher construction costs, owners attempt to decrease the fees due to other stakeholders on the project. The impact is indeed far-reaching. This could be even more so if safety regulatory authorities decide to enforce very stringent and costly regulations with regards to safety (Gambatese et al, 1997). When recommendations are not considered, regulation becomes necessary and it is well within the responsibilities of OSHA and other regulatory agencies to introduce their measures towards decreasing injuries and fatalities. OSHA fines are also another cost associated with injuries to construction workers (Jaselskis et al, 1996).

The costs of litigation and lawsuits are another motivating factor for improving construction safety that applies to all project participants. In event of an injury incident, there is typically buck-passing among all project participants where each attempts to avoid liability. Expectedly, all parties incur some legal costs. Furthermore, these court cases may prove time-intensive. The only sure way of reducing potential liability of all parties for worker injuries is by reducing the frequency and severity of construction injuries (Levitt and Samelson, 1993). Another cost applicable to all project participants is that of insurance programs which are less costly where accident rates are lower (Toole et al, 2006).

Thirdly, all project participants may also benefit in that reducing the number of construction accidents and injuries could avoid disruption to work and avert delays in project completion and as a result, improve productivity (Huang, 2003). For the owner, these benefits are financial as project utilization will initiate earlier. The benefits for the contractor are also financial as workers' wages for the saved time are eliminated along with potential payment for compensatory damages to the owner. As for the architects and engineers, they may benefit by proceeding to other jobs sooner.

Additionally, poor safety performance and its resulting consequences such as court cases and lawsuits expose all project participants to bad publicity (Huang, 2003). This negative publicity could have such adverse impacts as preventing job awards or causing even more lawsuits from prior projects. This is yet another motivating factor driving the need to improve construction safety.

Based on all these reasons, it is clearly important to protect the safety of construction workers and through this research, DFCS, as a strategy, is to be enhanced so as to prevent or reduce accidents and injuries on capital projects.

## **2.0 Background**

### **2.1 Construction in the United States**

#### **2.1.1 The U.S. Construction Industry**

Construction is one of the largest industries in the United States with its 7.2 million wage and salary jobs, and 1.8 million self-employed and unpaid family workers (BLS, 2010). In 2008, there were roughly 884,300 construction establishments in the United States, out of which 70% have no payroll and the 30% with payroll performing 93% of the work (BLS, 2010). This is as a result of the fact that there is more than \$800 Billion in new construction annually, and low barriers to industry entry (BLS, 2000-2009). Licensing is relatively easy and the capital requirements are minimal. As such, less than 100,000 companies have project volume over \$10 million with the ten largest companies performing around 15% of non-residential construction work. Furthermore, over 60% of all contractor construction in the U.S is performed by the top 400 contractors (Hendrickson, 2008). This alludes to the fact that the construction industry is highly fragmented (Haskell, 2004).

The goods and services produced by the industry include building and infrastructure facilities. The activities of the industry include the building of new structures, and additions and modifications to existing structures. The industry is organized into a number of segments which include building construction, heavy civil engineering construction, and specialty construction (BLS, 2010). Building construction includes residential, institutional and commercial construction (Hendrickson, 2008). Heavy or civil construction includes the construction of such infrastructure as bridges, dams and airports. Out of the 884,300 construction firms in the U.S., roughly 269,700 are building construction contractors; 57,600 are heavy construction contractors; and 557,000 are specialty trade contractors (BLS, 2010). Most of the establishments are small with 68% employing fewer than 5 workers. Earnings in construction are higher than the average for all industries (BLS, 2010).

Workers and individuals with a variety of specialties are employed by the construction industry. They include construction trades workers, engineers, accountants, clerical workers and truck drivers among many others (BLS, 2010). Construction trades workers are employed in such trades as carpentry, masonry, equipment operation, electrical work, plumbing, painting, roofing, boiler making, and metalwork. The construction industry employs in nearly all of the construction craft occupations (BLS, 2010).

Division C of the Standard Industry Classification (SIC) is for the construction industry. Three SIC major industry group codes apply to this division. These

include 15 for 'Building Construction General Contractors and Operative Builders', 16 for 'Heavy Construction Other Than Building Construction Contractors', and 17 for 'Construction Special Trade Contractors'. The North American Industry Classification System (NAICS) code for the construction industry is 23.

A complimentary industry to that of construction is the Architectural, Engineering, and Related Services industry. The NAICS code for this industry is 5413. The services of this industry are typically required to execute construction work. The industry employs roughly 1,376,000 people and is part of the larger industry sector of Professional, Scientific and Technical Services (BLS, 2010).

### **2.1.2 The Construction or Capital Project**

There are a number of participants typically involved on a construction or capital project. Given consideration to the major types of projects, four categories of participants are identified; owners (and stakeholders); architects; engineers; and contractors (and subcontractors).

Owners and stakeholders refer to the individuals or groups who own a project and ultimately stand to benefit from its completion. They are the driving force since they conceived the project to meet certain demands or needs (Hendrickson, 2008).

Architects are trained and licensed professionals who design buildings and structures to be functional, safe and economical (BLS, 2010). Engineers meanwhile, are trained and licensed professionals who design economical solutions to enable the construction and function of buildings, infrastructure and other facilities (BLS, 2010). They include civil, structural, mechanical, electrical, plumbing and other engineers. Both architects and engineers, known as the design professionals, also inspect construction work and in some cases, participate in supervising the work.

Contractors refer to an organization or individual that contract for the construction of buildings, infrastructure and other facilities (Hendrickson, 2008). Subcontractors meanwhile refer to individuals or businesses that sign a contract to perform part or all the obligations of the contractor's contract.

From the owner's perspective, the lifecycle of a project initiates from the conceptual phase and concludes at the disposal phase (Hendrickson, 2008). In each of these phases, certain activities are typically carried out.

#### ***Phase 1: Concept and Feasibility Studies***

At this phase of the project, the owner and/or stakeholders determine their requirements and the needs of the project users. With the project objectives and scope defined, a project is selected and initiated (Hendrickson, 2008). At this point, the owner engages the architect and/or the engineer. They sign a

contractual agreement requiring the design professional to design the facility, and to serve as the agent of the owner in supervising and monitoring the project. The design professional then develops a schematic design and program then, conducts a feasibility study for the design (Hendrickson, 2008). Such issues as regulatory requirements and financing are addressed at this point. Once the design is approved by the owner, other design professionals are engaged. The owner may also choose to engage a project manager or consultant to serve as his/her agent to all parties throughout the project.

#### Phase 2:     *Design and Engineering*

At this phase of the project, the design professionals work on developing the design. Through further design, investigation, costing and review, working drawings are developed along with specifications and other construction documents (Hendrickson, 2008). The design phase comprises of preliminary design, design development, and construction documents stages. According to the AIA (2011), preliminary design often produces the site plan, floor plans, elevations, sections, and other illustrative materials such as computer images, renderings, or models. The drawings typically include overall dimensions, and allow for the estimation of the project construction cost. Meanwhile, design development often produces floor plans, elevations, and sections with full dimensions. These drawings typically include door and window details and also outline material specifications. Lastly, the construction documents stage produces a set of drawings that include all pertinent information required for the contractor to price and build the project. It must be noted that for all three stages, the contract may distinctly spell out what is to be delivered.

#### Phase 3:     *Procurement*

During this phase, bidding and procurement documents are prepared by the design professionals with agreement of the owner. Once the bids and proposals are received, they are evaluated based on the contractor selection process defined in the procurement documents. Once the contractor is selected, a contractual agreement is signed defining the performance and cost expectations for all project participants (Hendrickson, 2008). With the project team organized, the project is planned and all preparations for initiating construction activities are completed. Some design modifications may be made during this phase. The contractor may also engage subcontractors to execute certain services.

#### Phase 4:     *Construction*

This is the execution phase of the project. The contractor and subcontractors execute the construction activities. Meanwhile, the design professionals inspect and supervise to ensure the work is adhering to the determined requirements and expectations. The project progress, quality, resources, communication and safety are all monitored and managed during this phase. This is continued until completion where all the applicable systems have been constructed and installed for the facility (Hendrickson, 2008). Changes are also managed in this phase through the development of change orders by the contractors, and approval by the design professionals.

*Phase 5: Start-up and Commissioning*

This project phase evaluates the functionality and performance of the facility against the requirements of the contract and also that of the owners/stakeholders. The as-built operation is tested and the facility is commissioned. Where there are unmet requirements, a punch list is created and administered. An operation and management plan is then developed. These activities are mostly executed by all project participants. The outcome of this phase is the acceptance of the constructed facility (Hendrickson, 2008). At this phase, the lessons learned during the project may also be documented.

*Phase 6: Operation and Utilization*

This phase is the purpose of the project, utilization. In this phase, facility and user management is carried out along with continual maintenance. Construction activities in this phase include remodeling, renovation, retrofits, upgrades and additions.

*Phase 7: Disposal and Decommissioning*

This project phase is the end of the project lifecycle when the project has fulfilled its useful life (Hendrickson, 2008). At this point, the project is decommissioned and its salvageable components are salvaged. Those systems that are recyclable are also recycled. The hazardous and utilities waste are also managed at this stage. The land is also reclaimed during this phase. The major construction activities at this stage involve the demolition of the constructed facility.

As evident from the activities in the different project phases, project participants are differentially involved in the phases. The design professionals are mostly involved in design and supervisory activities while the contractors and subcontractors execute the actual construction activities. Many of the project tasks involve many participants at a time with at least one performing the primary role. This is indicated in *Table 6*.

The specified procedures collectively provide a general view of activities executed in different phases of a typical design-bid-build construction project. In the case of design-build projects, the design and construction phases overlap. Many construction projects have procedures and activities that are different from those discussed. Projects are also structured differently with functional, matrix, projectized, owner-builder and design-build organizations among others. Projects may also utilize different types of contractual agreements such as lump-sum, unit-price, cost plus fixed fee, cost plus fixed percentage, and guaranteed maximum price contracts (Hendrickson, 2008).

As these many features apply differently for projects, the definition of a project is emphasized; a distinct one-shot, time-limited, goal-directed, major undertaking, requiring the commitment of various skills and resources (Meredith and Mantel, 2009).

Task	Responsible Party		
	Owner	Design Professional	Construction Contractor
Provide adequate time and funding for shop drawing preparation and review	Prime		
Arrange for structural design	Prime		
Provide structural design		Prime	
Establish overall responsibility for connection design		Prime	
Accomplish connection design (by design professional)		Prime	
Alternatively, provide loading requirement and other information necessary for shop drawing preparation		Prime	
Alternatively, accomplish some or all of connection design (by constructor with a licensed P.E.)			Prime
Specify shop drawing requirements and procedures	Review	Prime	
Approve proper scheduling	Prime	Assisting	Assisting
Provide shop drawing and submit the drawing on schedule			Prime
Make timely reviews and approvals		Prime	
Provide erection procedures, construction bracing, shoring, means, methods and techniques of construction, and construction safety			Prime

**Table 6:** Recommended Responsibility for Shop Drawings (Source: Hendrickson, 2008)

## **2.2 Causes of Poor Safety in the Construction Industry**

### **2.2.1 Reasons for the Poor Safety Record**

The nature of work is mostly responsible for the high precedence of safety incidents in the construction industry. This work includes many inherently hazardous tasks and conditions (NIOSH, 2009). I compiled and classified different reasons for the construction industry's poor safety record from earlier literature. While these may not be the only reasons for the poor safety record, they constitute the more notable ones. They are briefly discussed.

#### ***A. Nature of the Construction Site and Projects***

##### **1. Site Conditions**

- a. Topography/Slope of Site: A site with an uneven topography may affect stability of equipment, materials and even workers during

construction activities (Ringen et al, 1995). This constitutes a hazard risk. Additionally, a site with a moderate to steep slope has the tendency to cause accidents through the movement of equipment and materials down the slope.

- b. Soil Conditions: Soil conditions differ by site. Poor soil conditions may affect stability of equipment, materials and workers during construction activities (Levitt and Samelson, 1993). Also, poor soil conditions require more extensive site engineering activities and this could increase worker exposure to hazards such as excavation collapses.
- c. Space Constraints: Constrained sites have the tendency of causing site accidents particularly considering the heavy equipment and materials that get transported to and from the site in addition to construction worker traffic. Also, confined spaces present hazardous working conditions (NIOSH, 2009).
- d. Temporary Duration of Work Sites: The temporary duration of work sites makes it difficult to establish an effective permanent site strategy for safety (Levitt and Samelson, 1993; and Reese and Eidson, 1999).

## 2. Geographical Factors

- a. Climatic Conditions: Most construction work takes place outside thereby leaving workers exposed to both mild and harsh weather conditions as they carry out their activities. Harsh conditions are very likely to cause safety hazards (Rowlinson, 2004).
- b. Regional Factors: There are also regional factors that affect construction site safety. They include such factors as dust storms, mudslides and seismic activity that may lead to the collapse of site structures and other hazards.

## 3. Scope of the Project

- a. Height of Structure: The height of a structure presents the risk of falls from elevations and injuries as a result (NIOSH, 2009).
- b. Heavy Materials: Construction materials are typically heavy and bulky thus having the tendency to cause injury to those working with them when they either fall on or strike them (Levitt and Samelson, 1993).

- c. Foundation and Soil Work: Foundation work presents the risk of excavation walls caving in or, falls into the foundation (NIOSH, 2009).
- d. Use of Heavy and Hazardous Equipment: The use of heavy equipment presents the risk of transport accidents, structural and other collapses. Cranes, bulldozers and graders are examples of such heavy equipment. Smaller equipments such as power tools are also capable of causing harm to workers (NIOSH, 2009). Additionally, noisy equipment may distract workers making it more likely for accidents to occur (Levitt and Samelson, 1993).

#### 4. Design Considerations

- a. Challenging and Difficult Designs: Difficult designs have a higher tendency of causing accidents since workers may not be familiar with methods for safely executing their construction (Rowlinson, 2004).
- b. Changing Design Requirements: During construction, some design requirements may change with short notice. As a result, prior construction site safety planning may become inadequate to address the newly introduced hazards (Rowlinson, 2004).

### *B. Nature of the Construction Workforce and Organizations*

#### 1. Worker Considerations

- a. Worker Training: Some workers are appropriately trained while others are not. Untrained workers are more likely to either cause or be involved in site accidents (Toole, 2002).
- b. Worker Experience: More experienced workers are less likely to cause or be involved in site accidents than those with little or no experience (Levitt and Samelson, 1993).
- c. Labor Considerations: Some unions are known to extensively train their members with regards to both the profession and safety through their apprenticeship programs. In such cases, union workers have been found to have better safety performance (Weil, 1992). Union workers were also found to pay more attention to safety (Weil, 1992). About 17% of U.S. construction trades workers were found to be union members or covered by union contracts (BLS, 2010).

- d. Cultural Factors: With the extensive use of migrant workers in the construction sector, there are sometimes failures of communication and understanding that lead to site safety hazards (Brunette, 2004).
- e. High Degree of Subcontractor Involvement: The construction industry mostly utilizes subcontractors for specialty services. A high degree of subcontractor involvement tends to cause accidents because coming from smaller establishments; they are usually not well trained with regards to site safety (Rowlinson, 2004).
- f. Worker Compensation and Welfare Problems: Many construction workers are not adequately compensated while some have welfare problems. This leads to apathetic behavior and half-hearted work that is more likely to result in site safety hazards (Fang et al, 2006; and Langford et al, 2000).
- g. Seasonal Employment and High Labor Turnover: The seasonal employment that is typical in the construction industry results in high turnover. As a result, one may train workers in safety and the next season, realize they have either left the company or the profession as a whole (Levitt and Samelson, 1993; and Hinze and Gambatese, 2003).

## 2. Organizational and Industry Considerations

- a. High Industry Fragmentation: The construction industry is highly fragmented. The large numbers of small firms mostly lack the resources to ensure appropriate safety training. Furthermore, the high industry fragmentation makes it difficult to enforce safety regulations (Rowlinson, 2004).
- b. Competitive Tendering: Competitive tendering seeks the lowest “responsible” bidder. There is no component for safety. Companies add safety costs at the risk of not winning the bid. Furthermore, the lower the bid, the smaller the contractor’s margin and the less likely safety will be factored into the project (King and Hudson, 1985).
- c. The Fragmented Project Delivery Process: The project delivery process is sequential and involves the design professionals passing on the design to the contractor for construction. The contractor then bears the risk for construction site safety. As a result of this fragmented project delivery process, there is no collaborative approach to site safety (Anumba, 1999; and Leather, 1987).

## **2.2.2 Construction Site Safety Hazards and Root Causes**

### **2.2.2.1 Construction Site Safety Hazards**

Certain safety hazards are common to the construction site. Based on the classification used by the U.S. Bureau of Labor Statistics (BLS), these hazards are stated and briefly discussed.

1. Falls of Individuals  
Workers are typically required to work at heights at the construction site. These heights include both temporary structures such as scaffolding and permanent structures such as roofs. It is also important to note that serious injuries can occur even when falling on the same level (Hinze et al, 1998; and Haslam et al, 2005).
2. Falls of Materials  
The delivery of construction materials constitutes a hazard in itself because they are mostly heavy and may have to be delivered to several locations at different heights using cranes or other equipment. The materials may potentially fall and injure construction workers (Hinze et al, 1998). Additionally, the materials may also fall while in storage.
3. Strike by Equipment  
The multitudes of equipment used on site can be hazardous as they could strike construction workers while at work. Struck-by accidents mostly involve heavy equipment (Hinze et al, 1998; and Haslam et al, 2005).
4. Electrical Shocks  
Contact with overhead electric power lines and building power constitute the most common sources of electric shock (Hinze et al, 1998). These typically occur when utility lines are being linked to a facility or, during the use of electric powered construction tools. Both the facility wiring and construction tools may also be faulty thus causing electric shocks.
5. Transport Accidents  
The transportation of rocks, concrete, steel, wood and other materials to and from the construction site may result in accidents both on and off the site (Haslam et al, 2005). Construction vehicle accidents are included in this hazard category.
6. Excavation Collapses  
Trenches, excavations and tunnels have the tendency of caving in before they are fully supported (Hinze et al, 1998). Those workers caught in the cave-in are likely to be injured as a result.

7.     **Exposure to Hazardous Substances**  
Exposure to hazardous substances such as silica dust, asbestos and solvents is also considered a site safety hazard as it could lead to illness and injury with inhalation or skin contact. Asphyxiation could also result from exposure to toxic substances (Hinze et al, 1998).
8.     **Fires and Explosions**  
This could occur as a result of ruptured utility gas lines, flammable fumes, and also from electrical connections to the construction site. Severe and fatal injuries could result from such occurrences (Hinze et al, 1998).
9.     **Overturning or Collapse of Site Structure**  
The collapse of a site structure could cause significant injuries to any individual within vicinity (Davies and Tomasin, 1996). This refers to both existing site structures and those under construction.

#### **2.2.2.2         Root Causes of Safety Hazards**

Construction site hazards are mostly initiated or caused by a number of factors. Some of the most common root causes are listed and briefly discussed.

1.     **Human Error**  
Human error and sudden deviations from prescribed behavior are responsible for a large number of site accidents (Huang, 2003; and Toole, 2002). Though human error is inevitable, consequences on the construction site could be severe considering site conditions, and the materials and equipment in use.
2.     **Strenuous Work / Overexertion**  
Overexertion could lead to site accidents (BLS, 2010). This is usually the result of long working hours, engaging in hard labor and/or fatigue (Toole, 2002).
3.     **Unsafe Practices**  
This refers to unsafe practices by a construction worker in executing his/her duties. This could be through the unsafe use of equipment and/or the use of unsafe or inappropriate methods (Toole, 2002).
4.     **Poor Supervision and Monitoring of Site Activities**  
This refers to the failure of supervisory personnel to monitor and direct site activities. This is particularly important considering certain activities require some form of guidance to ensure safety. Additionally, when supervisors fail to enforce site safety practices, accidents are more likely to occur (Toole, 2002).

5. **Drug and Alcohol Use**  
An intoxicated worker is a single ingredient for an accident (CII, 2003). He/she could cause serious harm considering the nature of materials and equipment, and conditions at a construction site (Huang, 2003).

### **2.2.3 Macro-Level Factors affecting Construction Safety**

There are a number of macro-level factors that can impact safety performance on construction projects. The more notable ones from literature are provided and briefly discussed.

1. Size of Construction Firm  
Larger construction firms were found to exhibit better safety results (Hinze, 1997; and CII, 2003). This is largely due to the fact that they have more financial means to not only train their workers on safety but to utilize other safety strategies (CII, 2003).
2. Type of Contractual Agreement  
The type of contractual agreement between the owner and prime contractor may also impact construction site safety. CII (2003) found projects bound by cost plus contracts experienced lower recordable injury rates when compared with lump sum contracts. Safety expenditures have a direct impact on decreasing the profit margin particularly in lump sum contracts thereby, making it more likely that very little is expended on safety (CII, 2003).
3. Management and Owner Commitment to Safety  
Another important macro-level issue is management commitment to safety. It drives the implementation of safety strategies and the development of a safety culture by construction firms (CII, 2003). Owner commitment to safety may also determine the implementation of certain safety strategies (Huang, 2003). For example, the owner may choose to use safety as a criterion in contractor selection.
4. Number of Firms involved in a Project  
Having a large number of firms involved in a project may impact safety by affecting the dissemination of relevant information. It may also decrease the effectiveness of site monitoring as the enforcement of particular safety strategies throughout the project site may prove difficult. For example, a larger number of subcontractors on a project will require a more extensive and effective subcontractor safety management plan (Levitt and Samelson, 1993; and CII, 2003).
5. Type of Project Delivery Method  
The type of project delivery method may also impact construction site safety on the macro-level. A design-build project may impact safety

differently than a design-bid-build project. In a design-build project, the designers and contractors are more likely to collaborate in eliminating or minimizing hazards either during design or during construction (Coble and Blatter, 1999). Liability issues prevent such collaboration in design-bid-build projects.

## **2.3 Strategies for Improving Construction Safety**

There are several strategies used towards ensuring or improving construction worker safety. Such strategies include best practice measures, protective measures, safety initiatives, technological approaches and regulations. These are discussed.

### **2.3.1 Best Practice Measures**

An investigation was conducted by the Construction Industry Institute to identify strategies that have shown better safety records (CII, 2003). Through interviews and statistical analysis, data was collected and interpreted from large construction firms listed among the top 400 construction firms by ENR magazine. The results determined by the CII research team encouraged a number of “best practice” measures.

1. Management Participation in Accident Investigation  
Companies where top management participated in the investigation of recordable injuries had decreased recordable injury incidence rates on average. This also applied to companies where the president and/or senior management reviewed the safety performance report.
2. Safety Staffing  
The study found safer firms employ full-time safety representatives. Furthermore, the safer firms were found not to utilize consultants for fundamental safety tasks.
3. Safety Planning  
The study found companies that executed site-specific safety plans and programs had lower recordable injury incidence rates on average.
4. Safety Training and Education  
Companies where workers received formal safety orientation were found to have lower recordable injury incidence rates on average than where workers received informal orientation. Additionally, the study found that where every worker on project received orientation training, there were lower injury rates. Additional safety training after orientation was also found to be characteristic of safer firms.

5. Worker Participation and Involvement

Projects that employed a formal, behavior-based safety program were found to have better safety records. Behavior-based safety programs use safety observers to assist in correcting unsafe behavior and to help in reinforcing good safety practices. Hourly craft workers, foremen and other supervisory personnel were found to mostly function as the observers. Also, projects where worker safety surveys were administered were found to have lower injury rates.

6. Recognition and Rewards

The study found companies where workers receive incentives on a more frequent basis had lower recordable injury rate on average. Safer firms were those that had their worker incentives based on a specific level of performance typically below a prescribed injury frequency level.

7. Subcontractor Management

Safer results were noted when subcontractor safety meetings were held daily. Also, where subcontractors were required to submit site-specific safety plans, it was found that those firms had lower recordable injury incidence rates on average. Lastly, safer firms were found to impose sanctions for subcontractors that did not comply with project safety requirements.

8. Accident Reporting and Investigation

While accident reporting and investigation for recordable injuries is required by law, the documentation of near misses is not. Companies that tracked near misses were found to have better safety performance. Additionally, injury rates were found to be lower for companies that recorded more near misses.

9. Drug and Alcohol Testing

Companies that conducted random drug and alcohol testing were found to be safer. The CII study found safer firms were those with less positive results on their random drug testing.

### **2.3.2 Protective Measures**

There are also a number of protective measures that can be taken during construction to prevent site safety hazards or to reduce injury in the event of their occurrence. Some are briefly discussed.

1. Personal Protective Equipment

Personal Protective Equipment (PPE) is to be worn and utilized on the construction site at all times (Davies and Tomasin, 1996). They could help prevent injuries and also decrease injury severity in the event of construction site safety hazards (Huang and Hinze, 2003). Basic PPE

includes a helmet, a reflective jacket, safety-toed boots and safety eyewear (Reese and Eidson, 1999). Other PPE include those for hearing and respiratory protection.

2. Safety Harnessing Systems and Safety Nets

Safety harnessing systems connect a construction worker to a rigid anchor point thereby supporting the worker to carry out his/her duties at heights (Reese and Eidson, 1999). This decreases the risk of falling, and prevents the worker from falling to the ground in the event of a fall. The latter also applies to safety netting (Huang and Hinze, 2003).

3. Guardrail Systems

Guardrails could be installed around elevated work areas such as roofs. When installed, they may arrest the fall of workers or that of materials (Reese and Eidson, 1999).

4. Signs, Signals and Barricades

Signs and signals alert workers to certain site safety hazards and hazardous conditions. This notifies the workers to take extra caution to avoid such hazards (Davies and Tomasin, 1996). Barricades meanwhile may serve to indicate inaccessibility or to block accessibility in the interest of avoiding certain hazards.

5. Housekeeping and Construction Waste Disposal

In order to prevent the slips, trips and falls of individuals both on the same and different levels, there is a need to continually clear the building area of construction tools, materials, waste and debris (Reese and Eidson, 1999). Other hazards may also be prevented through the implementation of this measure.

### **2.3.3 Safety Initiatives and Programs**

There are initiatives and programs that can be utilized towards improving worker safety in the project lifecycle. A number of these were identified from literature and are briefly discussed.

1. Project Safety Assessment

This is the comprehensive evaluation of potential safety concerns that are present or could occur on a project (Hislop, 1999). After identifying potential hazards, strategies can be developed and/or project requirements can be modified to minimize or eliminate their risk of occurrence. Project stakeholders either conduct the assessment by themselves or engage an analysis and planning team which can include both project designers and contractors (Hislop, 1999).

2. Design for Construction Safety (DFCS)

DFCS is the explicit consideration of construction worker safety in the design of a project (Toole and Gambatese, 2008). It involves the identification of design features that are potentially hazardous and then adding elements to minimize or eliminate their construction safety risks (Gambatese et al, 2005). The features themselves may be modified or eliminated to address the safety risks they pose. DFCS is typically executed by the project design professionals.

3. Best Value Bid Approach

The Best Value Bid (BVB) approach is the evaluation of bid proposals and the determination of winning bids on the basis of price and a specified set of technical criteria that may include safety (Scott et al, 2006). The bid with the highest value to the project owner secures the contract. By assigning scores/priorities to safety planning and/or record, contractors are motivated to develop and adhere to safety plans and safe practices. BVB allows contractors to make cost provisions for safety with less risk of losing out on a contract.

Project owners and/or stakeholders determine the technical criteria and then assign scores/priorities to each criterion, including that of safety, for the bid proposal evaluation. Both the bid approach and evaluation criteria are then publicized in the solicitation for bids (Heisse, 2002). When received, the value of each of the bids is determined using mathematical and subjective evaluations.

4. Collaborative Project Procurement

Collaborative project procurement approaches such as Concurrent Engineering (CE) and Integrated Project Delivery (IPD) address the fragmented project delivery process by encouraging the collaboration of all project participants in matters that could include safety, early on in a project (Anumba, 1999; and AIA, 2010). Such approaches integrate people, systems, and practices into a process that collaboratively harness the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases from design to construction (AIA, 2010).

To implement collaborative project procurement, key project participants are convened to form an integrated or multi-functional matrix team during the pre-construction project phases. The team then evaluates how project features and decisions impact each project phase. On this basis, changes are made to optimize project results with regards to cost, time and other factors including safety (AIA, 2010). Through this process, safety hazard risks that may exist throughout the project lifecycle can be identified and mitigated.

5. Fire Protection Programs

A fire protection program is intended to prevent the occurrence of fires and also to address the fires should they occur (Levitt and Samelson, 1993).

The program should indicate protective features and egress strategies. It should also specify guidelines on where flammable material such as fuel is stored or piped and locations where hot work operations such as welding are permitted (Reese and Eidson, 1999). The protection program should also prescribe locations for fire extinguishing equipment and fire hazard signs. Fire suppressant systems and fire retardants may also be specified for use on the project (Reese and Eidson, 1999).

6. Site Safety Monitoring

This involves the monitoring of site activities to ensure the safety plan including its specified strategies and measures are adhered to on the construction site. Safety monitoring may also prevent unsafe practices on site and alert workers in case of potential hazards.

Staff may be exclusively designated to monitor the safety of construction workers (Reese and Eidson, 1999). They may also be designated to monitor and recognize specific hazards such as falls.

7. Facility Management and Maintenance Safety Programs

These programs provide guidelines for facility users and maintenance staff for the safe use, operation and maintenance of completed facilities. The program should identify potential safety hazards and provisions made to prevent them. Precautions and requirements should also be provided for hazardous/toxic materials, fire, electric and fall hazards (Cotts et al, 2010).

8. Demolition Safety Planning

Demolition is executed at the end of one project lifecycle and at the beginning of another. As this is a very hazardous activity, adequate safety planning is required to eliminate or minimize risk of injury to not only workers but to the general public. There should be clear specifications for the use of explosives, fire and fall protection (Reese and Eidson, 1999). There should also be guidelines for the safe disposal of demolished project components and waste materials.

### **2.3.4 Technological Approaches**

Technological developments have been made towards making specific construction activities safer and also towards improving the effectiveness of certain safety strategies. A number of these were identified from literature and are briefly discussed. They include material, automated construction, site surveillance, site planning and other technologies.

A. Material and Method Technologies

1. Materials Technologies

Material assembly and construction technologies have the ability to improve construction site safety through decreasing the difficulty of construction. With less difficulty, construction will require less time and

thus a reduction in the period of exposure to risks of certain site safety hazards (Haas et al, 2000). Additionally, with less construction difficulty, the opportunity for human error is also decreased. Examples of such technologies are prefabricated and lighter materials technologies such as insulated concrete forms (Haas et al, 2000).

2. Portable Hazardous Substances Testing Technologies

These technologies may enable the quick detection of hazardous substances thereby preventing the exposure of construction workers or decreasing their period of exposure. Furthermore, the use of such technologies enables immediate response as opposed to response when the situation becomes critical. Examples of such technologies are personal air monitoring systems (Goldberg et al, 1994).

3. Emergency Response Technologies

These technologies do not target the safety of construction processes but the procedure after the occurrence of site safety hazards such as falls of individuals and strike by equipment. This immediacy of attention may prevent a severe injury from becoming fatal. An example of such technologies is the Emergency Automated Response System or EARS (Phillips et al, 2004).

B. Automated Construction Technologies

Automated construction technologies can assemble certain project components and systems with little or no use of construction workers. An example of such technologies is the Smart System by Kajima. This system assembles the exterior of buildings. At the point when structural work is complete, the system is assembled around the building footprint and initiated. For economic feasibility, most of the projects utilizing this system are of high-rise building construction. The use of the Smart System improves safety by eliminating the risk of worker injuries and/or fatalities during construction of the building exterior (Howe, 2000).

C. Site Surveillance Technologies

1. Combined Ultra-Wideband Positioning and Range Imaging Sensing Systems

This technology is designed for productivity and safety monitoring on construction sites. It comprises of three advanced systems and utilizes high-speed communication networks (Teizer and Castro-Lacouture, 2007). A small device is to be situated in the name tag of a construction worker and from then on, his/her position on the site is relayed to the data screen. Should the worker venture into an area designated as unsafe, he/she would be immediately alerted by the device. Meanwhile, worker productivity is to be measured by movements and positioning systems.

2. Global Positioning Systems and Sensor Technologies for Equipment  
These technologies are mostly applicable to heavy equipment used on construction sites. The technologies serve to provide equipment operators with situational awareness. The operators are then able to sense their environment with the objective of increasing safety and improving productivity on construction sites (Oloufa et al, 2003). Accidents involving the equipment are then more likely to be averted.

D. Project and Site Planning Software

1. BIM (Building Information Modeling)  
BIM can better enable site safety planning (Sulankivi et al, 2010). There is a significant difference between viewing stacks of floor plans and elevations at two-dimensions versus viewing a three-dimensional model of the same facility against time. With BIM's ability to generate these three and four-dimensional models, certain spatial safety concerns can be identified and addressed prior to construction (McKinney and Fischer, 1998). Such spatial features may otherwise not be noticed in two-dimensions. With regards to more effective site safety plans, four-dimensional modeling can generate alternative sequences for constructing structures thereby enabling the selection of a sequence that least interferes with adjacent construction activities (McKinney and Fischer, 1998). Additionally, the ability to integrate heavy equipment, vehicles, paths and people into a building model enables the determination of the safest and most effective site layout plan as well.
2. Laser Scanning and Point Cloud Data Processing  
3D laser scanners help give a highly definitive survey of the construction site. They are able to provide site grades, conditions and proximities thereby substituting the need for manual site survey which requires measurements from points where one could easily get injured such as heights and roadways (AHMCT, 2007). The use of laser scanning and point cloud data processing technologies can thus decrease risk of injury on the construction site while also decreasing the period of exposure to construction site risks as the duration of the survey may be shortened.
3. Site Layout Optimization Technologies  
These technologies are used in planning construction site layouts. They are used towards maximizing functional effectiveness and construction safety while minimizing cost of resources on site (El-Rayes and Khalafallah, 2005). This then yields an optimal site layout. Such technologies can decrease the occurrence of transport and other accidents caused by poor site planning.
4. Scheduling-Based Risk Estimation and Safety Planning Systems  
These technologies utilize risk data for construction activities, environmental risks, site maps, and the activity schedule to determine site

locations with high safety hazard risks (Yi and Langford, 2006). This determination is made considering the combined nature of activities taking place in specific vicinity over a particular period of time. There are two alternative preventive measures. The first of which is to provide more safety resources to the activities in the high risk area, and the second, the adjustment of the construction schedule (Yi and Langford, 2006).

5. Collaboration Software and Technologies

Collaborative software provides a medium for safety related dialogue between project stakeholders (Nitithamyong and Skibniewski, 2004). Examples of such software are Buzzsaw, Constructware and FieldManager. However, the effectiveness of such internet-based technologies is fully dependent on the commitment of all project stakeholders to construction worker safety.

E. Other Technologies

Purdue University's Division of Construction Engineering and Management have a listing of emerging technologies that could impact construction safety. These technologies are identified and briefly discussed.

1. Digital Hardhat System

This technology has two functions. It serves as protective equipment while offering the ability to collaborate with project stakeholders that are offsite. Project stakeholders can therefore identify safety issues without being present and also without jeopardizing the safety of the construction worker utilizing the equipment.

2. Safe Excavation with Active Metal Detector

This technology prevents the rupture of pipe mains by notifying equipment operators of utility lines. This could prevent exposure to harmful gases and the occurrence of fires and explosions in case of easily-flammable gas sources.

3. Multi-span Bridge Decking and Shileding (Safespan)

This technology provides a protective floor area on which bridge construction can be more safely executed thereby decreasing risks of falls of both individuals and materials.

4. Engineering Control System for Asphalt Paving

The engineering control system is designed to capture fume emissions from asphalt paving. Thus, it decreases the exposure of construction workers to the harmful chemicals and substances released during the paving process.

5. Device for improving Crane Productivity and Safety (Cranium)  
This technology limits the need for construction workers to be in direct line of sight of cranes to guide activities. It reveals those engaged in construction activities within the cranes' vicinity.
6. Soundless Chemical Demolition Agents  
Explosives are inherently dangerous. This technology can reduce their use in the demolition process. The chemical agents expand when added to water and poured through borings thereby causing the breakup of rocks and concrete materials. The use of this technology also eliminates the risk of premature detonation.
7. Integrated Building System (ATLSS)  
ATLSS is a family of structural systems that primarily involve the use of uniquely designed beam-to-column connections which possess the capability of being erected by automated construction techniques as well as manually. Thus, this technology can make the methods of construction, especially for steel, easier and more structured than the conventional method. Therefore, it can improve safety performance by decreasing human error and overexertion of construction workers.
8. Trench Safety System (Pipeman)  
This technology guides and lines up underground pipes without assistance from construction workers in the excavation trench itself. It eliminates or minimizes risks associated with working in pipe trenches, which are typically subject to risks of collapse and falls of materials.
9. Automated Tank Surface Finishing System  
This technology, as with all automated system activities, eliminates the risk of human error and safety hazards associated with the activity. This system specifically mitigates the risk associated with falls from elevated work areas and exposure to harmful substances which are characteristic of tank surface finishing.
10. Human Modeling (Delmia Safework)  
This technology determines if the human fit, form and function are suitable for certain construction activities without exposure to unacceptable safety risks. This system aids in the identification of potential hazards and also in the determination of scenarios where alternative construction methods should be utilized.

### **2.3.5 Safety Regulations**

Governments address worker safety through mandatory requirements that aim to prevent or reduce injury. In many jurisdictions, there are specific agencies charged with enforcing these safety requirements or regulations. In the United

States, the Occupational Safety and Health Administration (OSHA) of the Department of Labor is the official conductor of safety regulatory oversight in all sectors and industries.

OSHA was created along with the National Institute of Occupational Safety and Health (NIOSH) by the United States Congress on December 29, 1970 under the Occupational Safety and Health Act. Unlike OSHA, NIOSH is responsible for conducting research and making recommendations for the prevention of work-related illnesses and injuries.

OSHA has since established safety regulations for the construction industry. Failure to adhere to these regulatory requirements will directly result in liability and fines either in the event of a hazard or if observed by an OSHA inspector. Some of the aforementioned safety strategies and measures in earlier sections are currently required by OSHA.

Safety and health requirements for the construction industry are situated in Part 1926 of OSHA's regulatory standards and include 26 subparts addressing a significant number of issues and activities ranging from fall protection to excavations, ladders, and steel erection among many others. The subparts are listed.

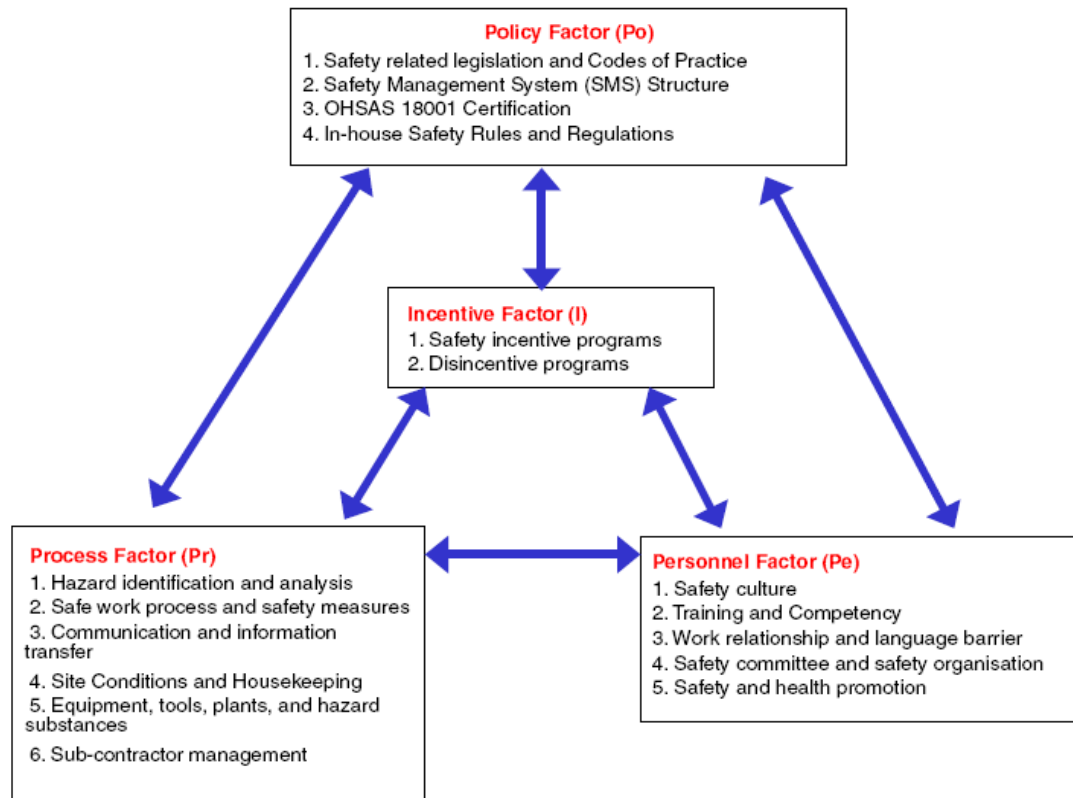
Subpart A:	General
Subpart B:	General Interpretations
Subpart C:	General Safety and Health Provisions
Subpart D:	Occupational Health and Environmental Controls
Subpart E:	Personal Protective and Life Saving Equipment
Subpart F:	Fire Protection and Prevention
Subpart G:	Signs, Signals, and Barricades
Subpart H:	Materials Handling, Storage, Use, and Disposal
Subpart I:	Tools - Hand and Power
Subpart J:	Welding and Cutting
Subpart K:	Electrical
Subpart L:	Scaffolds
Subpart M:	Fall Protection
Subpart N:	Cranes, Derricks, Hoists, Elevators, and Conveyors
Subpart O:	Motor Vehicles, Mechanized Equipment, and Marine Operations
Subpart P:	Excavations
Subpart Q:	Concrete and Masonry Construction
Subpart R:	Steel Erection
Subpart S:	Underground Construction, Caissons, Cofferdams, and Compressed Air
Subpart T:	Demolition
Subpart U:	Blasting and the Use of Explosives
Subpart V:	Power Transmission and Distribution
Subpart W:	Rollover Protective Structures; Overhead Protection
Subpart X:	Ladders
Subpart Y:	Commercial Diving Operations
Subpart Z:	Toxic and Hazardous Substances

### 2.3.6 Models of Construction Safety

Earlier research developed a number of models for addressing construction safety. The models differ in purpose and function. A number of them are presented and briefly discussed. Though not likely the only models of construction safety that have been developed, those presented address a variety of safety goals and utilize a variety of formats. They also show different factors, features and issues that can impact construction site safety.

#### 1. 3P + I Model

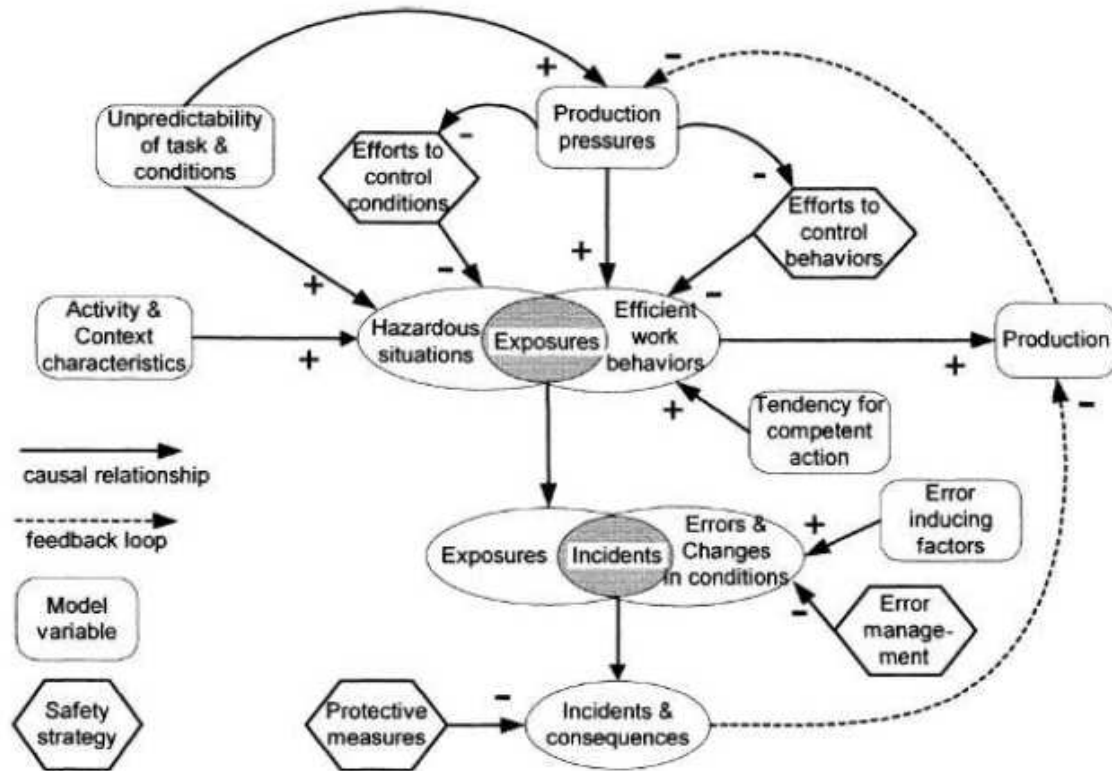
This probabilistic model is a tool to ascertain the effectiveness of Safety Management Systems (SMS) and that of SMS audit by calculating their Construction Safety Index (CSI) scores (Teo et al, 2006). An ineffective SMS is one with a low CSI score. Steps can then be taken to improve an organization's SMS. The model has four principal components that include Policy Factor, Process Factor, Personnel Factor and Incentive Factor (3P + I), each of which comprise of several attributes. The Analytic Hierarchy Process (AHP) procedure and 5-point Likert scale are then used to determine the weighting of attributes in the model. The model is illustrated in *Figure 3*.



**Figure 3:** 3P + I Model (Source: Teo et al, 2006)

## 2. Accident Causation Model

This qualitative system model illustrates safety strategies and measures that impact incidents and exposures along with interrelationships and the direction of the relationships (Hallowell, 2008). With this understanding, a safety guideline can then be developed. The model is illustrated in *Figure 4*.



**Figure 4:** Accident Causation Model (Source: Hallowell, 2008)

## 3. Accident Root Causes Tracing (ARCT) Model

The ARCT model serves to complement construction accident investigation techniques by raising many important questions and possible answers that help to identify the root causes behind occupational accidents (Abdelhamid and Everett, 2000). It identifies areas where prevention efforts should be directed, so that labor and management may provide more effective measures for preventing accident occurrence. This qualitative model emphasizes the need to consider worker training, worker attitude, and management procedures when the prevention efforts are contemplated. The model is illustrated in *Figure 5*.



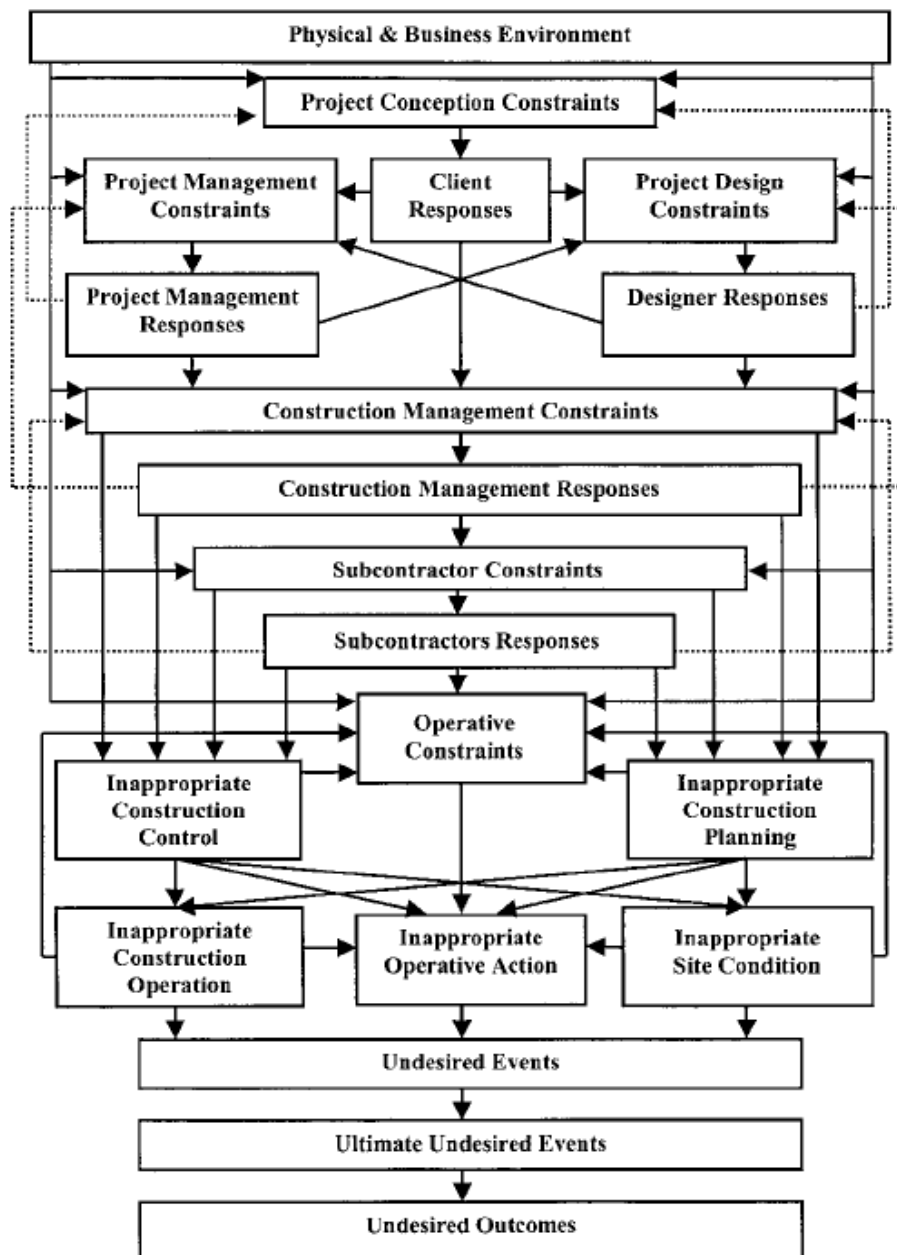
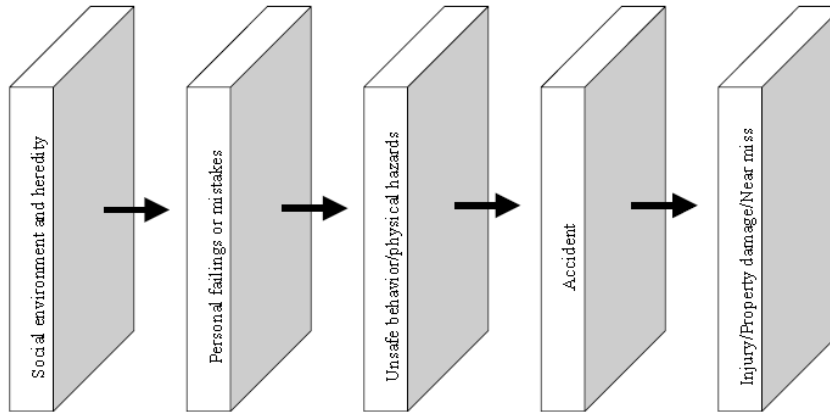


Figure 6: Constraint-Response Model (Source: Suraji et al, 2001)

##### 5. Domino Accident Causation Model

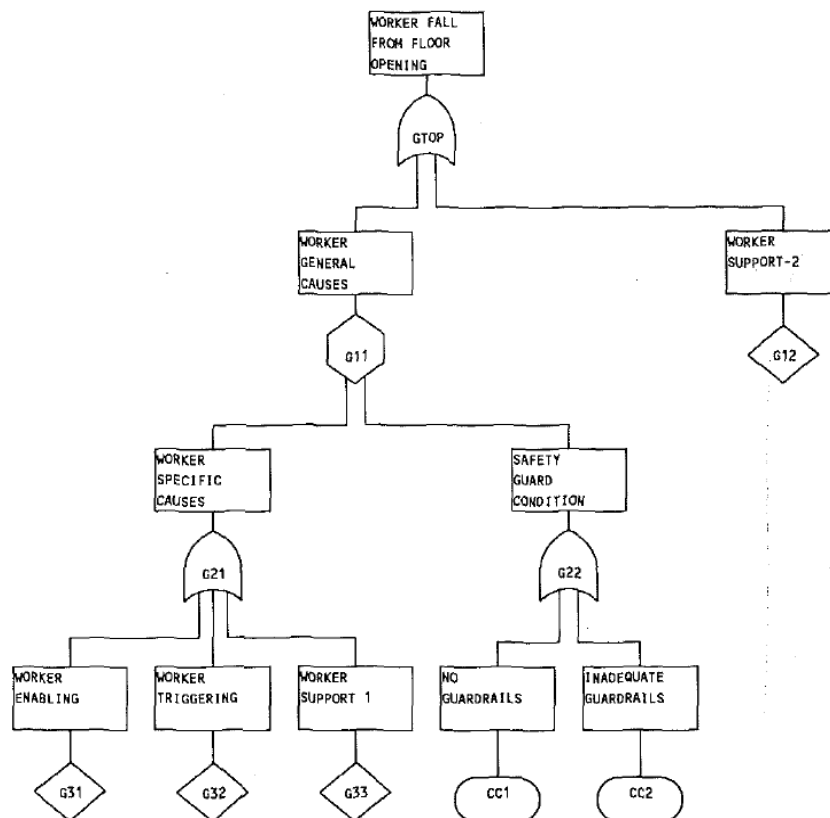
This qualitative model indicates that accidents occur as a result of a series of events which include the social environment and heredity, personal failings or mistakes, physical hazards and unsafe behavior (Heinrich, 1959). If these events are permitted to occur in continuity, an accident and/or injury will occur. An accident is prevented by removing an event in any location. The model is illustrated in *Figure 7*.



**Figure 7:** Domino Accident Causation Model (Source: Heinrich, 1959)

## 6. Fault-Tree Model

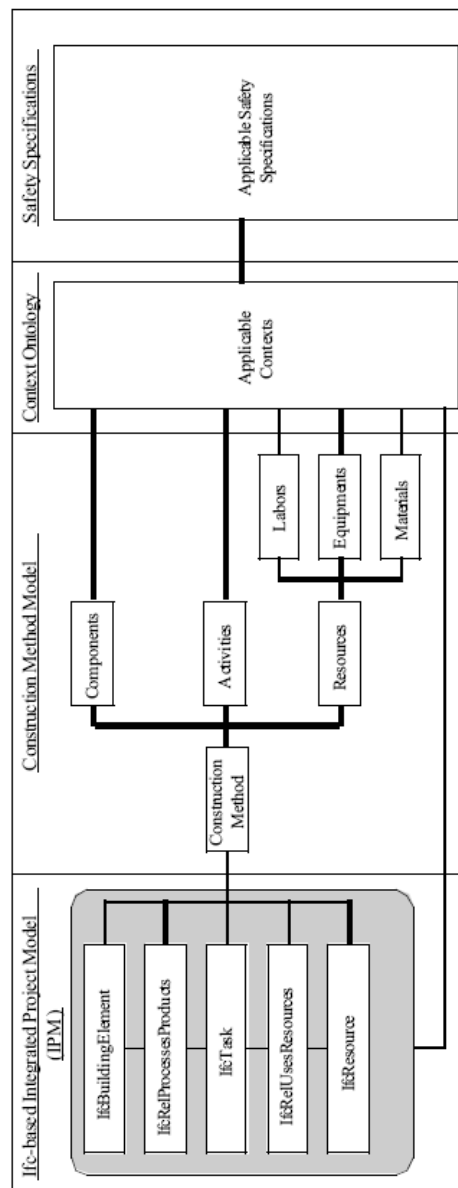
This probabilistic model is a tool to simulate and diagnose construction accidents. It represents the frame of knowledge concerning causal relationships of reasonable and possible causes of accidents (Hadipriono, 1992). Causes are classified as enabling, triggering, and support-related. Furthermore, each cause is expanded to reach the basic and conditional causes that contributed to an accident. A fault tree model for worker fall is seen in *Figure 8*.



**Figure 8:** Fault-Tree Model (Source: Hadipriono, 1992)

## 7. Integrated Project Model and Construction Method Model

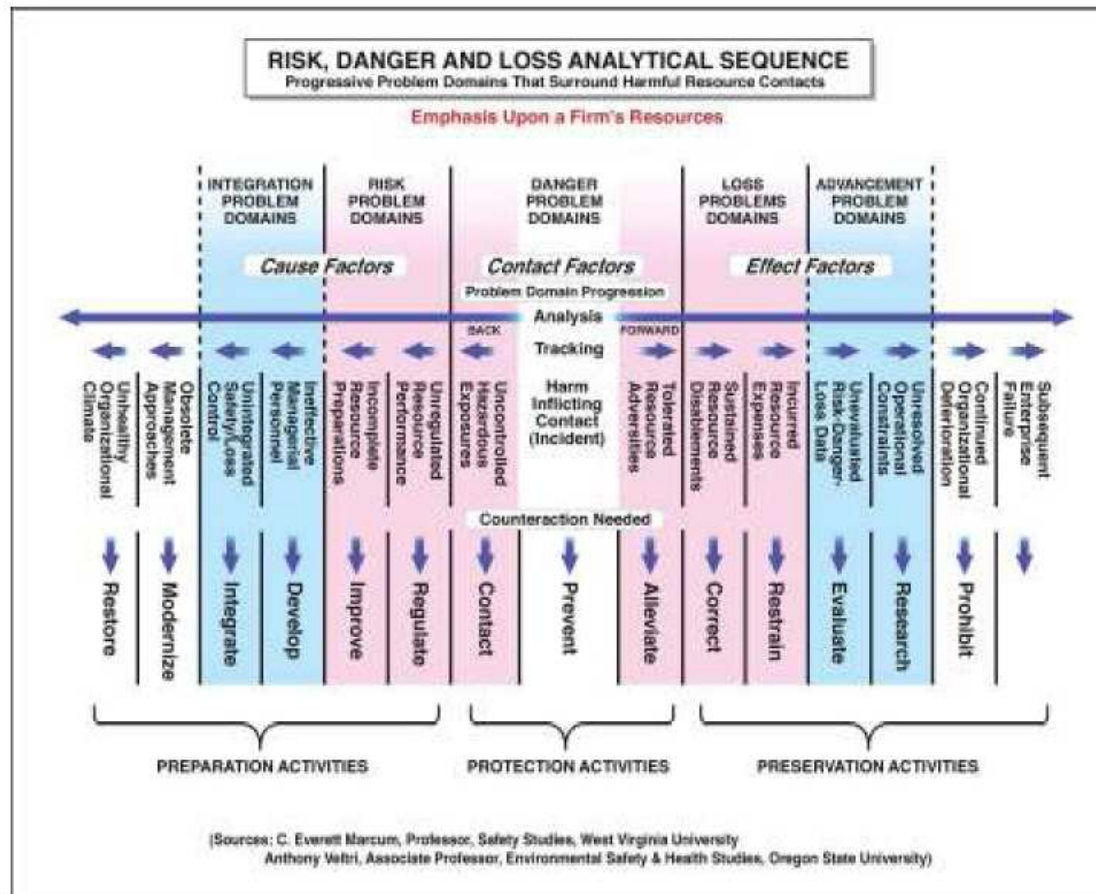
This model functions to facilitate site safety improvement and management in an automated manner by supporting the identification of safety requirements during the design and construction phases (Wang and Boukamp, 2007). This allows requirements to be taken into account early in a project life cycle. This also serves to support guidance for field engineers and inspectors during safety planning and construction safety inspection. Additionally, this qualitative model helps in developing project-specific safety requirement lists. It integrates a construction methods model and an integrated project model to achieve automated identification of safety requirements imposed by standards. The model is illustrated in *Figure 9*.



**Figure 9:** Integrated Project Model and Construction Method Model (Source: Wang and Boukamp, 2007)

### 8. Marcum and Veltri's Analytic Model

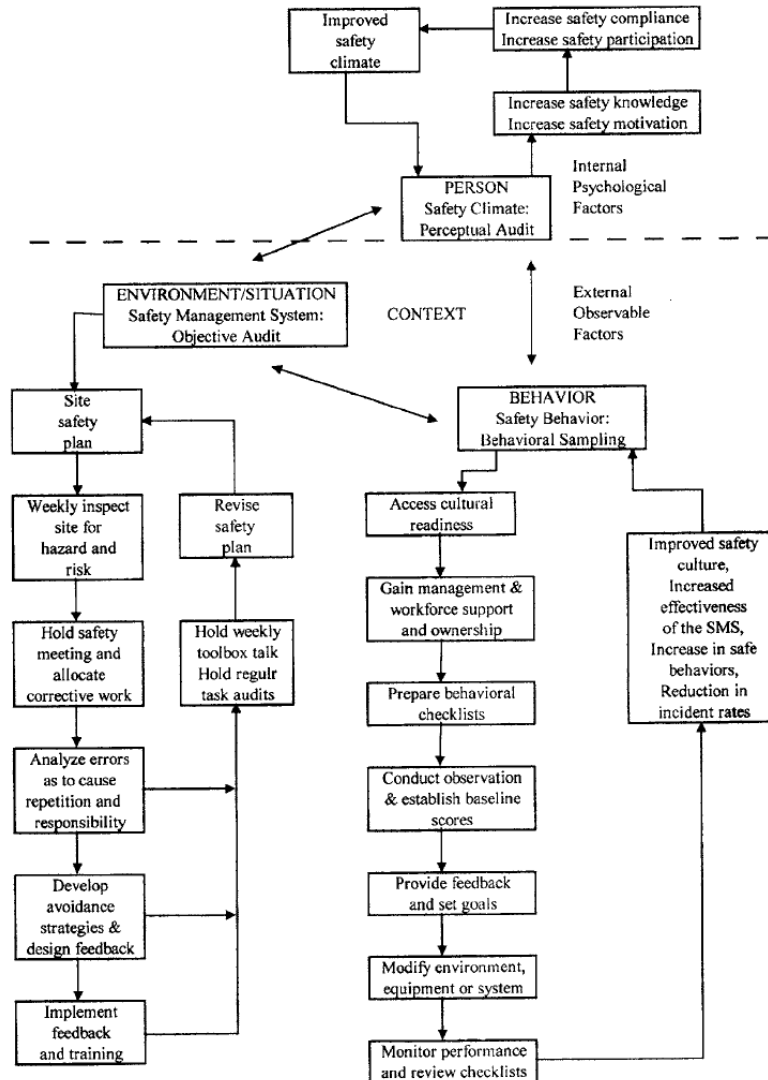
This qualitative model provides a guideline to aid in the development of safety programs (Hallowell, 2008). The objective of the model is to identify the cause and effect factors of incidents and the measures that may be taken to learn from incidents and prepare an organization to mitigate such future risks. The model is illustrated in *Figure 10*.



**Figure 10:** Marcum and Veltri's Analytic Model (Source: Hallowell, 2008)

### 9. Model of Construction Safety Culture

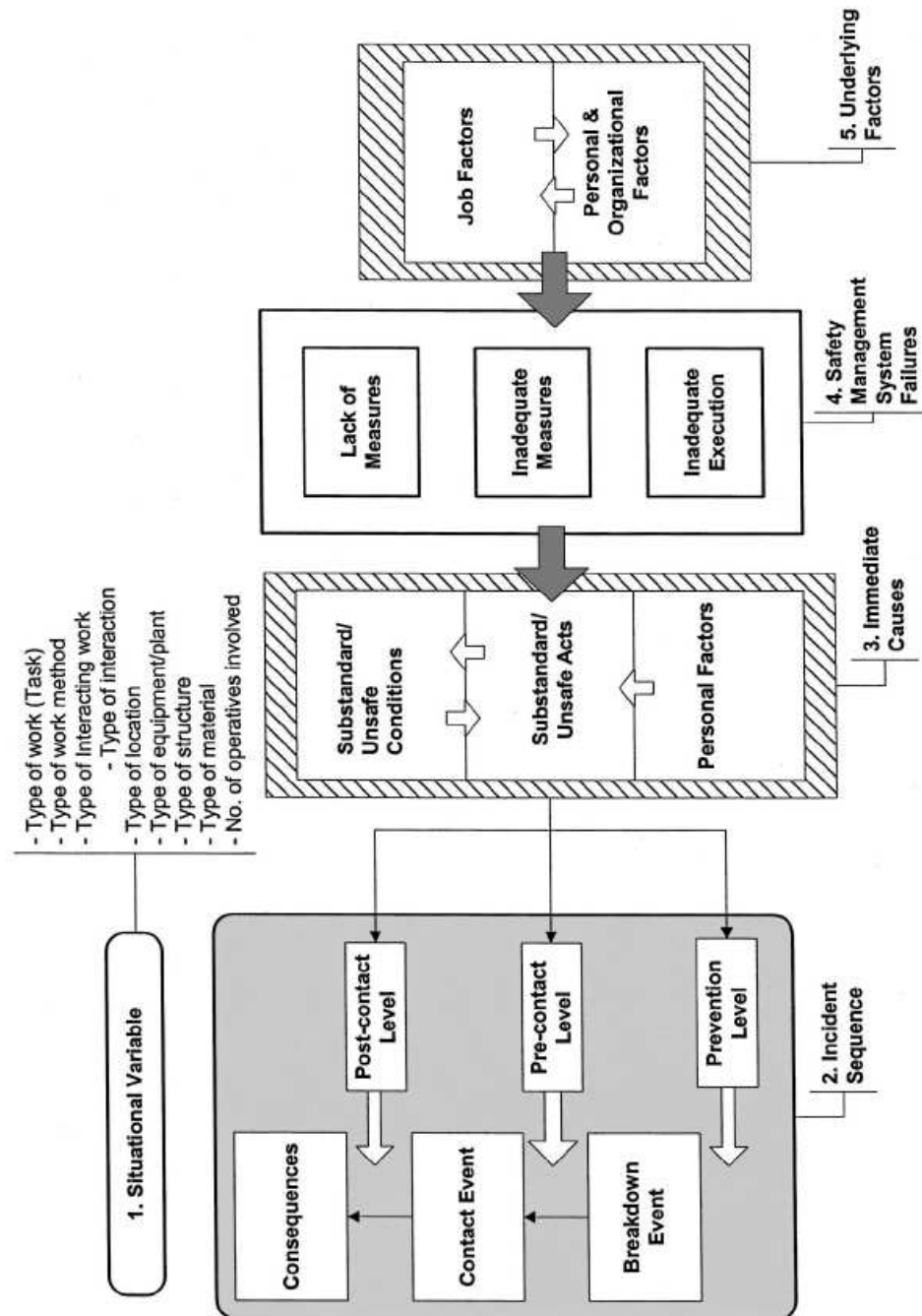
This model serves as a basis for determining what and how to analyze and assess the different aspects of construction safety culture (Choudhry et al, 2007). It analyzes safety culture in construction site environments by utilizing a systematic approach that recognizes human, technical, situational, and organizational elements as well as their interactions. It is anchored in three fundamental categories that include safety climate, behavior-based safety, and safety system. This model is qualitative. It is illustrated in *Figure 11*.



**Figure 11:** Model of Construction Safety Culture (Source: Choudhry et al, 2007)

#### 10. Modified Loss Causation Model

This incident causation model is intended to facilitate feedback to improve the construction safety management system (SMS) of companies (Chua and Goh, 2004). The feedback is in two levels, first, to the SMS that had failed, and second, to the safety planning process for future construction projects. In order to achieve the two levels of feedback, the MLCM is designed to provide a systematic and logical structure for both incident investigation and safety planning. Based on this, systematic actions can be implemented to remove flaws in the management system and organizational culture. This qualitative model is composed of five main components which include situational variables, incident sequence, immediate causes, SMS failures, and underlying factors. The model is illustrated in *Figure 12*.

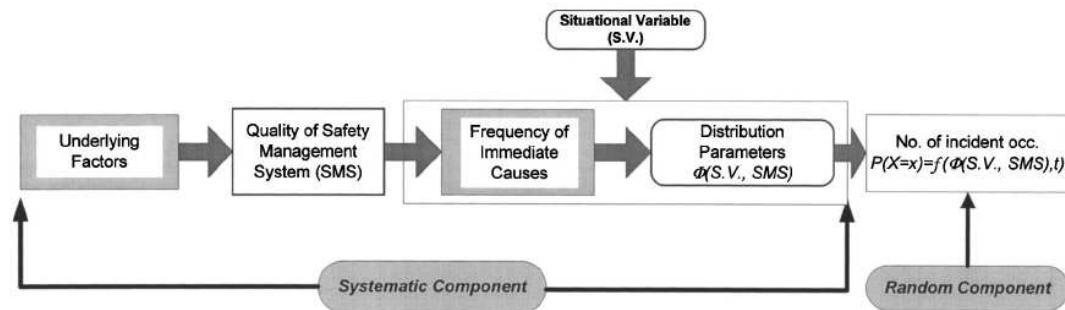


**Figure 12:** Modified Loss Causation Model (Source: Chua and Goh, 2004)

### 11. Poisson Model of Construction Safety

This probabilistic model utilizes a Poisson statistical framework based on the modified loss causation model (MLCM) to determine the effectiveness of construction safety policies and programs (Chua and Goh, 2005). The random component of the MLCM is represented by a probability density function which has parameters influenced by the systematic component of the MLCM, while the systematic component is represented by the situational variables and quality of the safety management system. During

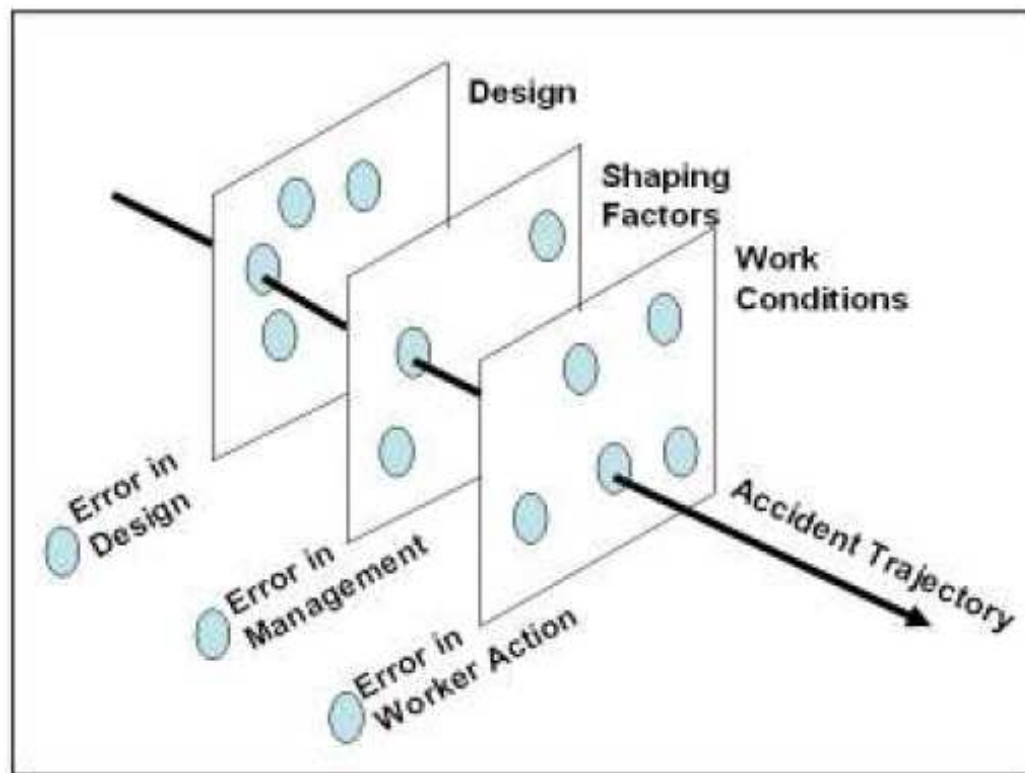
the planning stage, the risk level of different work activities or work contexts is evaluated. Based on the estimate of the Poisson parameter or incident rate, safety measures may be devised for improvement. The model approach is illustrated in *Figure 13*.



**Figure 13:** Poisson Model of Construction Safety (Source: Chua and Goh, 2005)

## 12. Reason's Accident Trajectory Model

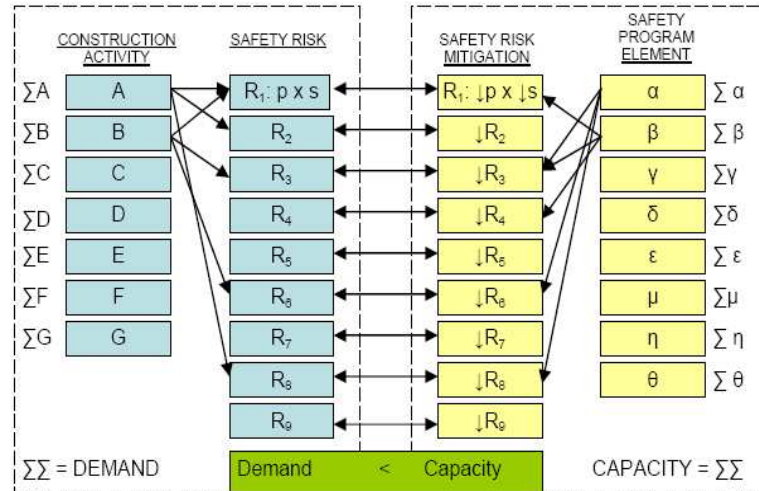
This model provides a guideline to develop safety programs that minimize or address errors in each of the accident filters that include design, shaping factors and work conditions (Hallowell, 2008). The model indicates that where any filter is free of errors, accidents will not occur. The model is qualitative. It is illustrated in *Figure 14*.



**Figure 14:** Reason's Accident Trajectory Model (Source: Hallowell, 2008)

### 13. Safety Equilibrium Model

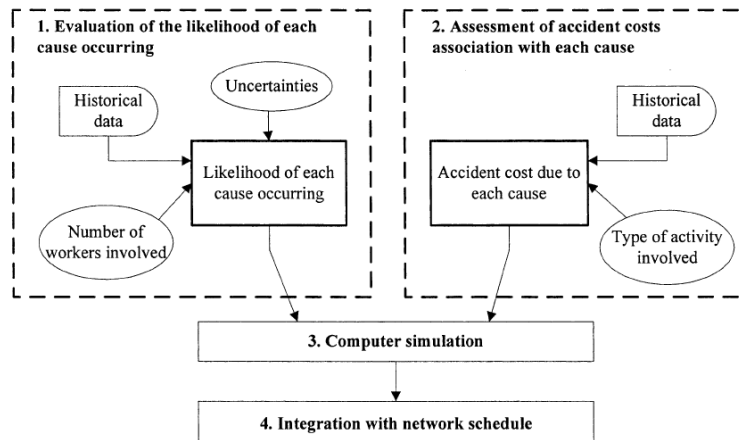
This model aims to provide direct guidance for the selection and implementation of safety program elements (Hallowell, 2008). It evaluates safety and health risks of construction processes and the management methods that can be used to reduce the risk of safety incidents. When the cumulative safety risk capacity exceeds the safety risk demand, a safety program is determined to be adequate ( $S_u < S_n$ ). The model is probabilistic. It is illustrated in *Figure 15*.



**Figure 15:** Safety Equilibrium Model (Source: Hallowell, 2008)

### 14. SimSafe Model

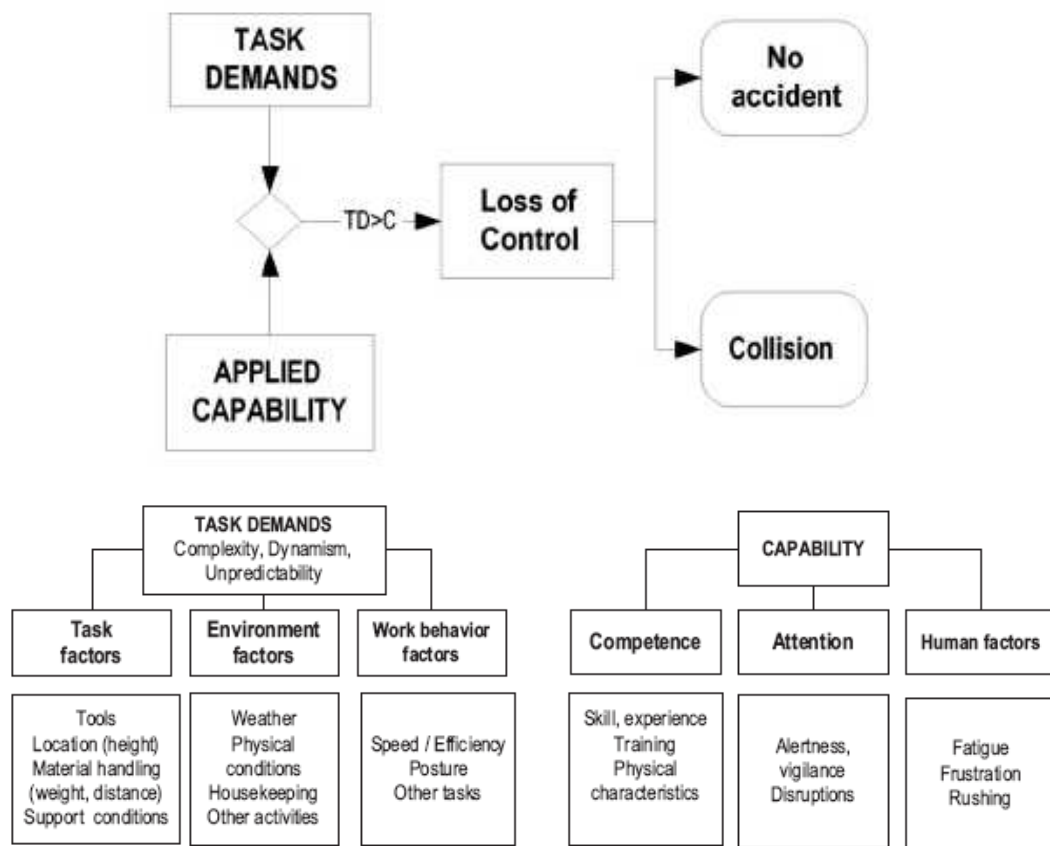
This simulation-based model assesses the hazard or expected accident costs for each activity in a network schedule (Wang et al, 2006). Safety managers can then evaluate activities or working zones with high expected accident costs. SimSafe provides factor sensitivity information to support safety risk management. The model uses three-point estimation in determining the likelihood of certain accident causes. Additionally, it utilizes historical information for the construction activities, schedule and costs. This model is probabilistic. The model approach is seen in *Figure 16*.



**Figure 16:** SimSafe Model (Source: Wang et al, 2006)

### 15. Task Demand-Capability Model

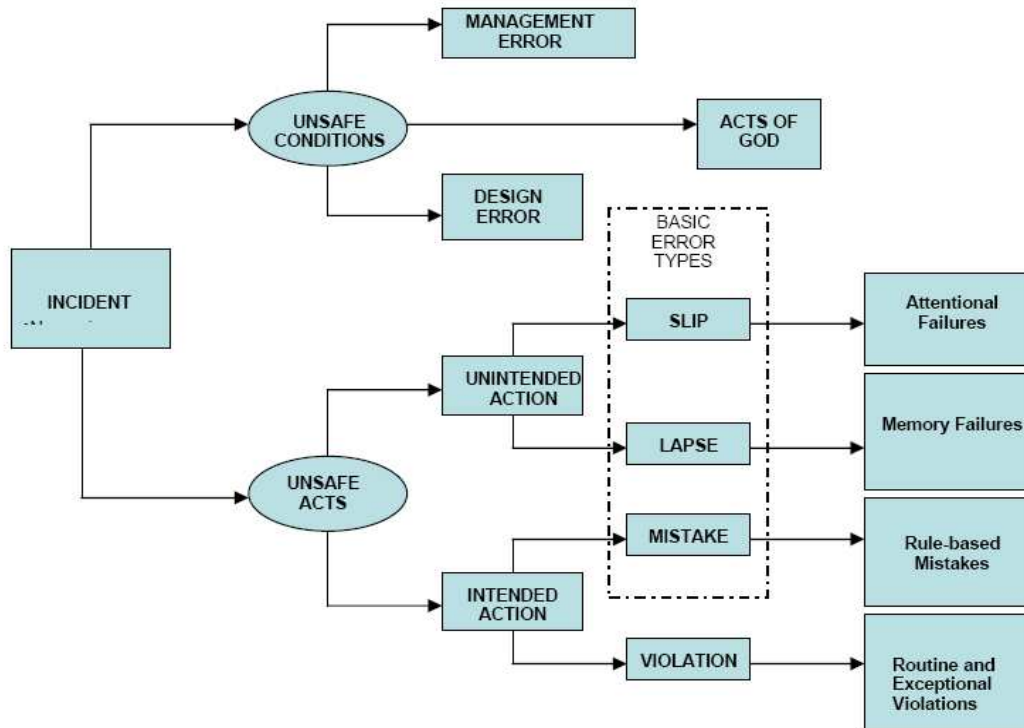
This model functions to emphasize that the design and organization of construction work and teamwork processes both be safe and productive (Mitropoulos et al, 2009). This cognitive model of construction safety conceptualizes safety as an emergent property of the production system. The model proposes that during a task, the task demands and the applied capabilities determine the potential for errors and accidents. It also proposes that the production practices and the teamwork processes of the crew shape the work situations that the workers face. Towards this, the model evaluates task demands and errors, production practices, and teamwork practices. The model is probabilistic. It is illustrated in *Figure 17*.



**Figure 17:** Task Demand-Capability Model (Source: Mitropoulos et al, 2009)

### 16. Two-Factor Model

This qualitative model is intended to serve as the foundation of an effective safety and health management program (Hallowell, 2008). Construction safety programs are to be designed to reduce or eliminate uncontrolled hazardous exposure or unsafe worker actions. The model is illustrated in *Figure 18*.



**Figure 18:** Two-Factor Model (Source: Hallowell, 2008)

Among all the presented models of construction safety, only three consider issues potentially arising from the pre-construction phases. These include the Two-Factor model, Reason's Accident Trajectory model, and the Constraint-Response model.

The Two-Factor model, as seen in *Figure 18*, specifies that both unsafe conditions and unsafe acts must be present to cause an incident though one factor may contribute more than the other (Hallowell, 2008). It also indicates that management error, Acts of God, and design error lead to unsafe conditions. Management error refers to such issues as inadequate safety management programs and plans by the contractor which lead to unsafe conditions on the construction site. Acts of God, also known as force majeure, refers to unforeseen circumstances or uncontrollable external events such as labor strikes, war and natural disasters that could impact project execution and lead to unsafe conditions (Hendrickson, 2008). Design error refers to features in the project design that result in unsafe conditions. This is the element that may be situated in the pre-construction phases. One could argue that the Design for Construction Safety (DFCS) concept could serve to minimize or eliminate design error. However, one cannot state that a design has error because DFCS was not implemented. Design professionals strive to ensure they meet all their specified obligations to avoid exposure to liability. Where their designs have met all functional, occupant safety, and code requirements, one cannot indicate their design to have error, even if it is difficult to construct. The design error would thus more likely refer to the contractors' design of the construction process and

sequences for completing the project. After all, the function of the Two-factor model is to serve as the foundation of an effective safety and health management program which is to be developed and used by the contractor (Hallowell, 2008).

The Reason's Accident Trajectory model, as seen in *Figure 14*, specifies that where all the filters of design, shaping factors, and work conditions are not compromised by error in design, error in management, and error in worker action respectively, then no accident will occur (Hallowell, 2008). The work conditions filter pertains to the worker interaction with the work site. Errors in this filter are avoided by adequate training of the workers to recognize and avoid uncontrolled hazardous exposures. The shaping factors filter includes all the activities conducted by the general contractor's safety management team. Errors in this filter are avoided by the recognition and removal of hazards by the contractor's employees that could include foremen, superintendents, and safety managers. This design filter is the element that may be situated in the pre-construction phases. On the basis of this model, if design is properly executed, safety hazards can be designed-out of a project during the design phase. Hallowell (2008) further notes that DFCS might serve to eliminate the error in design if the concept matures and becomes more sophisticated. However, as in the case of the Two-Factor model, one cannot state that a design has error because DFCS was not implemented. Again, where a design meets all functional, occupant safety, and code requirements, one cannot identify the design to have error. Also in this instance, error in design seems to pertain more to the contractors' design of the construction process and sequences for completing the project. This is especially since effective contractor safety programs developed using this model are to minimize the presence of errors or omissions in one or more of the three filters (Hallowell, 2008).

The Constraint-Response model, as seen in *Figure 6*, highlights the underlying and complex interaction of constraints and responses experienced by the parties involved in project conception, design, and construction, which may affect accident causation. The model is based on the notion that each participant in the lead up to an accident experiences constraints on their activity and the responses to these constraints in turn lead to further constraints to subsequent participants in the process (Eppenberger, 2008). These constraints, the distal factors, and associated responses eventually manifest themselves downstream into the proximal factors which then lead directly to the risk exposure or accident involving the worker (Suraji et al, 2001). It must be noted that Reason's Accident Trajectory model was theoretically utilized in the development of this model which extends the scope of the accident causation process to include management and organizational aspects (Dalton, 2002). The proximal factors include inappropriate construction planning, inappropriate site condition, inappropriate operative action, inappropriate construction operation, and inappropriate construction control which are all situated in the construction phase. The distal factors include project conception constraints, project design

constraints, and project management constraints which are situated in the pre-construction phases. An example of the model mechanism was provided by Dalton (2002). The project owner or client may encounter funding difficulties and reduce the project budget which now constrains the design professional with an inadequate design budget. The designer may then respond by reducing the design resources for the project which in turn results in the late delivery of design details that now constrains the project management team. This may then continue until the proximal factors manifest and safety incidents occur.

This Constraint-Response model is most suitable for the DFCS concept. The project design constraints are determined by the physical and business environment, owner/client responses, project management responses, and construction management responses. If any or all the responses specify or request for DFCS implementation, then the designer responses could include DFCS implementation. This is since the project design constraints guide the designer responses. The requirement for DFCS implementation may also originate from the project conception constraints and cascade to the responses that set the project design constraints for the designer.

### **2.3.7 Monitoring, Investigation and Analysis of Near Misses**

A near miss is an unplanned incident that did not result in injury, illness, or damage but had the potential to do so. The injury, fatality or damage was only prevented by a fortunate break in the chain of events. This break may be due to the presence of trained and concerned persons on the scene/site, due to a serious site safety program in place, or just due to luck (ENR, 2009).

All safety incidents need to be recorded and investigated to identify the root causes and take measures towards preventing their occurrence in the future. This should also apply to near misses. Near misses provide a good opportunity to study the safety program of a company or project to see if it possesses all the elements and processes necessary to prevent a major accident (ENR, 2009). Though the documentation and investigation of near misses is not required by law as in the case of accident reporting and investigation for recordable injuries, addressing the root causes of near misses could serve to prevent the incidents from reoccurring but with more tragic results.

In the investigation of a near miss, it must be ensured that the focus remains on identifying the root causes and not setting blame or distributing potential liability. The investigation of near misses should identify the flaws or weaknesses in the safety management program through the discovery of the contributing factors to the accident or incident. Changes can then be made to prevent future occurrences.

ENR (2009) provides an example of a near miss involving a cracked casting in a tower-crane mast at a high-rise building extension project in Chicago, IL. The operator shut down the crane when he heard a loud noise. Upon investigation, a crack was found in the crane, and work was halted as a result. The matter was then intensively investigated and many cranes were assessed to identify if the problem was generic. Given the number of major accidents, injuries and fatalities involving cranes, the outcome could have been catastrophic. This near miss investigation process ultimately involved the general contractor, the crane owner, the crane manufacturer, and the project owner.

Project participants, particularly the contractor, should have an effective program of managing near misses. According to ENR (2009), risk experts indicate that there are eight elements in an effective near miss process. These include:

1. Identification of an incident as a near miss
2. Having a reporting and disclosure structure
3. Prioritization of incidents according to potential severity
4. Distribution of the information to the parties analyzing the causes
5. Identification of the direct and root causes of the near miss
6. Finding solutions for each identified cause
7. Dissemination of the solutions to the parties who will execute them
8. Tracking solutions to ensure their execution

The monitoring, investigation and analysis of near misses is to serve towards strengthening the safety management programs of projects and companies. And if the lessons learned are integrated into the safety training programs of construction workers, it could increase their ability to recognize dangerous or hazardous circumstances before an accident occurs, thus decreasing the prevalence of safety incidents and injuries. After all, research by CII (2003) found companies that tracked near misses to have better safety performance. The research also found that injury rates were lower for companies that recorded more near misses.

## **2.4 Safety Delivery Lifecycle**

I developed the safety delivery lifecycle to indicate major strategies for safety delivery in their applicable phases of the project lifecycle. This project lifecycle is considered from the owner's perspective and is directly applicable to design-bid-build projects. In the case of design-build projects, the design, procurement and construction phases overlap. Though projects are usually distinct, this phase-based placement of the safety strategies is derived based on the provided details from literature for each of the strategies. The safety delivery lifecycle is seen in *Table 7*.

<b>Project Phases</b>	<b>Applicable Safety Strategies</b>
<i>Concept and Feasibility Studies</i>	Project Safety Assessment
<i>Design and Engineering</i>	Design for Construction Safety
<i>Procurement</i>	Best Value Bid Approach
	Collaborative Project Procurement
	Safety Planning
	Safety Staffing
	Safety Training and Education
	Worker Participation and Involvement in Safety
	Fire Protection Program
<i>Construction</i>	Personal Protective Equipment and Systems
	Site Safety Monitoring
	Subcontractor Safety Management
	Drug and Alcohol Testing
	Housekeeping and Construction Waste Disposal
	Safety Enforcement by Regulatory Agencies
	Management Participation in Accident Investigation
<i>Start-up and Commissioning</i>	Recognition and Rewards for Safety
<i>Operation and Utilization</i>	Facility Management and Maintenance Safety Programs
<i>Disposal and Decommissioning</i>	Demolition Safety Planning

**Table 7:** Safety Delivery Lifecycle

## **2.5 Role of Key Project Participants in Construction Safety**

Key project participants play certain typical roles with regards to construction worker safety. The roles of the contractor, owner and design professionals are discussed.

### **2.5.1 Role of Contractors in Construction Worker Safety**

Construction worker safety has often been regarded the sole responsibility of the contractor (Hinze and Wiegand, 1992). As the primary party that executes construction, the contractor is also responsible for ensuring the safety of its workers. Root causes for construction accidents such as unsafe methods or sequencing, deficient enforcement of safety, lack of proper worker training and absence/non-use of safety equipment are all issues that fall under the contractor's responsibility to address (Toole, 2002). Though contractors may attempt to shift liability in the event of construction accidents, the traditional general contracting method of project delivery recognizes them as the party responsible for construction site safety (Gambatese, 1998; and Mroszczyk, 2006). Model contracts explicitly state the contractor as being responsible for construction site safety methods or programs. This is indicated in both the AIA A201 contract document which is used by architects and the EJCDC E-500 contract document which is used by engineers. Thus, contractors have the exclusive responsibility of implementing safety strategies applicable to the construction phase.

Additionally, OSHA regulations specify that the prime contractor assumes all obligations prescribed in its standards for construction, whether or not any part of the work is subcontracted by the contractor (OSHA Standards; 1926.16). Where the contractor subcontracts the construction work, both the prime contractor and subcontractor may have responsibility for adherence to the standard either jointly or for their portions of the work.

In a survey of 105 firms which included civil engineering design firms, general contractors and subcontractors located throughout Pennsylvania, a majority from all groups surveyed indicated that general contractors should have primary responsibility for site safety (Toole, 2002). 65 percent of the general contractors themselves indicated that they should have primary responsibility for site safety.

### **2.5.2 Role of Owners in Construction Worker Safety**

Project owners are the primary beneficiaries of construction services, the sources of project finances, and in many cases, the end users of the facilities (Huang, 2003). Project owners have traditionally had no involvement in construction worker safety. This is for a number of reasons. Firstly, construction is typically not the core competency of most project owners. This is the basis for their contracting of the construction work and all it entails including safety management. In the traditional contractual structure, the owner hires a design professional to design the project and then hires a general contractor to oversee the construction (Toole, 2002). The design professionals are also typically expected to serve as the owner's agent to the contractor, inspecting and ensuring the work adheres to the contractual agreement. Secondly, owners do not get involved in construction safety to avoid economic losses and legal entanglements resulting from worker injuries (Huang, 2003).

However, increases in accident costs and legal cases involving owners as the third-party defendants has resulted in their becoming cognizant of the importance of safety on the construction site (Huang, 2003). Owners have also come to realize that the costs of injuries are ultimately reflected in the cost of construction through delay, investigation, litigation and corrections (Huang, 2003). As a result, since the 1980's, more owners have voluntarily expanded their role to include ensuring worker safety. As owners are also at the pivotal position of their projects, their involvement can have a significant influence on project safety performance. They can improve safety by setting safety objectives, selecting safe contractors, and participating in safety management during construction (Huang, 2003).

Some owners, particularly institutions, have safety and health rules for project services that they provide to all project participants for adherence. These owner safety policies incorporate OSHA safety standards in addition to other requirements that are applicable to contractors and in many cases, design professionals, performing work on the owner's project. Some of the safety

policies also specify that the contractors have prime responsibility for ensuring all subcontractors are aware of OSHA safety requirements, including safety training and physical examinations, as well as the requirements in the owner's safety policies. The policies typically require the contractor to monitor for safety compliance and also indicate that the owner may monitor the contractor for safety compliance. Some policies even require for the appointment of a safety coordinator by the contractor and subcontractor to ensure safety considerations are properly addressed. Ultimately, owners use their safety policies for the recognition, evaluation and control of safety hazards associated with work spaces and tasks in their projects to shield them from potential liability and litigation costs associated with safety incidents. Many institutions actually have departments dedicated to assuring compliance with federal, state and local safety regulations, along with addressing certain specified environmental, health and safety issues. As an example, the Environmental Health and Safety Department of Duquesne University states its primary goal is to provide a safe workplace for all employees, students, contractor personnel, and visitors so that work may be accomplished effectively while eliminating occupational injuries, illnesses, and related property loss.

There are also a number of reasons why owners should not participate in addressing construction safety. Firstly, a majority of owners have been determined to have low task expertise as they neither spend much time on a jobsite nor have they received technical training in construction safety. Therefore, the owners' ability to identify both visible and hidden unsafe conditions is low (Toole, 2002). Also due to their lack of site presence, owners have a low ability to affect the root causes of safety incidents (Toole, 2002). Additionally, owners typically have minimal interaction with contractor and subcontractor workers, and most lack the knowledge and staffing to exercise any control over the jobsite (Toole, 2002). A study by Toole (2002) surveyed design professionals, general contractors and subcontractors, and among them, only 3%, 8% and 2% respectively, believed that owners should have primary responsibility for site safety. This further emphasizes that not only are owners not responsible for safety, key project participants believe they should not even be involved. Without regulatory requirements as in the case of the U.K Construction, Design and Management (CDM) regulations, the owner's assumption of a role in construction worker safety may interfere with their goal of completing their project at the highest value but for the lowest possible cost. Furthermore, should the involvement of owners interfere with the contractor's means, methods and sequences, they will be exposed to liability in the event of a safety incident. These issues collectively serve to inhibit the involvement of owners in construction safety.

### **2.5.3 Role of Designers in Construction Worker Safety**

Designers influence many decisions about how construction tasks are performed although construction methods are often not recognized as being dictated by

designers (Gambatese and Hinze, 1999). This is because the design dictates not only how a project will appear but how the project and its components will be assembled. A project design and its designers can thus have an influence on the safety of the project's construction.

In the design and construction of Crystal Palace for the Great Exhibition of 1851 in London, England, the designers played a major role in worker safety. With significant time constraints for the project, the designers namely Joseph Paxton, William Cubitt and Charles Fox decided on using modular construction with a guttering system. The guttering system allowed the roof to drain through the cast-iron pipes that held it up and also, enabled the use of a special trolley that allowed glaziers to install glass with a high level of efficiency (Nash and Nash, 1998). Glaziers thus had a supported mobile platform to work and as a result experienced improved productivity and safety.

In past centuries, the master builder or mason was charged with both design and construction. Under direct contract with the owner, the master builder developed the project and directly supervised construction work. This system has since been disintegrated with the division of the professional disciplines. These disciplines have been further specialized over the past two centuries with design disciplines and construction trades placing borders around their work which have been fortified contractually and positioned by standards of practice (Gambatese, 1998). The industry now has architects, engineers, contractors and subcontractors shouldering responsibility for their specialized areas of work on projects.

In a survey of 105 firms which included civil engineering design firms, general contractors and subcontractors located throughout Pennsylvania, 18 percent of designers indicated that designers should have responsibility for site safety (Toole, 2002). Another survey of major U.S. design firms found only one-third of respondents said they made design decisions with the specific intent of improving safety conditions for construction workers (Hinze and Wiegand, 1992). These studies indicate that designers have neither been cognizant of their influence nor have they acknowledged the importance of their role in worker safety (Gambatese and Hinze, 1999).

In recent years, there has been a new emphasis on the role of designers in construction safety with the establishment of the United Kingdom's Construction, Design and Management (CDM) regulations of 1995. This regulation mandated the involvement of all major project participants in construction worker safety related matters. Towards this, it also mandated the appointment of a planning supervisor to coordinate and advise all project participants with regards to project safety. While there is no such regulation in the United States, OSHA has incorporated the involvement of professional engineers into their construction safety standards. This is to apply to work environments where ensuring worker safety requires the experience and expertise of professional engineers to assess

and design safety features (Toole and Gambatese, 2002). The standards either require or suggest the involvement of a professional engineer. The subparts and paragraphs of the OSHA standards that make reference to engineers and engineering controls include Subpart C (General Safety and Health Provisions: 1926.32(f)(m)), Subpart Q (Concrete and Masonry Construction: 1926.701(a)), Subpart L (Scaffolds: 1926.451(f)), Appendix C to Subpart M (Fall Protection), Subpart P (Excavations: 1926.651(i); and 1926.652(b)(c)(d)), Appendix B to Subpart P (Excavations), and Subpart Q (Concrete and Masonry Construction: 1926.705(a)). Despite these specific OSHA standards, the role of the designer remains restricted to the design of a building, facility, or structure such that it conforms to accepted engineering practices, local building codes, and is safe for the public (Mroszczyk, 2006).

A study by Toole (2005) investigated five tasks in which designers could potentially increase their safety roles. The first task is review for safety. Designers could increase safety through a peer review of the completed design to ensure that it provides an acceptable level of worker safety. Safety would thus join cost, functionality, and constructability as key design criteria that are part of the peer review process.

The second task is the creation of design documents for safety. This involves the consideration of worker safety throughout the design process. This could include design modifications to maximize worker safety and also, special details and technical specifications in the construction documents to facilitate safety. The third task is procuring for safety. Designers frequently assist the project owner in soliciting and reviewing bids from contractors. They often create the technical drawings, specifications and also, the requests for bid proposals. Designers often review the submitted proposals and recommend to the owner which bidding contractor should be awarded the contract. While the selected bidder is typically the lowest “responsible” bidder, designers review information such as the proposed time of completion and the contractors’ past performance with regards to quality, cost, timeliness and scope of past projects. Designers could recommend that safety be one of the criteria for selecting the winning bidder thereby requiring bidders to submit information about their safety program and safety performance. Alternatively, satisfactory safety performance could be included as one of the requirements to be considered a responsible bidder.

The fourth task is reviewing submittals for safety. Typical contractual agreements with owners require designers to review design-related documents submitted by the contractor. These contractor submittals typically include shop drawings that indicate the specific materials, layout, and occasionally, procedures the contractor and subcontractors intend to use. As the submittals provide information about the inherent risk of the construction process to workers, designers could review submittals to identify and mitigate safety hazards, particularly for features that involve the application of engineering principles. The fifth task is the inspection of site operations for safety. Typical contractual

agreements with owners require designers to periodically inspect the construction site to ensure the work in progress complies with the plans and technical specifications. Designers could also monitor the site for compliance with the safety requirements indicated in the contract documents, plans, technical specifications, submittals, owner standards, and/or OSHA standards.

While all these tasks can meaningfully contribute to construction worker safety, not all are feasible for implementation. This stems from a number of barriers or risks that include increased exposure to liability and increased conflict with budget, duration, functionality and aesthetics. An additional barrier is designers' lack of safety expertise which could limit the effectiveness of their role in construction safety. These barriers have also collectively limited designer's motivation and interest in construction safety (Gambatese et al, 2005). Gambatese (2000) conducted surveys and found almost half of the design professionals never considered worker safety. Additionally, Toole and Marquis (2004) surveyed 75 U.S. design engineering firms and found 30% reported that employees in their firms often failed to report hazards they observed on construction sites. This is largely due to fear of liability exposure, which constitutes the strongest barrier to designer involvement in construction safety (Toole, 2005).

Among the five tasks discussed, the implementation of three will require deviations from the current contractual structure which will in turn expose designers to liability. Assisting the owner in procuring safe construction could expose the project designer to liability, should the selected contractor deliver poor safety performance. Meanwhile, reviewing submittals for safety, may prescribe procedures for the contractor and this could also expose the project designer to liability in the event of safety incidents. With regards to inspecting the work site for safety, the designer can once again be exposed to liability if he or she specified any changes that can be remotely linked to site safety incidents.

According to Dixon and Cromwell (1993), roughly one in every ten liability claims against architects and engineers is related to safety on the project site. It is thus imperative that designers conduct their practices prudently by avoiding any contract language that could make them liable for safety on the construction site (Dixon and Cromwell, 1993). The use of such words as 'inspect' and 'supervise' are even cautioned against as they can establish obligations that were never intended. If a designer is 'inspecting' a project, it could also be claimed that the designer failed to detect unsafe conditions on the construction site and be blamed at least in part, for workers' injuries (Dixon and Cromwell, 1993). Designers are also advised to carefully describe their construction phase duties in their workscopes which they should then fully adhere to. Additionally, designers are advised to add a precise definition of 'construction observation' to the definitions section of their contracts. There are several other guidelines utilized by design professionals to avoid liability exposure.

Model contracts explicitly identify the design professional as not being responsible for construction site safety methods or programs. This is indicated in both the AIA A201 contract document which is used by architects and the EJCDC E-500 contract document which is used by engineers. Furthermore, in United States construction contract law, most project designers sign an indemnification clause with contractors to “hold them harmless” in case of safety incidents and injuries (Bockrath, 2002). By directly impacting activities during construction, the designers nullify the indemnity. It is thus understandable why the fear of increased litigation is the biggest deterrent to addressing construction worker safety in design decisions (Hinze and Wiegand, 1992). Some designers even stated that they deliberately avoid addressing construction safety to minimize their liability exposure (Gambatese and Hinze, 1999).

In the case of design-build projects where the same firm is contracted for both design and construction, the liability for accidents and injuries is borne by a single firm. In such design-build firms, many designers were found to address construction worker safety in their designs (Gambatese and Hinze, 1999). These designers may also have been motivated by the fact that cost provisions are not made for safety in competitive tendering (Anumba, 1999). Given that the lowest bidder secures the contract, and making cost provisions is impractical for winning a bid, the design-build firm will present a low bid. Once contracted, its designers may minimize safety costs by incorporating design features that eliminate certain construction hazards and as a result, eliminate certain safety requirements and their costs.

As most projects are design-bid-build projects, two of the proposed designer safety tasks are considered generally more feasible for implementation. These include reviewing designs for safety and creating safety-related design documents. Through these two tasks, designers can increase worker safety by supplementing but not replacing contractors’ knowledge of means and methods (Toole, 2005). They also fall within the traditional responsibilities of the design professional. However, the latter task will be more effective in improving construction worker safety while minimizing liability exposure. This is for two reasons. Firstly, the ability to influence safety declines as a project advances (Symberski, 1997). This is indicated by the time/safety influence curve seen in *Figure 1*. As the review of design documents is placed later in the project process, the creation of the design documents is more effective for addressing construction worker safety. Changes at the review stage are also expectedly more time and cost intensive than at earlier stages (Toole, 2005). Secondly, the design process typically includes reviews which can be incorporated after the creation of the safety-incorporated design documents. Therefore, reviews for safety may inherently be part of the process of creating design documents for safety.

To avoid liability exposure, designers’ role in construction safety must not infringe on the contractors’ responsibilities. Designers must therefore not attempt to

manage worker and site safety during construction. They should thus focus on minimizing or eliminating safety hazards through their designs. Also, their expertise should address the safety aspects of permanent structures and not the temporary structures used during construction. These guidelines collectively underlie the Design for Construction Safety (DFCS) concept.

As there are currently no U.S. regulations mandating the involvement of designers in construction safety, this is a voluntary consideration. Design professionals should realize that they can have a significant role in improving construction worker safety without impacting their exposure to liability and while minimizing or avoiding other potential negative implications.

## 2.6 **Constructability and Construction Safety**

Constructability is defined as the integration of construction knowledge and experience in the planning, design, procurement, construction, operation, maintenance, and decommissioning phases of projects consistent with overall project objectives (Gambatese et al, 2007). Constructability may be addressed on projects either through informal or formal processes though the format may depend on the type of project and contracting environment. Addressing constructability earlier in the project offers increased opportunity to influence cost and quality which expectedly diminish as the project progresses (Gambatese et al, 2007). It must be noted that addressing constructability has time and cost implications.

Potential benefits of a high level of constructability include decreased construction cost, shorter construction schedules, less re-work of completed construction, and improved construction site safety among others (Gambatese et al, 2007). *Table 8* provides the benefits of enhanced constructability and the applicable project phases.

Project Phase	Benefit
Construction Only	Buildable plans and specifications
	Biddable plans and specifications
	Reduced construction cost
	Shortened construction schedules
Construction, Operation, and Maintenance Phases	Improved project quality
	Improved safety
	Improved risk management
Operation and Maintenance Phases Only	Improved maintainability
	Improved operability
	Improved reliability

**Table 8:** Benefits of Enhanced Constructability (Source: Gambatese et al, 2007)

There are barriers to addressing constructability on projects. The lack of construction experience in the design team and the absence of tools to

adequately assist designers in addressing constructability limit the design professionals' effectiveness in executing constructability reviews. It must however be noted that more than 20 tools have been developed to aid the constructability review process. However, these tools were determined to require further development to effectively aid constructability review. That is except if all the tools were collectively mapped onto a constructability planning process model and then utilized for the development of an implementation strategy by the user (Gambatese et al, 2007). Additionally, utilizing the construction knowledge and experience of the contractor may not be feasible as the competitive tendering process does not allow for engaging the contractor early enough to allow for input in the constructability analysis and review process (Gambatese et al, 2007).

Project owners were identified as a key aspect that can assist in overcoming these barriers (Gambatese et al, 2007). Firstly, this is by requiring constructability analysis and review on the project. Secondly, this is by making the time and cost provisions to allow for the execution of the constructability reviews. Often, tight deadlines set by the owner make it either impractical to conduct constructability reviews and implement their outcomes or make the process unproductive and ineffective. Thirdly, the owner may engage construction engineers or a contractor to participate in the constructability review process. Lastly, the owner may specify the use of alternative project delivery methods, to the traditional design-bid-build method, that will allow for the involvement of the contractor or construction engineers such as the design-build method.

The goal of constructability reviews is to minimize potential problems that could occur during project construction which could result in change orders, claims and time extensions if not properly addressed. According to AASHTO (2000), the constructability review process should assure that:

1. The project, as detailed in the plans and specifications, can be constructed using standard construction methods, materials and techniques.
2. The plans and specifications provide clear and concise information that can be utilized by contractors to prepare a competitive cost-effective bid.
3. The project, when constructed in accordance with the plans and specifications, will result in a project that can be maintained in a cost-effective manner over the project lifecycle.

In achieving these goals, the constructability reviews are to rectify inconsistencies between plans and specifications, identify limitations of access for the construction work, and ensure the compatibility of materials. Additionally, the reviews are to achieve effective project scheduling and coordination of trades.

In conducting constructability analysis and review on a project, a number of considerations should be made (AASHTO, 2000). Firstly, the owner or design team could consider appointing a champion. The champion is to ensure that all project participants on the team cooperate and that communication flows freely. It may be necessary for the champion to authorize the design team to redo plans and specifications when the constructability review uncovers significant problems. Secondly, the team composition must be considered. It should include the necessary expertise to address the major issues relevant to the project. The constructability review team should include the design professionals and the construction professionals. It could also include consultants, material suppliers, representatives of the relevant utilities companies, and representatives of the relevant regulatory agencies. However, it must be noted that the constructability review team should not be so large as to preclude effective discussion and resolution of the project issues (AASHTO, 2000).

Another consideration is the location of the reviews which should preferably be the project site to allow for the detailed assessment of its conditions. An additional consideration is the frequency of reviews which must factor the available resources, expected benefits, the number of parties involved in the constructability review process, and the timing of the reviews. As stated earlier, constructability analysis and reviews should be conducted beginning from the earlier stages of the project design phase. Reviews conducted earliest have the most potential for providing meaningful benefits without adversely impacting project schedules (AASHTO, 2000). At least two reviews are recommended with the first at the 30% design completion stage and the last at the 95% stage. Where there are three reviews, the second typically occurs at the 60% design completion stage. Beginning the reviews in the late stages will result in costly schedule delays (AASHTO, 2000).

The constructability review team should also define the type and length of the review meeting. All participants should be provided with guidance on the purpose of the constructability review process, the desired outcomes, the responsibilities of the constructability review team members, the format for the meetings and reviews, along with the methodology for resolving issues raised during the review process (AASHTO, 2000). Checklists may also be developed to guide the constructability process particularly since not all the parties have significant construction expertise. The constructability review plan should also include a mechanism for follow-through on the comments produced during the review. There should also be a mechanism for dissemination of review comments to the appropriate project participants. And, in order for the project owners, design firms and construction companies to utilize the lessons learned from the constructability review process, the benefits and costs could be measured and documented (AASHTO, 2000). Post-construction reviews also serve towards this purpose.

Constructability review involves the incorporation of construction knowledge in the design of a project (Gambatese, 2000). Decreased cost, decreased schedule and improved quality constitute the primary objectives of constructability analysis and review. Improved safety is typically an added benefit. Decreased schedule means there is less period of risk exposure for the construction workers to get injured. Improved quality means less need for rework which also means a lesser period of risk exposure for the construction workers. Additionally, ensuring the ability to complete the project using standard construction methods, materials and techniques means the workers are more likely to have both the training and experience to execute the tasks with less safety risk.

Safety constructability involves addressing construction safety in project design. It can be considered a subset of overall project constructability (Gambatese, 2000). Safety constructability is essentially the inclusion of enhanced construction safety as a primary objective of constructability analysis and review. Through this, safety will likely become a more pronounced benefit and hence minimize the costs of injuries which are ultimately reflected in the cost of construction through delay, investigation, litigation and corrections (Huang, 2003). It can thus serve towards achieving two main objectives of constructability review, decreased cost and decreased schedule.

The barriers to addressing constructability also apply to safety constructability. Design professionals typically lack construction safety expertise as they have traditionally not been involved in construction safety (Gambatese, 2000). Studies have accumulated guidelines and developed tools to assist designers in conducting safety constructability reviews (Gambatese, 2000). However, designers' involvement has remained limited and this has largely been attributed to fear of increased liability exposure (Gambatese, 2000). With research to address this and other impediments, designer concerns can be allayed and the safety constructability process can be enhanced towards minimizing and eliminating construction site hazards in the project design phase.

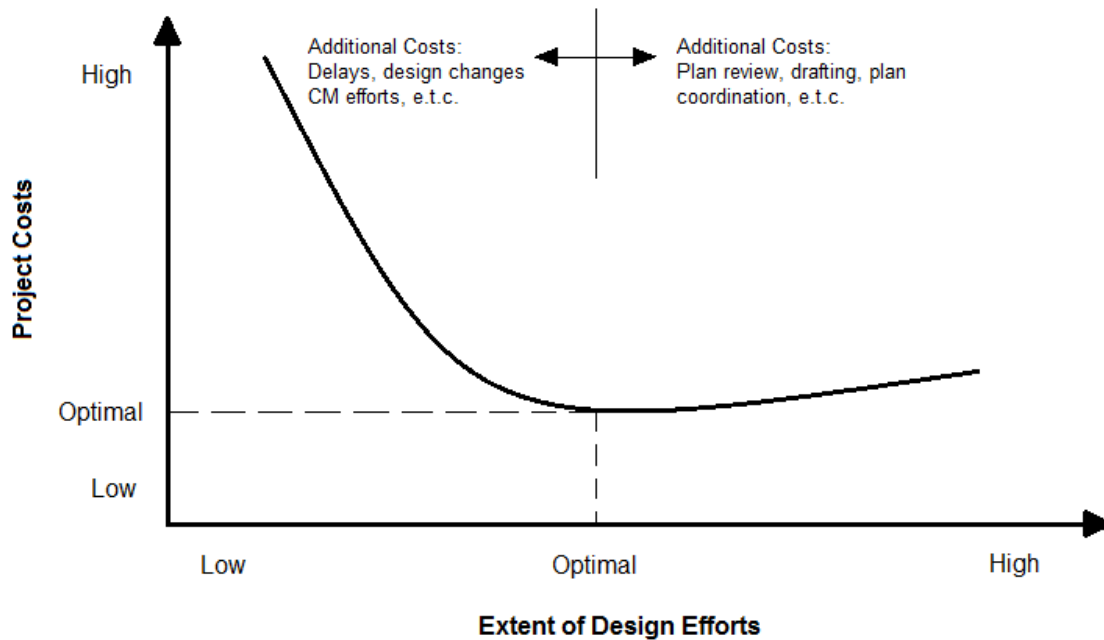
## **2.7 Addressing Construction Safety through Design**

### **2.7.1 The DFCS Implementation Process**

DFCS is the explicit consideration of construction worker safety in the design of a project (Toole and Gambatese, 2008). It involves designing the permanent features of projects to support the safety of workers during construction. DFCS also involves the inclusion of worker safety considerations in the constructability review process (Gambatese et al, 2005).

Accordingly, the process of implementing DFCS involves conducting reviews in the project design phase. The key feature of the process is the input of site safety knowledge into design decisions (Toole et al, 2006). A study by Gambatese

(2000) indicated five different levels for safety review namely planning, preliminary design, 30%, 60% and 90% reviews. However, the same study stated that the optimal number of constructability reviews for a project should be based on a tradeoff between design effort and project cost. Low and high levels of design effort may incur additional construction-related and design-related costs respectively. Gambatese (2000) illustrated this relationship between design effort and project costs. This is seen in *Figure 19*.



**Figure 19:** Relationship between Design Effort and Project Cost (Source: Gambatese, 2000)

The consideration of safety throughout the project design phase is to be ensured through the constructability progress reviews. As the review stages advance, the degree of detail of the design measures are to increase. Examples of design considerations for each level of review are provided in *Table 9*. During the reviews, the designer weighs the merits of implementing the DFCS measures based on project characteristics, features and constraints, then decides which to implement (Gambatese, 2000).

Earlier research stated that few design professionals possess the site safety expertise necessary to effectively perform DFCS (Gambatese et al, 2005; and Toole, 2005). There are however a number of sources that may be utilized for the safety knowledge that is to be incorporated into project design. Firstly, site safety expertise can be provided by in-house employees, trade contractors and outside safety consultants who possess the required knowledge (Toole et al, 2006). Toole et al (2006) also discuss the possibility of using OSHA employees but also note that they are currently neither willing nor capable of providing such expertise given their regulatory restrictions. Safety knowledge can also be secured through

the use DFCS tools such as guidelines and computer software developed through research (Toole et al, 2006). For example, design professionals could utilize the CII's DFCS Toolbox with the over 400 design suggestions incorporated in it, to minimize or eliminate certain safety hazards in their designs (Gambatese et al, 1997). Pictorial examples of some of the design suggestions are provided in *Appendix A*.

Review Level	Best Design Practice
Planning Review	<ul style="list-style-type: none"> <li>- Minimize the amount of night work and do not allow schedules that contain sustained overtime.</li> <li>- Design and schedule different projects or construction phases that occur at the same location to be performed simultaneously.</li> <li>- Provide a list and location of toxic substances and other hazardous materials that are located on the site.</li> </ul>
Preliminary Design Review	<ul style="list-style-type: none"> <li>- Locate underground utilities and other below-grade features in areas easily accessible for excavation.</li> <li>- Provide a large, unobstructed, open area below elevated masonry work.</li> <li>- Orient the project or grade the site accordingly to minimize the amount of work on steep slopes.</li> <li>- Minimize the number of plan offsets, and make the offsets a consistent size and as large as possible.</li> </ul>
30% Review	<ul style="list-style-type: none"> <li>- Provide a clear, unobstructed, spacious work area around all permanent mechanical equipment.</li> <li>- Design window sills and roof parapets to be 107 cm (42 inches) above the floor/roof level.</li> <li>- Design stairways and ramps to run parallel and immediately adjacent to the structure.</li> <li>- Keep dimensions similar from story-to-story to facilitate the reuse of concrete forms.</li> </ul>
60% Review	<ul style="list-style-type: none"> <li>- Design member depths to allow adequate head room clearance around stairs and all areas of egress.</li> <li>- Locate rooftop mechanical equipment away from skylights and roof edges.</li> <li>- Position equipment controls and control panels away from passageways and work areas.</li> </ul>
90% Review	<ul style="list-style-type: none"> <li>- Design perimeter beams and beams above large floor openings to support lifelines. Provide tie-off locations for lifelines.</li> <li>- Provide attachment points on the roof for connection of safety lines.</li> <li>- Design beam-to-column connections to have full support for the beams during the erection process.</li> <li>- Use a single size of bolts, nails, and screws. If more than one size is required, specify sizes that vary greatly and are easily distinguishable.</li> <li>- For mat foundations and slabs, design closely spaced reinforcing steel to provide a continuous walking surface.</li> </ul>

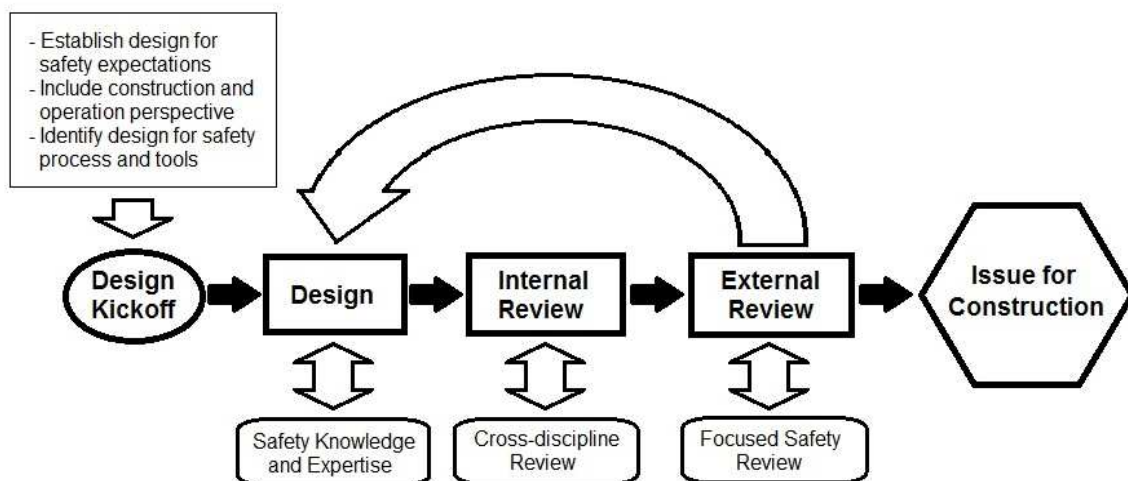
**Table 9:** Sample Design Considerations for Each Level of Review (Source: Gambatese, 2000)

Safety knowledge and expertise may suggest that certain proposed design features be eliminated or modified to prevent an identifiable hazard. They may

also recommend the inclusion of additional permanent features either to address the hazard or to provide a means to aid construction workers in safely executing activities that expose them to the hazard. It is important to note that DFCS only applies to the design of a permanent facility, and to the aspects of the completed facility that make it inherently safer to build (Toole et al, 2006). It does not focus on making the different methods of construction engineering safer. For example, it does not focus on how to use fall protection systems, but it does include design measures that influence how often fall protection will be needed (Toole et al, 2006).

The DFCS concept utilizes a performance-based approach. This approach for DFCS implementation is contextually similar to that of the 'Pattern Language' developed by Alexander et al (1977). In Pattern Language, each presented pattern forms a word or thought of a true language rather than being a prescriptive way to design or solve a problem. Each solution to a design problem is stated in such a way that it gives the essential field of relationships needed to solve the problem, but in a very general and abstract way. This is so the designer can solve the problem in his own way, by adapting it to his preferences, and to the local conditions at the place where the designed building is to be built. In DFCS, the designer is to consider specific construction safety hazards and design project features to minimize or eliminate their risks in his/her own way.

Upon completing DFCS implementation, the design documents should not look different from typical drawings and specifications. They should however reflect an inherently safer design that minimizes or eliminates risks of certain construction hazards (Toole et al, 2006). The design professionals may also specify safety enhancing details and notes in the drawings and specifications (Toole et al, 2006). It is important that these details specify the function of the safety features without requiring a procedure for their use lest they expose the designer to liability in event of safety incidents linked to the features. A typical DFCS process is illustrated in *Figure 20*.



**Figure 20:** A Typical DFCS Process (Source: Gambatese, 2003)

It must also be noted that where DFCS is implemented, it may be important for the design professional to monitor contractor change orders so as not to eliminate the safety features incorporated in the design and construction documents of the project. Toole and Hallowell (2005) conducted a detailed analysis of the technical specifications from 5 design-bid-build commercial building projects and reported that 24 building components had engineering design performed by entities associated with the project construction phase and not by design professionals associated with the design phase.

In the pre-construction phases, the design professional should also monitor to ensure the safety features are at least evaluated during the constructability reviews and during the value engineering process before being selected for elimination due to cost and time constraints. Constructability focuses on the optimization of the construction process and this might result in the omission or modification of certain DFCS features during the design phase (Arditi et al, 2002). Meanwhile, the primary objective of value engineering is to reduce the total life-cycle cost of a facility and it is also normally performed during the design phase of the capital project delivery process (Arditi et al, 2002). Value engineering might thus involve having to eliminate certain DFCS measures and the inclusion of others with less cost implications.

As discussed, the fragmented design process could result in the elimination of safety features from the project design and thereby serve as a barrier to the DFCS implementation process (Toole et al, 2006). Where there is a consultant engaged on the project, he/she could be charged with ensuring the DFCS features are retained until implemented in the construction phase. Optionally, the quality assurance department of the design firm could be required to evaluate the completed design drawings and construction documents to ensure they include certain intended DFCS features. After all, the quality assurance department typically evaluates the final design documents to ensure they adhere to building code requirements including the Americans with Disabilities Act (ADA) design standards.

Toole (2007) provided the recommended process for implementing DFCS within owner organizations. Firstly, a DFCS team with a leader or champion should be appointed along with other diverse representatives. Designers should then be provided with training on construction safety fundamentals and on applying DFCS in their particular expertise. Design checklists and tools should then be developed to identify design suggestions that may improve site safety performance. Formal processes should also be established to ensure designers utilize the checklists. Furthermore, processes need to be established to ensure managers monitor and document the effectiveness of the DFCS effort. Lastly, where possible, construction personnel could be provided with opportunity for safety constructability input in the design phase.

## **2.7.2 Future Trajectories for DFCS**

Toole and Gambatese (2008) investigated the DFCS concept, the current publication rate and breadth of professional organizations promoting DFCS, the current design and construction process, and the structure of the AEC industry to identify five future trajectories DFCS is likely to follow. These include increased prefabrication, increased use of less hazardous materials and systems, increased application of construction engineering, increased spatial investigation and consideration, and increased collaboration and integration (Toole and Gambatese, 2008).

### **2.7.2.1 Increased Prefabrication**

Prefabricated construction involves the construction and assembly of components in temporary locations, followed by, the transportation of the assemblies to their permanent location and the final fit up to create the completed facility (Toole and Gambatese, 2008). The use of prefabrication has increased steadily over the past century as it facilitates improvements in cost, schedule, performance and also, safety (Hewitt and Gambatese, 2002). Common examples of components that are often prefabricated include wall panels, joists and trusses, steel stairs and bridge segments among others.

Prefabrication improves construction site safety by shifting the location of construction work to a lower hazard environment, such as from a confined space to an open space or from a high elevation to the ground (Gambatese et al 1997). An application of the latter example is the use of roof trusses and assembled roof panels instead of roof rafters (Toole and Gambatese, 2008). Additionally, prefabrication would decrease hazards by allowing work to be shifted from the field to the factory floor, which would allow for the use of equipment with improved safeguards in a more controlled environment (Toole and Gambatese, 2008). However, it is important to note that the diffusion and use of prefabrication for safety is likely to be limited by size limitations and shipping costs (Toole and Gambatese, 2007).

### **2.7.2.2 Increased Use of Less Hazardous Materials and Systems**

With increased availability of information, design professionals will soon be able to specify materials not only based on expected performance and cost but on the inherent safety of the materials for construction and maintenance workers (Toole and Gambatese, 2007). Some alternative materials offer similar performance and cost as that of common traditional materials but are less hazardous to apply and install. This may be directly applicable to such materials as coatings, adhesives and cleaners, which are associated with flammability, air quality and skin hazards (Weinstein et al, 2005).

Toole and Gambatese (2008) also believe designers will eventually be expected to consider the inherent hazard level of various building systems in their designs. These may include the assembled components or portions of the facility and not just individual materials. Continued safety research is expected to eventually identify building systems that offer safer installation processes (Toole and Gambatese, 2007).

Additionally, Toole and Gambatese (2008) believe designers' increasing interest in sustainable design will have spillover effects on DFCS. Thus, increasing specification of materials that are less hazardous to the environment may lead to increasing specification of materials that are less hazardous to construction workers. This development will be facilitated if and when reducing unnecessary risk to construction workers is considered a valid social equity issue (Toole and Gambatese, 2008).

#### **2.7.2.3      Increased Application of Construction Engineering**

The increased involvement of engineers in construction engineering tasks typically conducted by contractors may result as project owners realize that such work is sometimes performed by unqualified personnel or not even performed at all (Toole and Gambatese, 2008). There are many instances when engineering is required to plan or execute a construction task. Construction tasks such as soil bearing analysis for supporting construction equipment and also temporary load analysis require the application of engineering principles as they involve forces and stresses (Toole and Gambatese, 2007). Contractors have traditionally executed these construction engineering tasks through in-house employees or consultants. The increasing number of design-build projects has resulted in increased construction engineering capability among designers (Toole and Gambatese, 2008). These designers should have the ability to perform construction engineering more effectively and less expensively than contractor personnel.

A barrier to progress along this trajectory is fear of exposure to liability. Another barrier is the unfamiliarity of designers with construction methods and hazards (Toole and Gambatese, 2008). Of recent, several national construction trade organizations have been clamoring for safety features and specifications to be shown on structural drawings (Gambatese et al, 1997; and Behm, 2005). Such initiatives may drive progress along this trajectory.

#### **2.7.2.4      Increased Spatial Investigation and Consideration**

This trajectory highlights the possibility of designers beginning to communicate potential site hazards to the constructor on project drawings and documents (Toole and Gambatese, 2008). For example, engineers typically obtain site utility

plans from the municipality or site owner. However, such utilities are not shown on the design plans. Through the diffusion of DFCS and also design-build projects, the standard of care for design may be elevated to include depicting all identifiable potential site hazards on the project drawings (Toole and Gambatese, 2007).

Design professionals may also provide adequate working distances in their designs for the various construction trades and common tools. For example, adequate clearance between steel bolts and adjacent steel members could be provided to allow the use of typical positioning and bolting or welding tools (Toole and Gambatese, 2008). Ergonomic issues may also be included in spatial considerations for constructability.

Progress along this trajectory will likely occur once research and other publications identify the necessary clearances and ergonomic issues for specific trades. This is yet to be done (Toole and Gambatese, 2008).

#### **2.7.2.5      Increased Collaboration and Integration**

This trajectory identifies that increased collaboration could occur across the project participants with regards to DFCS. Such project participants include the owner, design professionals, contractor, and relevant manufacturers among others. The increased communication could be with regards to risks, costs, time, quality and safety, and could apply to all project phases. This is essentially the integration of the different project phases as in the case of design-build projects which show significant integration of the design and construction phases.

Hence, the increasing number of design-build projects will likely result in increased collaboration and integration (Toole and Gambatese, 2008). The growth or development of information technology will also offer more opportunity for increased collaboration on projects and with regards to DFCS. It might however remain necessary for the owner to facilitate collaboration by requiring it on the project and perhaps, requiring it contractually. There are also barriers to progress along this trajectory. These primarily include fear of exposure to liability, and the unfamiliarity of designers with construction methods and hazards (Toole and Gambatese, 2008).

## **3.0 Research Design**

### **3.1 Evaluation of Data Collection Methods**

Towards producing the research deliverables, a number of elicitation methods were to be utilized. This section provides the evaluation and review of available approaches for data collection and research.

#### **3.1.1 Data Collection Methods**

There are a number of data collection methods identified by Marshall and Rossman (2006). These were classified as primary methods, secondary and specialized methods, and a combination of methods.

##### **A. Primary Methods**

1. Observation  
Observation entails the systematic reporting and recording of events, behaviors, and artifacts or objects in the social setting chosen for study. The observational record frequently referred to as the field notes should be detailed, non-judgmental and concrete descriptions of what has been observed (Marshall and Rossman, 2006).
2. Participant Observation  
Participant observation is an overall approach to inquiry and a data gathering method. Participant observation demands firsthand involvement in the environment chosen for study. Immersion in the setting permits the researcher to experience reality as the participants do. Ideally, the researcher spends a considerable amount of time in the setting (Marshall and Rossman, 2006).
3. In-Depth Interviewing  
Kahn and Cannell (1957) describe interviewing as a conversation with a purpose. In-depth interviews are typically more like conversations than formal events with predetermined response categories. The researcher explores a few general topics to help uncover the participants' views. Interviewing varies in terms of structure and in the latitude the interviewee has in responding to questions (Marshall and Rossman, 2006).
4. Background and Context and Review of Documents  
Data on the background and historical context surrounding a specific setting are gathered from reviewing documents. This is an unobtrusive method that can portray the values and beliefs of participants in the setting (Marshall and Rossman, 2006). The review of documents often entails content analysis. Research journals and samples of free writing about the specific topic can be utilized for information.

## B. Secondary and Specialized Methods

### 1. Focus Groups

This involves interviewing participants in groups comprising of roughly 10 people who are unfamiliar with one another and have been selected because they share certain characteristics relevant to a study's questions. The interviewer creates a supportive environment and asks focused questions to encourage discussion and the expression of differing opinions and points of view (Marshall and Rossman, 2006).

### 2. Life Histories and Narrative Inquiry

Life histories and narrative inquiry gather, analyze, and interpret the stories people tell about their experiences (Marshall and Rossman, 2006). The researcher, working closely with the participant, explores the story and records it. This method is particularly useful for giving the researcher an insider's view of a culture or era in history (Edgerton and Langness, 1974).

### 3. Historical Analysis

A history is an account of an event or combination of events. Historical analysis is a method of discovering what has happened using records and accounts. This is particularly useful for establishing a baseline of background prior to further data collection (Marshall and Rossman, 2006). Historical data sources may include oral testimony, documents, records, relics and books.

### 4. Films, Videos, and Photography

The concept and method of the research film have emerged and are now compatible with a variety of research methods to describe how people navigate in public places and how they use space, to present findings, and to empower participants (Marshall and Rossman, 2006). Also, various forms of photography can be used for data collection and for organizing, interpreting and validating qualitative inquiry. Film has the unique ability to capture visible phenomena seemingly objectively (Marshall and Rossman, 2006).

### 5. Interaction Analysis

Researchers wanting finely focused data on verbal and nonverbal communication can use forms of interaction analysis to quantify patterns of interaction (Marshall and Rossman, 2006). This is particularly true for cases where there has been much participant observation or prior research. An observer uses a predetermined coding scheme, often called a protocol, to produce a listing of the likely interactions. The observer then samples duration at predetermined intervals (Marshall and Rossman, 2006).

6. Unobtrusive Measures

Unobtrusive measures are ways of collecting data that do not require the cooperation of the subjects and may even be invisible to them. Webb et al (1966) describe these measures as nonreactive research because the researcher is expected to observe or gather data without interfering in the ongoing flow of everyday events. Data collected in this manner are categorized as documents, archival records, and physical evidence (Marshall and Rossman, 2006).

7. Questionnaires and Surveys

Researchers administer questionnaires and surveys to describe and statistically explain the variability of certain features in a population such as the distribution of characteristics, attitudes or beliefs (Marshall and Rossman, 2006). Researchers make the critical assumption that the characteristic or belief can be described or measured accurately through self reporting. Questionnaires and surveys typically entail several questions that have structured response categories. This data collection method relies on the honesty and accuracy of participants responses. Questionnaires and surveys are the appropriate modes of inquiry if the researcher wishes to obtain a small amount of information from a large number of subjects. Inferences are made about a large group of people based on data drawn from a sample in the group (Marshall and Rossman, 2006).

8. Projective Techniques and Psychological Testing

Interpretive psychological strategies are useful for obtaining personality data. The strategies have been used fairly extensively in comparative studies about culture and for analysis of personality dynamics. Based on an internal perceptual frame of reference, the techniques assume that one can get a valid picture of a person by assessing the way the individual projects his personality onto some standard and ambiguous stimuli (Marshall and Rossman, 2006).

9. Dilemma Analysis

Dilemma analysis can be used as a focused part of interviewing, particularly to get at the core of the respondents processes of thinking, assessing, evaluating and judging (Marshall and Rossman, 2006). This approach is particularly effective where research probes at moral issues and practical decision-making processes. It produces a thematic coherence that does not depend upon academic theories or hunches of the researcher (Winter, 1982).

10. Using Computer and Internet Technologies

The internet along with computer software and hardware has changed the methodologies of research. Searching the internet for resources, using software to manage citations and some aspects of data analysis,

interviewing by means of e-mail and dedicated chat rooms, and using dialogs and interactions online at sites, for study, are now part and parcel of much scholarship in the applied fields (Marshall and Rossman, 2006).

### C. Combining Data Collection Methods

Many studies combine several data collection methods over the course of research. The researcher can assess the strengths and limitations of each method, then decide if that method will work with the questions and in the setting for a given study. As limitations in one method can be compensated for by the strengths of a complimentary one, researchers can select the best combinations of methods (Marshall and Rossman, 2006). These choices should be logically linked to the conceptual framework, research questions and overall strategy of the study.

#### 3.1.2 Comparative Analysis of Data Collection Methods

Marshall and Rossman (2006) conducted comparative analyses of the different data collection methods. The strengths and weaknesses of each method were identified based on how they are generally used in research studies. The comparative analysis tables in *Table 10* and *Table 11* can aid in the selection of a method or a combination of methods.

#### 3.1.3 Selection of Elicitation Methods for the Research

Marshall and Rossman (2006) identified a number of criteria a researcher should consider in determining the data collection methods to be used in his/her research. These criteria include practicality, efficiency, ethicality, cost-effectiveness, provision of adequate information, and feasibility. The criteria were evaluated for the use of each data collection method in this DFCS research. I also weighted the criteria. The comparative analysis and scoring are seen in *Table 12*.

Marshall and Rossman (2006) also state that a researcher should carefully examine the methods based on questions guiding his/her study. As such, the ability of the data collection methods to yield or aid in yielding each research deliverable was examined as well. I assigned equal weights/priorities to each research deliverable. This comparative analysis and scoring are seen in *Table 13*.

For both determinations, I used identical scoring systems (Lowest Effectiveness = 1; and Highest Effectiveness = 5). I also weighted each determination. The effectiveness of each data collection method in meeting the specified criteria was given a 45% weight. Accordingly, the effectiveness of each data collection method in yielding the research deliverables was given a 55% weight. I perceived the latter as more important to this defined extent. The evaluation is seen in *Table 14*.

STRENGTHS OF DATA COLLECTION METHODS	PO	O	I	FG	DR	N	HA	F	IA	UM	Q	PT	DA	C
Fosters face-to-face interactions with participants	x		x	x		x						D		
Useful for uncovering participants' perspectives	x		x			x						D	D	
Data collected in natural setting	x	x	x	x	D	x		x	x	x				
Facilitates immediate follow-up for clarification	x		x	x		x			D					x
Good for documenting major events, crises, conflicts	x	x		x	x	x	x	x					x	
Collects data on unconscious thoughts and actions	x				D	D		x	x	x		x		
Useful for describing complex interactions	x	x	x	x		x	x	x	x			D		
Good for obtaining data on nonverbal behavior and communication	x	x	D	D		D		x	x	x		D		
Facilitates discovery of nuances in culture	x	x	x	x	D	x	x	x	x	x				
Provides for flexibility in formulating hypotheses.	x	x	x	x	D	x	x	x	x	x				
Provides context information	x	x	x	x	x		x	x					D	
Facilitates analysis, validity checks, and translation	x	x	x	x	x			x	x	x	x	x	x	
Facilitates cooperation	x	D	D	x		x						x		x
Data easy to manipulate and categorize for analysis					x				x	D	x			
Obtains large amounts of data quickly		x		x			x	x				x		
Allows wide range of types of data and participants	x			D	D				D	x				
Easy and efficient to administer and manage					x		x		x	x	x			x
Easily quantifiable and amenable to statistical analysis					x				x	x	x	x		
Easy to establish generalizability					D		D		x		x	x		
May draw on established instruments					x				x	x	x	x	x	x
Expands access to distant participants					x						x			x

NOTE: x = strength exists; D = depends on use; PO = Participant Observation; O = Observation; I = In-Depth Interviewing; FG = Focus Groups; DR = Background and Context and Review of Documents; N = Life Histories and Narrative Inquiry; HA = Historical Analysis; F = Films, Videos and Photography; IA = Interaction Analysis; UM = Unobtrusive Measures; Q = Questionnaires and Surveys; PT = Projective Techniques and Psychological Testing; DA = Dilemma Analysis; and C = Using Computer and Internet Technologies

**Table 10:** Strengths of Data Collection Methods (Source: Marshall and Rossman, 2006)

WEAKNESSES OF DATA COLLECTION METHODS	PO	O	I	FG	DR	N	HA	F	IA	UM	Q	PT	DA	C
<b>Leads researcher to fixate on details</b>	x	x		D	x	x		x	x	x	x	x		x
<b>Possible misinterpretations due to cultural differences</b>	x	x	x	x	x	x	x	x	x	x	x	x	x	
<b>Requires technical training</b>								x	x		x	x		
<b>Dependent on cooperation of key individuals</b>	x		x			x						x		
<b>Readily open to ethical dilemmas</b>	x	x	x			x		x		D		x	x	x
<b>Difficult to replicate</b>	x	x	x	x		x	D	x				x		
<b>Data more affected by research presence</b>	x	x	x	x		D		D	D			D	x	
<b>Expensive materials and equipment</b>								x		x				
<b>Can cause discomfort or even danger to researcher</b>	x											x		
<b>Too dependent on participant openness/honesty</b>	x		x			x							x	x
<b>Too artistic an interpretation undermines research</b>	x	x	x	x		x	x	x				x		
<b>Dependent on “goodness” of initial research question</b>		x		x	D		x	x	x	x	x		x	x
<b>Dependent on the researcher's interpersonal skills</b>	x	x	x	x	x	x	x					x		
NOTE: x = strength exists; D = depends on use; PO = Participant Observation; O = Observation; I = In-Depth Interviewing; FG = Focus Groups; DR = Background and Context and Review of Documents; N = Life Histories and Narrative Inquiry; HA = Historical Analysis; F = Films, Videos and Photography; IA = Interaction Analysis; UM = Unobtrusive Measures; Q = Questionnaires and Surveys; PT = Projective Techniques and Psychological Testing; DA = Dilemma Analysis; and C = Using Computer and Internet Technologies														

**Table 11:** Weaknesses of Data Collection Methods (Source: Marshall and Rossman, 2006)

CRITERIA	Priorities	PO	O	I	FG	DR	N	HA	F	IA	UM	Q	PT	DA	C
<b>Practicality</b>	15%	1	2	5	4	5	1	4	2	2	1	5	1	4	5
<b>Efficiency</b>	15%	2	3	4	4	4	2	5	3	2	1	2	3	4	4
<b>Ethicality</b>	10%	2	3	4	4	5	2	5	1	2	2	4	1	4	5
<b>Cost-effectiveness</b>	10%	2	2	3	4	5	3	4	1	2	2	5	1	3	5
<b>Adequacy of information provided</b>	25%	4	3	4	3	3	2	3	5	2	3	3	3	4	5
<b>Feasibility in terms of resources</b>	25%	1	2	3	2	5	3	5	1	1	1	5	1	3	5
<b>TOTAL</b>	<b>100%</b>	<b>2.10</b>	<b>2.50</b>	<b>3.80</b>	<b>3.25</b>	<b>4.35</b>	<b>2.20</b>	<b>4.25</b>	<b>2.45</b>	<b>1.75</b>	<b>1.70</b>	<b>3.95</b>	<b>1.80</b>	<b>3.65</b>	<b>4.85</b>
NOTE: 1 = Lowest Effectiveness and 5 = Highest Effectiveness; PO = Participant Observation; O = Observation; I = In-Depth Interviewing; FG = Focus Groups; DR = Background and Context and Review of Documents; N = Life Histories and Narrative Inquiry; HA = Historical Analysis; F = Films, Videos and Photography; IA = Interaction Analysis; UM = Unobtrusive Measures; Q = Questionnaires and Surveys; PT = Projective Techniques and Psychological Testing; DA = Dilemma Analysis; and C = Using Computer and Internet Technologies															

**Table 12:** Evaluation of Data Collection Methods for this DFCS Research

RESEARCH DELIVERABLES	Priorities	PO	O	I	FG	DR	N	HA	F	IA	UM	Q	PT	DA	C
<b>Applicable DFCS Measures to the Project Design Phase</b>	20%	2	2	4	5	5	3	5	3	2	2	4	2	3	2
<b>Impediments to Implementing design-phase DFCS Measures</b>	20%	4	2	5	5	4	2	3	3	3	3	4	4	4	2
<b>Revised DFCS Measures based on Impediments to Implementation</b>	20%	2	1	5	5	2	1	2	2	2	1	2	2	4	2
<b>Preventable Hazard Incidents from Applicable DFCS Measures</b>	20%	3	3	4	5	3	3	3	5	1	2	3	3	4	5
<b>Computer Application to aid DFCS Implementation</b>	20%	1	1	3	3	3	1	3	3	2	2	2	2	2	5
<b>TOTAL</b>	<b>100%</b>	<b>2.40</b>	<b>1.80</b>	<b>4.20</b>	<b>4.60</b>	<b>3.40</b>	<b>2.00</b>	<b>3.20</b>	<b>3.20</b>	<b>2.00</b>	<b>2.00</b>	<b>3.00</b>	<b>2.60</b>	<b>3.40</b>	<b>3.20</b>
NOTE: 1 = Lowest Effectiveness and 5 = Highest Effectiveness; PO = Participant Observation; O = Observation; I = In-Depth Interviewing; FG = Focus Groups; DR = Background and Context and Review of Documents; N = Life Histories and Narrative Inquiry; HA = Historical Analysis; F = Films, Videos and Photography; IA = Interaction Analysis; UM = Unobtrusive Measures; Q = Questionnaires and Surveys; PT = Projective Techniques and Psychological Testing; DA = Dilemma Analysis; and C = Using Computer and Internet Technologies															

**Table 13:** Effectiveness of Data Collection Methods in yielding Research Deliverables

Rank	METHODS	CRITERIA SCORE <span style="float: right;">Weight = 45%</span>		DELIVERABLE SCORE <span style="float: right;">Weight = 55%</span>		TOTAL SCORE
		Score	Prioritized Value	Score	Prioritized Value	
1	<b>I</b>	3.80	1.71	4.20	2.31	<b>4.02</b>
2	<b>FG</b>	3.25	1.46	4.60	2.53	<b>3.99</b>
3	<b>C</b>	4.85	2.18	3.20	1.76	<b>3.94</b>
4	<b>DR</b>	4.35	1.96	3.40	1.87	<b>3.83</b>
5	<b>HA</b>	4.25	1.91	3.20	1.76	<b>3.67</b>
6	<b>DA</b>	3.65	1.64	3.40	1.87	<b>3.51</b>
7	<b>Q</b>	3.95	1.78	3.00	1.65	<b>3.43</b>
8	<b>F</b>	2.45	1.10	3.20	1.76	<b>2.86</b>
9	<b>PO</b>	2.10	0.95	2.40	1.32	<b>2.27</b>
10	<b>PT</b>	1.80	0.81	2.60	1.43	<b>2.24</b>
11	<b>O</b>	2.50	1.13	1.80	0.99	<b>2.12</b>
12	<b>N</b>	2.20	0.99	2.00	1.10	<b>2.09</b>
13	<b>IA</b>	1.75	0.79	2.00	1.10	<b>1.89</b>
14	<b>UM</b>	1.70	0.77	2.00	1.10	<b>1.87</b>

NOTE: 1 = Lowest Effectiveness and 5 = Highest Effectiveness; PO = Participant Observation; O = Observation; I = In-Depth Interviewing; FG = Focus Groups; DR = Background and Context and Review of Documents; N = Life Histories and Narrative Inquiry; HA = Historical Analysis; F = Films, Videos and Photography; IA = Interaction Analysis; UM = Unobtrusive Measures; Q = Questionnaires and Surveys; PT = Projective Techniques and Psychological Testing; DA = Dilemma Analysis; and C = Using Computer and Internet Technologies

**Table 14:** Scoring and Ranking of Data Collection Methods for DFCS Research and Deliverables

Given the research deliverables and the need to obtain and validate information, a combination of data collection methods was to be used in this research. I selected these methods based on the evaluations in *Tables 12, 13 and 14*.

From the evaluations, it was apparent that interviews and focus groups would prove most effective for this research since they possessed the highest weighted scores. Interviews and focus groups are similar methods. In both cases, the interviewer or researcher asks focused questions to encourage discussion and expression of opinions and points of view (Marshall and Rossman, 2006). However, interviews typically involve a fewer number of participants than in focus groups. Interviews can direct attention to one participant and more effectively obtain his/her experience, insight and perceptions. The use of focus groups meanwhile, is inherently more convenient for the researcher as it allows him/her to interview more than one person in one sitting. However, given the number of design measures that were to be considered in this research, its effectiveness would prove limited as lengthy deliberation on a single measure could be unavoidable. Marshall and Rossman (2006) state other shortcomings and difficulties of using focus groups. Firstly, logistical problems may arise as the groups can vary a great deal and can also be hard to assemble. Secondly, the interviewer often has less control over a group interview than an individual one. Additionally, time can be lost while irrelevant issues are discussed. Lastly, power

dynamics may limit the participation of some members in the focus groups. For these reasons, I decided not to use focus groups as a data collection method. I however utilized interviews in this research.

The data collection method with the next highest weighted score was computer and internet technologies. Besides the fact that this method was to be used to access hazard incidents from the OSHA database, it was also to serve as a means through which other methods could be executed. For example, literature regarding the research topic could be located and reviewed using this method. Additionally, this method would be needed in the development of the relational database application. Expectably, computer and internet technologies had already been used and continued to be used through the duration of this research.

Background, context and review of documents and then historical analysis had the next highest weighted scores. Both these measures are part of literature review that is executed prior to and during research. As such, they had already been utilized and they continued to be utilized in the research. Literature review is necessary to develop a full understanding of the area of study. It also enables a researcher to capitalize on past work to guide his/her research while identifying research that may prove redundant.

The next highest weighted score was that of dilemma analysis. It can be considered as a focused part of interviews. This research was to probe at certain decision-making processes thereby highlighting the applicability of this particular data collection method (Marshall and Rossman, 2006). Hence, this method was utilized as part of interviews.

Following dilemma analysis, the data collection method with the next highest weighted score was the questionnaire and survey method. This method is preferred when the researcher wishes to obtain a small amount of information from a large number of subjects (Marshall and Rossman, 2006). As this research was to consider design measures that numbered in the hundreds and pertained to different professionals, the applicability of this method became apparent. Questionnaires and surveys were thus to be utilized in this research. It is also important to note a key shortcoming of this method, the low response rate of subjects. To address this, the survey must be designed and distributed in a manner to elicit as much useful information from as many subjects as possible. The remaining data collection methods were ranked in the lower half of the methods evaluated. Certain reasons prevented their further consideration.

Firstly DFCS is an emerging area. As such, research film was not available to show the design measures, their implementation, and how they could demonstrably improve construction safety. For this same reason, life histories and narrative inquiry and also, most unobtrusive methods would not prove useful. Other data collection methods such as projective techniques and psychological

testing and also, interaction analysis were simply not applicable for this particular research. They are more effective for the analysis of personality dynamics and interaction patterns (Marshall and Rossman, 2006).

The use of methods such as observation, participant observation and also surveillance through the use of films, videos and photography in data collection, would likely not have been welcomed by project participants. This is because it could have provided an additional avenue for liability exposure if a site safety incident occurred and was either observed by an outside party or even worse, recorded. Furthermore, observation and participant observation could expose the researcher to safety hazards and also, he/she could have become an obstruction for project participants and their obligations.

Additionally, even in a project implementing DFCS, it is very likely that only a few measures would be implemented. For example, in the case of a large \$1.5 billion semi-conductor plant project, Weinstein et al (2005) reported only 16 out of 26 DFCS measures considered were implemented in the full-scale DFCS initiative. Thus, the number of DFCS measures evaluated through the observation and surveillance methods would likely have been very little if at all, while requiring a substantial amount of time and other resources.

Conclusively, questionnaires and surveys, interviews, literature review, and computer and internet technologies were to be utilized as the data collection and research methods for this DFCS research. Also, in producing the research deliverables, the development of a relational database application is another approach that was part of the research method.

### **3.2 Selected Data Elicitation and Research Methods**

In this section, the selected data collection and research methods are discussed with regards to their technique, potentials, design and implementation. These include surveys, interviews, and relational database applications.

#### **3.2.1 Surveys**

Surveys are information-collection methods used to describe, compare, or explain individual and societal knowledge, feelings, values, preferences, and behavior (Fink, 2009). Fink (2009) highlights three reasons for conducting surveys. Firstly, surveys can be conducted when a policy needs to be set or a program must be planned. Secondly, surveys can be conducted to evaluate the effectiveness of programs to change people's knowledge, attitudes, health, or welfare. Thirdly, surveys can be conducted to get information about how to guide research studies and programs.

### **3.2.1.1      Advantages of using Surveys for Research**

1. Surveys have the ability to generalize about an entire population by drawing inferences based on data drawn from a small portion of that population (Rea and Parker, 2005).
2. Surveys can be implemented in a timely fashion. The survey project can be organized so that the actual data gathering is performed in a relatively short period of time (Rea and Parker, 2005).
3. Surveys, especially self-administered surveys, are relatively inexpensive (CSU, 2010).
4. Surveys provide for flexibility. As many questions can be asked about a given topic, considerable flexibility is given to the analysis. There is also flexibility in terms of survey administration such as face-to-face interviews, by telephone, as group or self administered, written or oral, or by electronic means. (CSU, 2010).
5. Surveys can be administered from remote locations using mail, email or telephone. Thus, very large samples are feasible, making the results statistically significant even when analyzing multiple variables (CSU, 2010).
6. Standardized questions make measurement more precise by enforcing uniform definitions upon participants. Furthermore, by presenting all subjects with a standardized stimulus, observer subjectivity is greatly eliminated (CSU, 2010). Well-structured sample surveys generate standardized data that are extremely amenable to quantification and consequent computerization and statistical analysis (Rea and Parker, 2005).

### **3.2.1.2      Disadvantages of using Surveys for Research**

1. Surveys are inflexible in that they require the design including the tool and administration, to remain unchanged throughout the data collection (CSU, 2010).
2. Surveys generally experience low response rates. Thus, the researcher must ensure that an adequate number of the selected sample will respond (CSU, 2010).
3. Participants' responses may be dishonest, inaccurate or incomplete (Marshall and Rossman, 2006). Also, it may be hard for participants to recall information or to tell the truth about a controversial question (CSU, 2010). There may also be no opportunity for respondents to clarify questions.

4. Surveys can seldom deal with context both in development and in data entry by participants (CSU, 2010).
5. Due to reliance on standardization and the need for appropriateness in eliciting responses, a researcher may develop questions that may miss what is most appropriate to many respondents (CSU, 2010).

### **3.2.1.3      The Survey Design and Administration Process**

The order of the discussed steps for administering surveys was determined based on the survey process presented and discussed by Bethlehem (2009), CSU (2010) and Punch (2003).

1. Develop data collection questions.  
Punch (2003) identified a number of steps for developing data collection questions for the survey. These are provided.
  - a. Develop a clear statement of the objective(s) of the survey.
  - b. Develop the general research questions from the objectives.
  - c. Develop the specific research questions from the general research questions.
  - d. Ensure each specific research question meets the empirical criterion.
  - e. Show the conceptual framework for the survey.
  - f. Develop data collection questions from the specific research questions.
2. Determine the type of administration method or form for the survey.  
CSU (2010) identified a number survey types. These are listed.
  - a. Written Surveys
    - i. Mail Surveys
    - ii. Group Administered Surveys
    - iii. Drop-off Surveys
  - b. Oral Surveys
    - i. Face-to-face Surveys
    - ii. Phone Surveys
  - c. Internet/Electronic Surveys

Czaja and Blair (2005) identified three broad categories of factors and their many subcategories that must be considered in choosing a method of survey administration. These include administrative or resource factors, questionnaire issues, and data-quality issues. With regards to these factors, the characteristics of the different methods are indicated. This is seen in *Table 15*. Using this, a researcher can select a survey method as appropriate to his/her study and available resources.

<b>Aspect of Survey</b>	<b>Written Surveys</b>			<b>Oral Surveys</b>		<b>Internet / Electronic Surveys</b>
	<u>Mail Survey</u>	<u>Group- Administered Survey</u>	<u>Drop-off Survey</u>	<u>Face-to-face Survey</u>	<u>Phone Survey</u>	
<b>Administrative or Resource Factors</b>						
<i>Cost</i>	Low	Low/medium	Medium/High	High	Low/medium	Very Low
<i>Length of Data Collection Period</i>	Long (10 weeks)	Medium (4-8 weeks)	Long (10-12 weeks)	Medium/long (4-12 weeks)	Short (2-4 weeks)	Very short/short (1-3 weeks)
<i>Geographic Distribution of Sample</i>	May be wide	Must be clustered	Must be clustered	Must be clustered	May be wide	May be wide
<b>Questionnaire Issues</b>						
<i>Length of Questionnaire</i>	Short/medium (4-12 pages)	Long (30-60 minutes)	Short/medium (4-12 pages)	Long (30-60 minutes)	Medium/long (15-35 minutes)	Short (<15 minutes)
<i>Complexity of Questionnaire</i>	Must be simple	May be complex	Must be simple	May be complex	May be complex	May be complex
<i>Complexity of Questions</i>	Simple/moderate	May be complex	Simple/moderate	May be complex	Must be short and simple	Simple/moderate
<i>Control of Question Order</i>	Poor	Good	Poor	Very good	Very good	Poor/fair
<i>Use of Open-ended Questions</i>	Poor	Good	Poor/fair	Good	Fair	Fair/good
<i>Use of Visual Aids</i>	Good	Very good	Good	Very good	Usually not possible	Very good
<i>Use of Household/Personal Records</i>	Very good	Fair	Very good	Good	Fair	Very good
<i>Rapport</i>	Fair	Good	Good	Very good	Good	Poor/fair
<i>Sensitive Topics</i>	Good	Fair	Good	Fair (Good with A-CASI)	Fair/good	Poor/fair
<i>Nonthreatening Questions</i>	Good	Good	Good	Good	Good	Good
<b>Data-Quality Issues</b>						
<i>Sampling Frame Bias</i>	Usually low	Low	Low	Low	Low (with RDD)	Low/high
<i>Response Rate</i>	Poor/good	Good/very good	Fair/good	Good/very good	Fair/good	Poor/good
<i>Response Bias</i>	Medium/high (favors more educated people)	Low	Low/Medium	Low	Low	Medium/high (favors more educated people)
<i>Knowledge about Refusals and Non- contacts</i>	Fair	Fair	Fair	Fair	Poor	Fair
<i>Control of Response Situation</i>	Poor	Good	Poor	Good	Fair	Poor
<i>Quality of Recorded Response</i>	Fair/good	Good/very good	Fair/good	Very good	Very good	Fair/good
<i>Source of Information on the Survey Methods</i>	Czaja and Blair (2005)	CSU (2010)	CSU (2010)	Czaja and Blair (2005)	Czaja and Blair (2005)	Czaja and Blair (2005)

**Table 15:** Comparison of Major Survey Methods (Source: Adapted from Czaja and Blair, 2005)

### 3. Create the survey questionnaire.

In developing the questionnaire, a number of features should be carefully considered. These are identified by Punch (2003) and CSU (2010). They are briefly discussed.

#### ○ Overall Design Issues

CSU (2010) provides a number of key issues to be considered when designing a survey or questionnaire. These are provided.

- Respondent attitude: A researcher should consider how a participant will respond to his/her developed survey instrument with consideration to the method of administration. This may enable the researcher to design a survey that will encourage more complete respondent participation.
- Nature of questions: It is important to consider the relationship between the survey administration method and the research questions asked. Certain question types and formats may be inappropriate for the selected method.
- Cost: Expense issues should enter into a researcher's decision making process when planning and designing a survey. The population under consideration, the geographic distribution of this sample population, and the type of questionnaire used all affect costs.
- Ability of instrument to meet needs of research question: There needs to be a logical link between the survey instrument and method to the research questions. The questions will therefore need to reflect both research goals and the choice of medium.

#### ○ Qualitative versus Quantitative Surveys and Questions

Qualitative methods involve a researcher describing kinds of characteristics of people and events without comparing events in terms of measurements or amounts (Thomas, 2003). Quantitative methods, meanwhile, focus attention on measurements and amounts of the characteristics displayed by the people and events that the researcher studies (Thomas, 2003).

Quantitative data use numbers to describe what exists (Gray et al, 2007). Qualitative data meanwhile, rely on words, especially nouns and adjectives that convey what exists (Gray et al, 2007). The main advantage of qualitative data is they can capture subtleties of meaning and interpretation that numbers do not convey (Gray et al, 2007). However, quantitative research makes it more likely that studies can be replicated and that the results are reliable as it is easier to repeat the data collection procedures that generate numbers than to exactly recreate the conversations and

observations that typically form the basis of qualitative research (Gray et al, 2007). The researcher should determine which type of survey or question is most appropriate to answer his/her research questions.

- Open-ended versus Closed-ended Questions

Open-ended questions do not give respondents answers to choose from; they are phrased so respondents can explain their answers with sentences or paragraphs. Open-ended questions allow respondents to include more information. They also cut down on response error by not allowing responders to disregard the questions and fill-in random answers. Surveys that use open-ended questions can be more readily used for secondary analysis.

Closed-ended questions meanwhile, limit respondents' answers to the survey by allowing them to choose from a pre-existing set of dichotomous answers, multiple choices or ranking scale response options. Closed-ended questions are more easily analyzed. Closed-ended questions can be more specific, thus more likely to communicate similar meanings. Surveys with closed-ended questions have a higher response rate than those with open-ended. They also take less time from the participant and the researcher.

- Question Format

There are a number of question formats that can be utilized. They include the following formats.

- Rating scales
- Ranking scales
- Magnitude estimation scales
- Split or unfolding questions
- Funneling questions
- Inverted funneling questions
- Factorial questions

- Wording of Questions

CSU (2010) presents techniques for wording questions.

- Questions should be written in a straightforward, direct language and specifically tailored for a group of respondents.
- Questions should be kept short and simple.
- Questions should be more specific and less general.
- Questions that are overly personal or direct should be avoided, especially when dealing with sensitive issues.
- Double-barreled and double-negative questions should be avoided.
- Hypothetical, ambiguous and biased questions should also be avoided.
- Questions with long lists should also be avoided.

- Order of Questions
 

CSU (2010) also presents a set of guidelines for ordering survey questions. These are presented.

  - Use warm-up questions to ease the respondent into the survey and set the tone and topic of the survey.
  - Sensitive questions should not appear at the beginning of the survey.
  - Consider transition questions that make logical links.
  - Topics should be placed into sets of questions and not mixed.
  - The most important questions should not be placed towards the end of the survey.
  - Contingency questions should be limited.
  - Where both open and close-ended questions are utilized, the latter should be placed earliest in the survey.
  
- Quality of Data
 

Punch (2003) presented a number of issues to consider in striving for the best possible quality of data.

  - Reliability: Survey questions should produce stable responses and that depends in part on whether the questions can be consistently and straightforwardly answered. Reliability means stability of response.
  - Validity: This has to do with whether respondents answer questions honestly and conscientiously. Validity means whether the data represent what they are expected to represent.
  - Response Rates: This refers to the proportion of the selected sample that completes the questionnaire. Adequate planning and preparation is necessary to maximize response rates. The researcher may consider offering incentives to motivate respondents in completing the questionnaire. Even small incentives have been found to significantly increase response rates (Edwards, 1997).
  - Frame of mind or attitude of respondent: The frame of mind of the respondent should preferably be cooperative when answering the questionnaire. For this, the survey must be professional, inviting, attractively presented, and account for ethical considerations.
  - Size of questionnaire: It is better to have a smaller body of good quality data than a larger body of data of doubtful quality. The size or length of the questionnaire should thus have an adequate length to encourage complete and accurate responses.

- Other Considerations
 

CSU (2010) provides a number of considerations researchers should make when designing surveys and their questions.

  - Researchers should use forced-choice questions when using agree and disagree statements.
  - As it is incorrect to assume that each respondent has an opinion regarding every question, a "no opinion" option can be offered for each question.
  - When using a close-ended question format with dichotomous options, respondents may not consider each question and just provide the same answer to all questions.
  - Researchers can use a reference point to prevent telescoping and forward telescoping by respondents.
  - When using long lists and/or rating scales, participants are more likely to exhibit response order bias.
  - To prevent fatigue effect on survey respondents, researchers should use transitions, vary questions and response options, and place easy to answer questions at the end of the questionnaire.

#### 4. Determine the sample and its features.

Sample is a technical term in research which means a smaller subset drawn from a larger group (Punch, 2003). The logic of surveys is to collect information from the sample in order to answer the research questions. There are a number of considerations that should be made when determining sample size, procedure and other features.

- Sample Selection
 

Punch (2003) identifies four general steps for selecting the sample. These are provided.

  - i. Decide the ideal sample for the study.
  - ii. Decide on the balance between generalizability and variability sought in the sample.
  - iii. Decide on the specific parameters of the sample.
    - The size of the sample
    - The method for selecting the sample
  - iv. Decide on the strategy for approaching and gaining access to the people selected in the sample.
- Sample Sizing
 

Fink (2009) presents a number of factors to consider in determining the sample size for a survey. These are provided.

  - Urgency of data
  - Type of survey planned
  - Availability of resources
  - Desired credibility of findings
  - Familiarity with and ability to utilize sampling methods

- Sampling Procedures and Methods
 

CSU (2010) identifies a number of sampling procedures and methods. These are briefly discussed.

  - Probability sampling methods: These methods ensure that there is a possibility for each person in a sample or a population to be selected. This approach attempts to prevent a bias in the sample selection. Some commonly used probability sampling methods for surveys are presented
    - Simple random sample: This is when a sample is drawn randomly from a list of individuals in a population.
    - Systematic selection procedure sample: This is a variant of a simple random sample in which a random number is chosen to select the first individual and so on from there.
    - Stratified sample: This involves dividing up the population into smaller groups, and randomly sampling from each group.
    - Cluster sample: This involves dividing up a population into smaller groups, and then only sampling from one of the groups.
    - Multistage sampling: This first involves sampling a set of geographic areas then sampling a subset of areas within those areas, and so on.
  - Non-probability sampling methods: These methods target specific individuals. Such methods are discussed.
    - Purposive samples: This is to purposely select individuals to survey. There are two main types:
      - i. Convenience sampling: This is when samples are selected on the basis of convenience to the researcher.
      - ii. Snowball Sampling: This is when survey participants are asked for references to other participants.
    - Volunteer subjects: This to specifically ask for volunteers to survey.
    - Haphazard sampling: This is to survey individuals who can be easily reached.
    - Quota sampling: This is to select individuals based on a set quota.
- Errors
 

Fox and Tracy (1986) indicate that surveys are subject to two major types of errors, sampling and non-sampling errors.

- Sampling error: This arises from the fact that samples inevitably differ from their populations. Survey sample results should therefore be seen as estimations. Weisberg et al (1989) stated that sampling errors cannot be calculated for non-probability samples, but only for probability samples. The more people surveyed, the smaller the error. According to Fox and Tracy (1986), this error can be reduced by increasing the representativeness of the sample.
    - Non-sampling error: This arises from a bias in survey data. This error is generally connected to response and non-response bias. There are random and nonrandom non-sampling errors. According to Fox and Tracy (1986), random errors decrease the reliability of measurements but can be reduced through repeated measurements.
  - Sample and Error Characteristics
    - Confidence Level and Interval: The confidence level and the confidence interval are used together to express the accuracy of the sample's statistics in terms of the level of confidence that the statistics fall within a specified interval from the true population parameter (CSU, 2010). These are typically presented in percentages. There are specified confidence interval limits for percentages based upon sample size.
    - Confidence Limits and Sample Size: When selecting a sample size, a researcher should consider that a higher number of individuals surveyed from a target group will yield a tighter measurement while a lower number yields a looser range of confidence limits (CSU, 2010). The confidence limits may need to be corrected if the sample size starts to approach the population size or if the variable under scrutiny is known to have a much smaller or larger occurrence than 50% in the whole population (Lauer and Asher, 1988). There are specified correction factors for the confidence limits.
5. Subject the designed survey to pilot testing or pretesting.
- To determine the effectiveness of the survey questionnaire, it is necessary to pretest prior to using it. Pretesting can help in determining the strengths and weaknesses of the survey (CSU, 2010). Pretests / pilot tests should specifically assess question variation, meaning, flow, order, skip patterns and timing. They should also assess task difficulty, respondent interest and attention, and overall respondent well-being. The reliability and validity of the survey questions can also be pre-tested (CSU, 2010). Pilot testing is necessary for survey questionnaires that have not already been used and field tested (Punch, 2003). However, borrowed questions from similar surveys can also be tested to examine context. Pilot tests have certain guiding objectives and types. These are presented.

- Objectives to guide Pilot Testing  
Punch (2003) identifies three general objectives to guide pilot testing.
  - Newly written items and questions need to be tested for comprehension, clarity, ambiguity and difficulty in responding to. Participants should be able to quickly, easily and confidently respond to the questions.
  - The survey needs to be tested for length and for time and difficulty to complete.
  - The proposed data collection method is to be tested with regards to issues of access and approach, ethical issues, covering letters and others. This will have a significant impact on response rates.
- Types of Pilot Tests  
CSU (2010) identifies two types of survey pretests.
  - Participating pretests: In participating pretests, respondents are informed that the pretest is a practice run. Rather than asking the respondents to simply fill out the questionnaire, this pretest usually involves an interview setting where respondents are asked to explain reactions to question form, wording and order. This kind of pretest will help in determining whether the questionnaire is understandable.
  - Undeclared pretests: In an undeclared pretest, the survey is conducted without informing respondents that it is a pretest. This allows for checking the choice of analysis and standardization of the survey. With available resources for more than one pretest, it may be best to use a participatory pretest first and then an undeclared test (Converse and Presser, 1986).

6. Administer the survey and collect the data.

Punch (2003) presents general steps for the administration of the survey and collection of the data. These steps need to be executed with the aim of achieving the highest possible survey response rates. The steps are presented.

- a. Select the method of survey administration and distribution and also collection after completion.
- b. Develop a detailed plan for the distribution and collection of the survey.
- c. Decide how participants or respondents will be approached.
- d. Produce a covering letter indicating the stated details.
  - i. The research or project topic
  - ii. The research or project purpose
  - iii. The researcher conducting the survey
  - iv. The intended use of the collected information

- v. The basis for selecting the respondents
    - vi. The confidentiality or anonymity of the survey responses
    - vii. Instructions for completing and returning the survey questionnaire
  - e. Decide on distribution methods and dates, collection methods and dates, follow-up procedures and cut-off date for the end of the data collection.
7. Analyze the collected survey data.
- Survey data and results must be processed and analyzed. The steps for analyzing the results depend on the research scope, the researcher's capabilities and the audience the research is directed at (CSU, 2010). Executing the steps may require significant attention to detail, statistics knowledge and often, an ability to utilize computer software packages. The steps are presented.
- a. Proofread completed questionnaires and decide what to do about missing data and ambiguous or unclear responses (Punch, 2003).
  - b. Edit the proofread data. Editing can ensure that the data analyzed are correct and complete. It can also reduce the bias, increase the precision and achieve consistency between the tables. Editing may however not always be necessary.
  - c. Enter the proofread data into the computer for analysis and also for record (Punch, 2003). The data must be entered and assembled in a useable format that allows analysis and comparison (CSU, 2010).
  - d. Interpret the data based on the earlier determined procedure and formulas (CSU, 2010). The statistical significance and other characteristics of the results should also be obtained.
  - e. Analyze the data and relationships. This involves the comparison of data and results within the survey group, between groups, or both (CSU, 2010). Such data analysis as the T-test, ANOVA, and correlation can be used in analyzing the results. Data analysis also involves summarizing and distilling the collected survey data (Punch, 2003).
  - f. Document the findings and results. This involves recording the information produced from the analysis of the survey results. For easier interpretation by the more general audience, this information can be represented in a number of ways including tables, graphs and charts (CSU, 2010).
8. Prepare and complete the survey report.
- The report of the results is the final stage of the survey (CSU, 2010). There is no format for the survey report as this depends on the intended audience. However, the report should typically state the objective, methods and findings (Punch, 2003). Additionally, a formal report might include contextual information, a literature review, the research questions, information on survey participants, the survey design, procedure, findings and results, and a discussion of the results (CSU, 2010).

### **3.2.2 Interviews**

Interviews are data collection methods that provide the researcher/interviewer with an understanding of the beliefs, experiences and perspectives of the participant/interviewee with regards to certain research topics and questions (McCracken, 1988). Interviews may be the overall strategy or only one of several data collection methods employed. There is no single universal protocol to follow in developing an interview study but there are sufficiently common approaches utilized (King and Horrocks, 2010). The most important aspect of the researcher's approach is conveying the attitude that the participant's views are valuable and useful (Marshall and Rossman, 2006).

#### **3.2.2.1 Advantages of using Interviews in Research**

1. Interviews can yield data in quantity quickly (Marshall and Rossman, 2006).
2. Interviews provide flexibility to explore new ideas and issues not anticipated during planning (McNamara, 2007).
3. Interviews provide opportunities for probing. They allow for immediate follow-up and clarification of responses (Marshall and Rossman, 2006).
4. Interviews can obtain highly personalized data from research subjects (McNamara, 2007).
5. Interviews are relatively simple to conduct (McNamara, 2007).
6. Interviews can address the issue of context for participant's responses (Case, 2007).

#### **3.2.2.2 Disadvantages of using Interviews in Research**

1. Interviews are time consuming to schedule, conduct, interpret and analyze particularly in the case of research requiring multiple interviews for data collection (Marshall and Rossman, 2006; and Thomas et al, 2010). The interpretation process may also prove tedious.
2. Interviews may prove to be expensive particularly when interviewee locations are not proximal (Fowler, 2009).
3. Interviews are susceptible to interviewer biases and lack of skill or expertise (McNamara, 2007).

4. Interviews are not appropriate where quantitative data are needed (McNamara, 2007).
5. As the interviewees or participants may provide dishonest or inaccurate responses, the outcome of the interview is hugely dependent on their cooperation (Marshall and Rossman, 2006).
6. It may be difficult to prove the validity of findings from interviews (McNamara, 2007).

### **3.2.2.3      The Interview Process**

The order of the discussed steps for administering interviews was determined based on the process presented and discussed by King and Horrocks (2010) and McNamara (2007).

1. Formulate and frame the research/study question.  
There are several issues that need to be taken into account when framing a research question (King and Horrocks, 2010).
  - Type of Research Question  
The type of research question should be appropriate for the kind of knowledge the researcher seeks to produce from analysis of the interview data.
  - Scope of the Research Question  
This involves determining the broadness or narrowness of the topic the study is seeking to examine.
  - Avoiding Presuppositions  
There is need to avoid presuppositions in the question that might distort the research process.
  - The Shifting Research Question  
There is need to consider the extent to which the research question itself might change in the process of executing the research.
  - Number of Study Questions  
McNamara (2007) state that study questions should generally be limited to five or fewer.
2. Choose the type of interview to use.  
The type of interview should be chosen based appropriateness to the research topic and/or the requirements of the methodological and theoretical stance to be taken (King and Horrocks, 2010). There are several types of interviews based on structure, format, mode of administration, number of participants and specialization.

- Types of Interviews by Structure  
Merriam (2009) presents three types of interviews that vary according to amount of structure inherent in the interview. These are presented in *Table 16*.

Highly Structured / Standardized	Semi-structured	Unstructured / Informal
<ul style="list-style-type: none"> <li>- Wording of questions is predetermined</li> <li>- Order of questions is determined</li> <li>- Interview is oral form of a written survey</li> <li>- In qualitative studies, usually used to obtain demographic data (age, gender, ethnicity, education, etc.)</li> <li>- Examples: U.S. Census Bureau survey, marketing surveys</li> </ul>	<ul style="list-style-type: none"> <li>- Interview guide includes a mix of more and less structured interview questions</li> <li>- All questions used flexibly</li> <li>- Usually specific data required from all respondents</li> <li>- Largest part of interview guided by list of questions or issues to be explored</li> <li>- No predetermined wording or order</li> </ul>	<ul style="list-style-type: none"> <li>- Open-ended questions</li> <li>- Flexible, exploratory</li> <li>- More like a conversation</li> <li>- Used when researcher does not know enough about phenomenon to ask relevant questions</li> <li>- Goal is learning from this interview to formulate questions for later interviews</li> <li>- Used primarily in ethnography, participant observation, and case study</li> </ul>

**Table 16:** Interview Structure Continuum (Source: Merriam, 2009)

- Qualitative versus Quantitative Interviews and Questions  
Johnson and Christensen (2007) present four types of interviews grouped into qualitative and quantitative interviews. These are presented in *Table 17*.
- Types of Interviews by Mode of Administration  
There are two major types of interviews based on mode of administration (Blaxter et al, 2006; and King and Horrocks, 2010).
  - Face-to-face Interviewing  
This is the conventional interview approach where the interviewer and interviewee interact in the same physical location (King and Horrocks, 2010).
  - Remote Interviewing  
Remote interviews are used by researchers for three main reasons; physical distance from participants, availability of participants, and the nature of the interview topic (King and Horrocks, 2010). King and Horrocks (2010) identify the main forms of remote interview and their characteristics. This is seen in *Table 18*.

Type of Interview	Characteristics	Strengths	Weaknesses
<u>Qualitative Interviews</u>			
Informal conversational interview	Questions emerge from the immediate context and are asked in the natural course of things; there is no predetermination of question topics or wording.	Increases the salience and relevance of questions; interviews are built on and emerge from observations; the interview can be matched to individuals and circumstances.	Different information collected from different people with different questions. Less systematic and comprehensive if certain questions do not arise "naturally". Data organization and analysis can be difficult.
Interview guide approach	Topics and issues to be covered are specified in advance, in outline form; interviewer decides sequence and wording of questions in the course of the interview.	The outline increases the comprehensiveness of the data and makes data collection somewhat systematic for each respondent. Logical gaps in data can be anticipated and closed. Interviews remain fairly conversational and situational.	Important and salient topics may be inadvertently omitted. Interviewer flexibility in sequencing and wording questions can result in substantially different responses from different perspectives, thus reducing the comparability of responses.
Standardized open-ended interview	The exact wording and sequence of questions are determined in advance. All interviewees are asked the same basic questions in the same order. Questions are worded in a completely open-ended format.	Respondents answer the same questions, thus increasing comparability of responses; data are complete for each person on the topics addressed in the interview. Reduces interviewer effects and bias when several interviewers are used. Permits evaluation users to see and review the instrumentation used in the evaluation. Facilitates organization and analysis of the data.	Less flexibility in relating the interview to particular individuals and circumstances; standardized wording of questions may constrain and limit naturalness and relevance of questions and answers.
<u>Quantitative Interviews</u>			
Closed quantitative interview	Questions and response categories are determined in advance. Responses are fixed; respondent chooses from among these fixed responses.	Data analysis is simple; responses can be directly compared and easily aggregated; many questions can be asked in a short time.	Respondents must fit their experiences and feelings into the researcher's categories; may be perceived as impersonal, irrelevant, and mechanistic. Can distort what respondents really mean or experience by so completely limiting their response choices.

**Table 17:** Classification of Types of Interviews (Source: Johnson and Christensen, 2007)

Remote interview form	Time frame	Data type
Telephone	Synchronous	Verbal
Remote Video (Video-conferencing and webcams)	Synchronous	Verbal (plus visual)
E-mail	Asynchronous	Written
Instant messaging	Synchronous	Written

**Table 18:** Main Forms of Remote Interview (Source: King and Horrocks, 2010)

- Types of Interviews by Number of Participants
  - One-to-one Interviews  
This is the conventional interview with one interviewer and one interviewee. This type of interview is most appropriate for exploring sensitive areas, and for obtaining more in-depth information from individual participants (King and Horrocks, 2010).
  - Group Interviews  
This type of interview includes either or both multiple interviewers and interviewees. Group interviews can encourage recall and stimulate opinion elaboration. Furthermore, stated views can often be amplified, quantified, amended or contradicted when expressed as part of a group interview (King and Horrocks, 2010).
- Types of Interviews by Specialization  
Marshall and Rossman (2006) present a number of specialized forms of interviews. These are presented.
  - Ethnographic Interviewing  
Ethnographic interviewing elicits the cognitive structures guiding participants' views and perspectives.
  - Phenomenological Interviewing  
The purpose of this type of interviewing is to describe the meaning of a concept or phenomenon that several individuals share.
  - Interviewing of Elites  
This is a specialized case of interviewing that focuses on a particular type of interviewee selected on the basis of their expertise in areas relevant to the research.
  - Interviewing Children  
Children may be the primary focus of a study or one of many groups the researcher wants to interview. In such interviews, special considerations must be given to age and role.

3. Define sample and recruit participants and key informants.

Key informants should be selected for their specialized knowledge and unique perspectives on the research topic (McNamara, 2007). Researchers should also ensure they select participants or interviewees with varying points of view (King and Horrocks, 2010). This process has a number of features and approaches. They are presented.

  - Tasks in Sample Selection and Recruitment

Sample selection consists of a number of tasks (McNamara, 2007; and King and Horrocks, 2010).

    - i. Identify groups and organizations from which key informants will be drawn.
    - ii. Select a number of people from each group/category to interview.
    - iii. Request to interview the selected participants.
  - Alternative Approaches to Recruiting Participants
    - Snowball Sampling: In snowball sampling, the researcher uses the initial few interviewees to recommend other potential participants who fit the inclusion criteria for the study (King and Horrocks, 2010).
    - Advertising for Participants: This involves utilizing some form of public advertising to recruit interviewees (King and Horrocks, 2010)
    - Gatekeepers or Insider Assistants: Researchers may gain access to interviewees through people with authority to grant or deny permission to access potential participants and/or the ability to facilitate such access. Researchers may also use organizational/group insiders to actively assist in recruiting participants (King and Horrocks, 2010).
4. Develop interview guide.

Interview guides should ideally specify each study question and list the major topics and issues to be covered (McNamara, 2007). Different guides may be necessary for interviewing different groups of participants or interviewees (McNamara, 2007). There are a number of considerations that should be made in the development of an interview guide. These are briefly discussed.

  - Sources from which to base guide

King and Horrocks (2010) suggest there are three main sources from which to identify topics to be included in the interview guide.

    - Experience of the research area and topic
    - Literature on the research area and topic
    - Preliminary work on the research area and topic

- Comprehensiveness in covering topics relevant to the research  
A researcher should determine the extent to which he/she wants to lead the direction of the interview. Also, in making this determination, the researcher must reflect on the aims of the study and his/her methodological position (King and Horrocks, 2010). When using a comprehensive interview guide, there is the danger that sufficient opportunity will not be allowed for participants to bring up perspectives that may be unanticipated but are actually of real value to the research. Meanwhile, when using a minimalist interview guide, the researcher may fail to address important issues should the participant move into lengthy digressions from the focus of the research (King and Horrocks, 2010).
- Types of interview questions  
Patton (1990) argues that there are six types of question that can be asked to elicit particular kinds of information from participants.
  - Background/demographic questions
  - Experience/behavior questions
  - Opinion/values questions
  - Feeling questions
  - Knowledge questions
  - Sensory questions
- Flexibility of interview guide to change  
This refers to the flexibility of changing the interview guide during the course of the study. King and Horrocks (2010) recommend that insights gained in the process of carrying out the first few interviews should inform subsequent ones. The interview guide should therefore change to reflect this. These changes however, must be controlled to avoid distorting the analysis of the data (King and Horrocks, 2010).
- Format of the questions or topic areas on the guide
  - King and Horrocks (2010) identify two styles of laying out the questions to be asked.
    - Full questions: This approach forces researchers to think carefully about question formulation. However, with full questions stated on the guide, the interviewer may tend not to use it as flexibly as he/she should.
    - Short phrases/ single words / bullet points: This approach encourages flexibility but does not help guard against inappropriate phrasing of questions.
  - King and Horrocks (2010) also identify two factors that may be useful when choosing the format of the guide.
    - The experience of the interviewer: Relatively inexperienced interviewers are recommended to opt for the full question format.

- The researcher's methodological approach: Where the methodology seeks to minimize the interviewer's directive role, the short phrase style is recommended.
  - Probes or prompts and their inclusion in the interview guide
 

Probes refer to follow-up questions that encourage a participant to expand on an initial answer in order to obtain more depth in their response (King and Horrocks, 2010). Prompts meanwhile refer to interventions that seek to clarify for the interviewee the kind of information a question is seeking to gather; this is usually used when the interviewee has expressed uncertainty or incomprehension about the initial question (King and Horrocks, 2010). A researcher will need to formulate many probes and prompts in the course of an interview as he/she seeks to obtain the fullest possible account from the interviewee.

It is often reasonable to anticipate that certain probes and prompts may be needed at a specific point in an interview. In such cases, it makes sense to include them on the interview guide (King and Horrocks, 2010). This may be done at the outset, when designing the guide. Probes and prompts may also be added in light of experience as the study progresses.
5. Conduct the interview.
- There are certain aspects of the actual interview process that must be addressed for effectiveness. These are discussed.
- The Interview Setting
 

The physical environment in which an interview is located can have a strong influence on how it proceeds (King and Horrocks, 2010). Comfort, privacy and quiet are the three aspects of the physical environment considered important (King and Horrocks, 2010). Distraction must thus be minimized (McNamara, 2007). In choosing the interview location, it is generally good practice to ask participants for their preferred location (King and Horrocks, 2010). They will likely feel more comfortable at the location (McNamara, 2007).
  - Recording
 

It is strongly preferable to have a full record of each interview. The mode or type of recording may have an impact on the interview process. The interviewee may be apprehensive and/or suspicious and as a result, less comfortable in providing their complete and/or honest perspective (King and Horrocks, 2010). As such, the permission of the interviewee should be sought particularly in cases where audio and/or video recording are intended for use. The type of recording should also be appropriate to the research and its methodology. King and Horrocks (2010) identify types of recording for interviews which include note-taking, audio-recording and video-recording.

- Building Rapport
 

Rapport enables the participant or interviewee to feel comfortable in revealing his/her honest and/or complete responses to the research questions (King and Horrocks, 2010). Building rapport is widely seen as a key ingredient in successful interviewing. Towards this, a number of issues need to be addressed.

  - Introducing the project: The researcher should begin with an explanation of the purpose of the interview, the intended uses of the information and assurances of confidentiality (McNamara, 2007). Identification of other relevant research officials may also be necessary in cases where interviewees want further assurances (McNamara, 2007).
  - Self-presentation: Self-presentation includes the researcher's wardrobe, use of non-verbal communication and kind of vocabulary used. These convey the researcher's personal qualities and provide information about the researcher's identity. King and Horrocks (2010) provide an example of an interview study conducted by a PhD student. When the student dressed formally, the interviewees were guarded. However, when the student dressed more casually emphasizing student status, the participants were more open and trusting.
- Asking Questions in an Interview
 

The researcher or interviewer has to be careful when formulating questions. Good practice in questioning stipulates that a number of question approaches be avoided (King and Horrocks, 2010). These are specified.

  - Leading Questions: A question is leading when its wording suggests to the interviewee the kind of response that is anticipated.
  - Over-complex and Multiple Questions: The wording of questions should be kept as simple, clear and direct as possible.
  - Judgmental Responses: The interviewer or researcher should avoid responding to the interviewee in a manner to suggest he/she is making a judgment about their position. Maintaining a neutral attitude is essential for an effective interview (McNamara, 2007).
  - Failure to Listen: Failing to listen to the participant's response can lead to inappropriate questioning, potentially leaving him/her irritated at the researcher/interviewer.
- Probing
 

Probing seeks to add depth to interview data. Majority of probes will need to be devised in the course of an interview (King and

Horrocks, 2010). Effective probing requires good listening skills. Probing must however be controlled to avoid lost time from collecting enormous detail on areas with limited relevance to the research topic (King and Horrocks, 2010). King and Horrocks (2010) identify three main types of probe. These are presented.

- Elaboration: Elaboration probes encourage the participant to keep talking in order for the researcher to gather more detail on the topic of discussion.
- Clarification: Clarification probes seek explanation of responses the interviewee has not fully understood.
- Completion: Completion probes ask the interviewee to finish an explanation that seems incomplete.

○ Other Considerations

- Question sequencing: Generally, questions should be sequenced to advance from simple to difficult (King and Horrocks, 2010). The interview should preferably begin with factual questions and progress to questions requiring opinions and judgments. The interview should also begin with questions about the present followed by those about the past or future (McNamara, 2007).
- Questions with single-word answers: Questions that can be answered with a simple yes or no should be avoided as they do not present a need for participants' explanation (McNamara, 2007).
- Non-verbal communication: An interviewer or researcher must not appear tense or nervous as this may also distract or unsettle the interviewee (King and Horrocks, 2010).
- Managing difficult interviews: A researcher or interviewer needs to be aware of certain difficulties in interviewing. King and Horrocks (2010) identified four of such situations which include interviews where there are significant status issues, interviewer role conflicts, interviews on emotionally sensitive topics, and dealing with under- and over-communicative interviewees. Interviewers should determine approaches for cases where such difficulties are anticipated.
- Translation difficulties: Where there is need for use of a translator, added difficulties will be encountered as information is often lost in translation (McNamara, 2007). Interviewers should appropriately determine strategies in such circumstances.

○ Pilot Interviews

Pilot interviews can aid the researcher in refining his or her interview agenda. The researcher can also get some practice at conducting the interview thereby enhancing his or her confidence (Gulati, 2009). Additionally, pilot interviews can aid the interviewer

in organizing his/her approaches before, during and after the interviews (Gillham, 2000). Pilot interviews might also be useful in sensitizing interviewers to the importance of body language (Kvale, 2008). Additionally, they may aid in determining necessary approaches for transcribing and analyzing the interview data (Gillham, 2000). The pilot interview should be conducted in an identical manner to the research interview. The interviewer could however request input on the structure and content of the interview at the end. Gillham (2000) recommends one or two pilots. Based on the pilots, certain adjustments and alterations may be required to improve the effectiveness of the proposed interviews (Gillham, 2000). These are stated.

- The interview content may be prioritized.
- The interview may be pruned for length.
- The interview may be pruned for manageability.
- The structure of the interview may be adjusted.
- The mode of recording for the interview may be changed or determined.

- Interview Administration Process

McNamara (2007) presents general steps for conducting the actual interview. Based on these steps, the process for administering the interview is presented.

- i. Explain the purpose of the interview.
- ii. Explain terms of confidentiality and anonymity of responses.
- iii. Explain the format of the interview.
- iv. Indicate the expected duration of the interview.
- v. Provide personal contact details.
- vi. Ask if there are any questions or concerns that pertain to the interview prior to starting.
- vii. If applicable, ask for permission to audio or video record the interview.
- viii. Ask questions indicated on the interview guide.
- ix. Record the interviewee's responses and probe for additional details.
- x. Thank the interviewee.

## 6. Transcribe and analyze interview data.

- Transcription

Transcription is the process of converting recorded material into text, and therefore, is usually a necessary precursor to commencing the analysis of interview data (King and Horrocks, 2010). There are a number of transcription decisions and features that can have an impact on interview data analysis. These are briefly discussed.

- Types and Systems of Transcription
  - Full or partial transcription: A full transcription constitutes a more sizeable investment of time and effort (King and Horrocks, 2010). This also applies to the analysis of a full transcription. Based on feasibility and the availability of time, a researcher can select between partial and full transcription.
  - Systems of transcription: Transcription systems seek to capture every aspect of an interview. These systems utilize different approaches to represent interview features such as emphasis, pauses and interruptions among many others (King and Horrocks, 2010). The researcher or interviewer should utilize a system that is applicable and effective for transcribing his or her interviews.
- Threats to the Quality of Transcription
 

King and Horrocks (2010) suggest three main threats to the quality of transcription that need to be minimized. These are listed.

  - Poor recording quality
  - Missing context
  - Inaudible or unclear transcribed talk
- Thematic Analysis
 

Themes are recurrent and distinctive features of participants' accounts that characterize particular perceptions and/or experiences, which the researcher sees as relevant to the research question (King and Horrocks, 2010).

  - Considerations for Thematic Analysis
 

King and Horrocks (2010) discuss a number of issues that need to be considered and/or addressed in conducting a thematic analysis. These are presented.

    - Balancing within-case and cross-case analysis: If within-case aspect is neglected, themes are treated as abstract notions detached from the particularities of personal experience. If cross-case analysis is not properly developed, a disjointed collection of case studies is likely to be produced. Both would not allow the thematic analysis to effectively address the research question.
    - Organizing themes: The researcher is required not only to produce a list of themes but also to organize those themes in a way that reflects how they are conceptualized to relate to each other.

- Balancing clarity and inclusivity: Themes have to be well defined and distinct and the thematic structure clear and comprehensible. Clarity and inclusivity can be conflicting to some extent. The balance between them should depend on the nature of the study and the kind of output being produced.
  - Auditability: Part of the process of thematic analysis includes demonstrating how themes were developed and how the final thematic structure was arrived at. This auditability means that a researcher must keep a record of all the major stages in developing and organizing his/her themes.
- Process of Thematic Analysis
- King and Horrocks (2010) break down the thematic analysis process into a series of stages.
- Stage One: Descriptive Coding  
The emphasis of this stage is to describe what is of interest in the participants' accounts. Coding involves a systematic recording of data. Descriptive and/or numeric codes can help organize responses. There are three main steps in this stage.
    - i. Read through and familiarize with interview transcript.
    - ii. Highlight anything in the transcript that might help in understanding the participant's views, experiences and perceptions as they relate to the topic under investigation and to write a brief comment on items of interest in the highlighted text.
    - iii. Use preliminary comments to define descriptive codes.
  - Stage Two: Interpretative Coding  
At this stage, the researcher defines codes that focus on the interpretation of participants' accounts. This is done by grouping together descriptive codes with common meanings and creating an interpretative code to capture the meanings.
  - Stage Three: Defining Overarching Themes  
At this stage, a researcher identifies a number of overarching themes that characterize key concepts in his/her analysis. These should be built upon the interpretative themes but at a higher level of abstraction.

- **Alternative Styles of Thematic Analysis**  
King and Horrocks (2010) identify two alternative styles of thematic analysis. These are discussed.
  - **Template Analysis**  
This approach involves the construction of a coding structure or template that is applied to the interview data and revised as necessary until it captures the analyst's understanding to an adequate extent (King and Horrocks, 2010). Template analysis has a number of characteristics. These are listed.
    - It does not stipulate a fixed number of hierarchical coding levels.
    - It does not systematically differentiate between descriptive and interpretive coding.
    - It allows the researcher to define some themes in advance of the analysis process. These are referred to as priori themes.
    - It can be used with any size of study. It is especially well suited to projects with a multitude of lengthy interviews.
  - **Matrix Analysis**  
This approach involves the use of visual displays of data, which typically tabulate units of analysis such as individual participants, groups, organizations against key concepts or issues relevant to the research questions of a study (King and Horrocks, 2010). These displays help the researcher to analyze the data and also help to make the process transparent. Matrix analysis has a number of characteristics. These are presented.
    - It involves defining thematic areas. This refers to the concepts, issues and behaviors into which the data relating to each case on the matrix are organized.
    - It uses thematic coding. This is through the identification of material to enter into the cells of the matrices.
    - It is useful where there is a large and complex data set. The approach is especially useful where the research design involves comparisons between sites, organizations or groups.
- **Writing-Up a Thematic Analysis**  
The most common way of organizing a report on the findings of thematic analysis is to describe and discuss each of the

overarching themes while referring to examples from the data and using direct quotes to help characterize the theme for the audience (King and Horrocks, 2010).

- Assessing the Quality of Interviews and their Data  
The universally recognized criteria for assessing the quality of analysis in any study are reliability and validity (King and Horrocks, 2010). Reliability is concerned with how accurately any variable is measured while validity is concerned with determining whether a particular form of measurement actually measures the variable it claims to. McNamara (2007) and King and Horrocks (2010) present a number of approaches for assessing the quality of interviews and their data. These are presented.
  - Check representativeness of interviewees/participants
  - Assess reliability of participants
  - Check interviewer or investigator bias
  - Check for negative evidence
  - Get feedback from interviewees/participants
  - Use of independent coding and expert panels
  - Use of detailed description and audit trails
  - Triangulation; this is the use of multiple methods of data collection or multiple sources of data to study a particular phenomenon. Triangulation types are listed.
    - Data triangulation
    - Methodological triangulation
    - Investigator triangulation
    - Theory triangulation
- Steps for Analyzing Interview Data  
McNamara (2007) presents the steps for analyzing interview data. These are indicated.
  - i. Prepare interview summary sheets.
  - ii. Perform descriptive and interpretative coding of interview data.
  - iii. Develop simple storage and retrieval system for interview data organized according to the codes.
  - iv. Condense information and present it in a clear format that highlights underlying relationships and trends. Such visual displays as tables, boxes and figures can be utilized.

### **3.2.3 Relational Database Application**

A database is a collection of data (Whitehorn and Marklyn, 2007). A database management system (DBMS) is the controlling software of a database. There are numerous ways in which data can be managed or modeled. Three of such models include hierarchical, network and relational models. However, the most

widely utilized is the relational model (Whitehorn and Marklyn, 2007). Dr. Edgar Codd is generally credited with developing the original idea for the relational database in 1970 (Whitehorn and Marklyn, 2007). The relational model uses a collection of tables to represent both data and the relationships among those data (Sumathi and Esakkirajan, 2007). A relational database stores data in a relation. A relational database management system (RDBMS) is a program that enables the creation, updating and administration of relational databases (Reynolds, 2004). After all, part of the reason for building databases is to simplify the interface that the user encounters (Whitehorn and Marklyn, 2007). A RDBMS is essentially a DBMS that adheres to the relational model (Whitehorn and Marklyn, 2007). Examples of RDBMSs include Access, SQL Server, MySQL, Informix, Sybase, Oracle and DB2 among many others.

#### **3.2.3.1      Basic Components of a Database**

The relational model provides the mechanisms needed to store and manipulate complex data in a way that ensures that it can be queried later and answers can be yielded as needed (Whitehorn and Marklyn, 2007). Whitehorn and Marklyn (2007) identify the basic components of a database. These are briefly discussed.

1. **Tables:** This is a repository for data. Tables are the basic structures in which data is stored within a database. Tables consist of rows/records (horizontal) and columns/fields (vertical). One enters data according to the table structure.
2. **Queries/views:** These are used to extract, subset, and summarize data from the table and to update the table. Queries are questions that one can ask of the data in a table. The answers are typically presented in a table and could also involve mathematical operations. These answer tables summarize data and therefore the parts should not be editable. Graphical querying tools and/or structured querying language (SQL) can be utilized in the querying process.
3. **Forms:** These are devices for viewing and entering data into the table. This is the interface through which users gain access to the data in a database. It is possible to create one or more forms per table. Text boxes can be placed in a form which show the data from one field or which combine and manipulate the data from more than one field. Not all fields have to be represented on a form and text boxes can be made read-only. Finally, the access that a user has to the set of forms can be controlled.
4. **Reports:** These are used to print out some or all of the data in the table. Reports can also present outputs of queries in a structured format.

### **3.2.3.2**      Single versus Multiple Tables

According to Whitehorn and Marklyn (2007), there are serious problems with single tables when used for storing complex information. Firstly, there is redundant data which makes the table large, slow and unwieldy. Secondly, there are typographic errors caused by typing the same information multiple times. Lastly, there are difficulties in updating and modifying data. Through the use of multiple tables, this complex data can be stored and manipulated more effectively.

### **3.2.3.3**      Key Considerations in building Databases

Whitehorn and Marklyn (2007) identify five key areas or questions which need to be considered before building a database.

1. How is information about the different objects to be stored in the database?

This can be addressed by providing a separate table for each class of object for which information is to be stored in the database.

2. What relationships can exist between real world objects?

There are four possible kinds of relationship between any given pair of objects. These are listed.

- One-to-many Relationship
- One-to-one Relationship
- Many-to-many Relationship
- None

3. How are these relationships modeled and maintained in a database?

There are two main tools used to model relationships in a database namely, keys and joins.

- Keys

There are two main types of keys.

- **Primary Key:** Primary keys are defined as part of the table structure. A primary key consists of one or more keys. Every table in a relational database must have a primary key. Values in the primary key must be unique and they cannot be left blank.
- **Foreign Key:** Foreign keys are defined when a join is made. Foreign keys are not essential requirements for each table. However, if a relationship exists between two tables, one of those tables will have a foreign key in which the values are drawn from the primary key of the other table. There can be multiple foreign keys in a table.

- Joins

Joins are the important elements that go into creating and maintaining relationships between tables.

The process of modeling a join includes the creation of a table for each class of object. This is followed by the selection and entry of appropriate primary keys in the tables. This is then followed by the selection and entry of foreign keys in the related tables which must be of the same field type as the primary key referenced. The intended join is then specified in the RDBMS. There are three types of joins. These are applicable to the different types of relationships between tables.

- One-to-many Joins: This join requires a primary key and a field set up to be a foreign key on a table. These foreign keys should be primary keys of tables at the 'many' end of the relationships. One-to-many joins are very common.
- One-to-one Joins: This join goes from a primary key in one table to a foreign key in the other. The only difference is that the foreign key in the second table is not allowed to contain duplicate values. One-to-one joins are uncommon.
- Many-to-many Joins: There is no special mechanism for making many-to-many joins. This join is built from two one-to-many joins. Multiple primary keys may be essential in a linking table. Many-to-many joins are very common.

4. How can the tables, forms, queries and reports be developed to work together in a database?

This can be achieved through closure. Closure can be defined as the relational property that the answer to a query is a full and proper table in its own right. Closure is an important part of the relational model particularly considering a form is based on the answer table from a query. Queries are perfectly capable of pulling together the information needed from different tables. In a relational database, it is imperative that the answer tables generated by queries must not only look like base tables but must have the same behavior as base tables. The queries also have to allow forms and reports to be based upon them without issue.

5. How can integrity be maintained within data that is stored in a database?

Data integrity is a general term which refers to several processes that attempt to keep the data in the database error-free. Whitehorn and Marklyn (2007) recommend adequate integrity and accuracy levels to exceed 95% for data entered in the database.

- Types of Integrity Error

There are four types of integrity errors that can occur in a database. Precautions and measures must be taken to prevent their occurrence.

- Errors in unique data within a single field
  - Errors in standard data within a single field
  - Errors between data in different fields
  - Errors between keys in different tables affecting referential integrity
- Referential Integrity
- Referential integrity is intended to keep the values in primary and foreign keys in synchronization. There are a few issues to consider in this regard. These are briefly discussed.
- Declarative and Procedural Referential Integrity Approaches  
In the case of a declarative approach, the database designer declares to the database engine that referential integrity be enforced from then on. In the procedural approach, the database designer defines the specific procedures in order to manually enforce referential integrity. The declarative approach is most commonly used.
  - Different Approaches/Flavors of Declarative Referential Integrity  
Whitehorn and Marklyn (2007) identify several different flavors of referential integrity that are offered by most database engines. These different flavors are necessary for model accuracy. In a database, two or more of the flavors can be set as appropriate, applicable and compatible. The flavors are briefly discussed.
    - On Delete Cascade: In this case, when a record is deleted from a parent table then all of the records in the child tables that reference it are also automatically deleted.
    - On Delete Set Null: In this case, a record is deleted from a parent table without deleting the records in the child tables that reference it.
    - On Delete No Action: This is the standard referential integrity where a parent record cannot be deleted without manually deleting all the child records first.
    - On Update Cascade: Here, changes or updates to a parent record cascade down to the child records.
    - On Update Set Null: Here, when the parent value is updated then foreign key values in the child records are set to null or to a chosen default value.
    - On Update No Action: Here, if changes or updates are made in existing records and the new value that appears in the foreign key is not one that already exists in the primary key field, the change is refused.

- Integrity and Security Issues

In applying data integrity mechanisms, the database designer is usually trying to protect the data from the users of the database. RDBMSs often provide other security mechanisms which can be used in conjunction with data integrity mechanisms (Whitehorn and Marklyn, 2007). User access to a database can be limited. Access is often limited to just forms while access is often denied to the base tables. Users are also often denied the ability to create new forms. A database is considered to be composed of layers with base tables at the bottom, queries in the middle and forms at the top. In some cases, forms are based on the base table (Whitehorn and Marklyn, 2007). Integrity rules, checks and controls should be applied in a manner to ensure that they cannot be subverted and the workload required in maintaining the database is kept at a minimum. As such, data integrity controls are best applied at the table level whenever possible because this makes them more difficult to subvert (Whitehorn and Marklyn, 2007).

#### **3.2.3.4      Database Design and Architecture**

The process of database design is typically separated into three different layers (Whitehorn and Marklyn, 2007). These are briefly discussed.

- User Model

This is the model that holds the view of what the users want from the database. This is an extremely non-technical view that is simply concerned with functionality and is not expressed in any formal way.

- Logical Model

The logical model is a formalization of the user view that captures all the functionality that the users want, but is expressed in a much more formal way. It is also true to say that the logical model is a model of the way in which the user processes and manages data. Computer-Aided Software Engineering (CASE) tools have been developed to help in creating logical models. These tools allow database designers to automatically generate database schemas. A database schema is a complete database description expressed in a formal language such as SQL. Logical models can be developed by acquiring existing data that users may already have collected. This is by normalization. Additionally, reverse engineering can be utilized. There are several methodologies of representing information in a logical model. Information Engineering (IE) and IDEF1X (Integration DEFinition for Information Modeling) are two of such methodologies.

- **Physical Model**  
The physical model encapsulates the information from the logical model and adds the detail necessary to fit it to a particular data model such as the relational model. This will include deciding on table names, data types, indexing considerations and so on.

## **Constructing a Database Application**

According to Whitehorn and Marklyn (2007), a database application can be thought of as being constructed from seven layers. These are presented.

- **Layer 1: User Interface**  
This is part of the application that contains the forms with which the user interacts. These display information, prompts, provide data and help allow the entry of information and control the activities undertaken. Building a user interface and controlling data entry at the form level are typically accomplished in one of three ways. Through using GUI (Graphical User Interface), macro language or programming language. GUIs are considered easiest to use but the least powerful while programming language is considered most difficult to learn but the most powerful (Whitehorn and Marklyn, 2007). Macro language lies between the two in difficulty and power.
- **Layer 2: Input Validation**  
This is the checking of the data as it is input to ensure that the data is of the correct form and type.
- **Layer 3: Application Tasks**  
These are specific application functions such as calculations that are applied during data retrieval. These manipulations do not permanently affect or alter the data in the database.
- **Layer 4: Requirements and Rules**  
These check for adherence to specific rules. This type of validation is often performed on the data in an entire record rather than on a specific field. Also, the checks are typically performed after the data has been entered into the form.
- **Layer 5: Data Integrity Rules**  
These are the rules that ensure that the integrity of the data as a whole is not compromised.
- **Layer 6: Data Management**  
This is the element that organizes, queries, manages and generally, manipulates the data.

- Layer 7: Data Storage  
This is where the data is actually stored and accessed. Examples of these are the computer hard-disk and servers.

## **Database Architecture**

The architecture of a database system defines its structure (Sumathi and Esakkirajan, 2007). Database architecture essentially describes the location of all the elements that constitute the database application (Whitehorn and Marklyn, 2007).

- Types of Database Architecture
  - Stand-alone (Single-tier) Architecture  
In this architecture, the entire database is developed on a personal computer (PC) and is used there. This is an excellent solution for allowing single user access to a set of data (Whitehorn and Marklyn, 2007).
  - Client-server (Two-tier) Architecture  
In this architecture, the user interface is written as an executable application and runs on the PC while the data, the processing and the conflict resolution moves to a database server (Whitehorn and Marklyn, 2007). This model is very commonly employed, particularly with database engines such as MySQL and SQL Server.
  - Multi-tier (Three-tier) Architecture  
The classic three-tier architecture inserts a tier in between the client and the server. The middle tier is there to hold interface information such as the code and data that make up the user interface and input validation (Whitehorn and Marklyn, 2007). The function of the middle tier can be adapted as appropriate for the database requirements.
  - Web-based Applications  
The web model works well with databases. Once a web server is introduced into the architecture, it is that server which communicates to the database server. The user runs browser software and that browser, communicates with the web server. The user therefore does not communicate directly with the database server in the case of web-based database applications (Whitehorn and Marklyn, 2007).

- **Selecting a Database Architecture**  
Database architecture should be designed and/or selected in a manner to serve as the most effective solution for a given situation. The selection should be based upon the interaction of a number of factors (Whitehorn and Marklyn, 2007). These are listed.
  - Number of users
  - Data size
  - Type of data access required (read-only, read-write)
  - Response time required
  - Available resources (including hardware, software and finances)
  - Expertise of database designer

## **Relational Database Topics and Issues**

- **Codd's Rules**  
Dr. Edgar Codd supplied a set of rules with which a DBMS should comply if it is claimed to be fully relational (Codd, 1985). These rules are presented.
  - **Rule 0: The Data Management via Relational Capability Rule**  
For any system that is advertised as, or claimed to be, a relational database management system, that system must be able to manage databases entirely through its relational capabilities.
  - **Rule 1: The Information Rule**  
All information in a relational database is represented explicitly at the logical level in exactly one way—by values in tables.
  - **Rule 2: The Guaranteed Access Rule**  
Each and every datum (atomic value) in a relational database is guaranteed to be logically accessible by resorting to a table name, primary key value, and column name.
  - **Rule 3: Systematic Treatment of Null Values**  
Null values (distinct from empty character string or a string of blank characters and distinct from zero or any other number) are supported in the fully relational DBMS for representing missing information in a systematic way, independent of data type.
  - **Rule 4: Dynamic On-line Catalog Based on the Relational Model**  
The database description is represented at the logical level in the same way as ordinary data, so authorized users can apply the same relational language to its interrogation as they apply to regular data.

- Rule 5: Comprehensive Data Sublanguage Rule  
A relational system may support several languages and various modes of terminal use (for example, the fill-in-blanks mode). However, there must be at least one language whose statements are expressible, per some well-defined syntax, as character strings and whose ability to support all of the following is comprehensible: data definition, view definition, data manipulation (interactive and by program), integrity constraints, and transaction boundaries (begin, commit, and rollback).
- Rule 6: View Updating Rule  
All views that are theoretically updateable are also updateable by the system.
- Rule 7: High-level Insert, Update, and Delete  
The capability of handling a base relation or a derived relation as a single operand applies not only to the retrieval of data but also to the insertion, update, and deletion of data.
- Rule 8: Physical Data Independence  
Application programs and terminal activities remain logically unimpaired whenever any changes are made in either storage representation or access methods.
- Rule 9: Logical Data Independence  
Application programs and terminal activities remain logically unimpaired when information preserving changes of any kind that theoretically permit un-impairment are made to the base tables.
- Rule 10: Integrity Independence Rule  
Integrity constraints specific to a particular relational database must be definable in the relational data sublanguage and storable in the catalog, not in the application programs. A minimum of the following two integrity constraints must be supported:
  - i. Entity integrity: No components of a primary key are allowed to have a null value.
  - ii. Referential integrity: For each distinct non-null foreign key value in a relational database, there must exist a matching primary key value from the same domain.
- Rule 11: Distribution Independence  
A relational DBMS has distribution independence. Distribution independence implies that users should not have to be aware of whether a database is distributed.

- Rule 12: Nonsubversion Rule  
If a relational system has a low-level (single-record-at-a-time) language, that low-level language cannot be used to subvert or bypass the integrity rules or constraints expressed in the higher-level (multiple-records-at-a-time) relational language.
- Triggers and Stored Procedures  
The defining feature of a trigger is the fact that it is attached to a table and cannot be subverted. If an operation sets off the trigger, there's nothing the user application can do to stop the trigger from firing (Whitehorn and Marklyn, 2007). Meanwhile, stored procedures can provide the ability to perform useful operations in a standardized manner for any user application with the necessary permissions (Whitehorn and Marklyn, 2007). Stored procedures are easy to run and to maintain. Familiarity with using both triggers and stored procedures is useful for developing effective database systems.
- Domain  
A domain is a pool of values from which the values found in a given field in a particular table can be drawn (Whitehorn and Marklyn, 2007). Domains are a safety mechanism as they are intended to prevent later users of the database from unfortunate errors. Domains can contain both alphabetical and numerical values (Whitehorn and Marklyn, 2007).
- Normalization  
Normalization is defined as a series of levels or forms (Whitehorn and Marklyn, 2007). This process is useful as tables become more complex to a stage where there is difficulty in deciding which fields go into which tables. Failure to normalize tables brings the threat of reduced data integrity and may result in a scenario where requested information cannot be correctly generated. It is however important to note that normalization does not automatically remove all redundancy (Whitehorn and Marklyn, 2007).
  - Forms of Normalization  
The first three forms of normalization are considered most important and are briefly discussed (Whitehorn and Marklyn, 2007).
    - First Normal Form (1NF): This is mainly concerned with basic table structure. The table must have a primary key and there must be no columns that store the same kind of data.
    - Second Normal Form (2NF): This is concerned with the relationship between columns in the primary key and those in the rest (the body) of the table. The table must already be in 1NF.
    - Third Normal Form (3NF): This is concerned with the relationships within the body of the table. Columns in the body of the table must not be dependent upon each other. The table must already be in 1NF and 2NF.

- Terms in Normalization

Whitehorn and Marklyn (2007) discuss a number of general terms used in the normalization process. These are briefly presented.

- Atomic data: This is a formal way of saying that tables must not contain repeating information either within or between columns.
- Primary keys, table body, keyed and non-keyed attributes: Columns that are not primary keys form the body of the table. Foreign keys are treated as part of the table body. Keyed attributes refer to the columns that make up the primary key while the rest are referred to as non-keyed attributes.
- Functional dependency: Foreign keys establish a dependency between the parent record and child record. This type of dependency is known as functional dependency.
- Transitive dependency: This is an indirect type of dependency where the dependency of a foreign key on a primary key is reliant on another dependency.
- Lossless decomposition: The process of breaking down one table into multiple tables is known as decomposition. If all the information that was in the original table is preserved, the process is referred to as lossless decomposition.
- Requirement definition: This formally describes the requirements that a database has to meet.
- Modification anomalies: The purpose of normalization is to eliminate modification anomalies. There are three types of modification anomalies and they serve to limit the flexibility and selectivity of certain table actions. These include insert, update and delete.

- Data Manipulation and Relational Operators

Data manipulation is a vital part of the relational model. This is part of querying. Querying as well as SQL is based upon the use of relational operators (Whitehorn and Marklyn, 2007). The operators and their functions are stated.

- Operators that operate on single tables
  - Restriction: This extracts rows.
  - Projection: This extracts columns.
- Operators that operate on two tables
  - Union: This adds the rows from two tables.
  - Difference: This subtracts the rows in one table from those in another.
  - Intersection: This locates the rows that are common to two tables.
  - Product: This multiplies the rows in the two tables.
  - Join: This both multiplies and restricts the rows in two tables.

- Divide: This extracts rows and columns from one table on the basis of data in the second.
- Standard Querying Language (SQL)

SQL is a database computer language designed for managing data in RDBMSs (Oppel and Sheldon, 2008). SQL statements are by convention written in uppercase. The statements generally represent the function they perform.

  - Parts of SQL

SQL has two parts (Whitehorn and Marklyn, 2007), Data Definition Language (DDL) and Data Manipulation Language (DML).

    - DDL is used to create, modify or delete database objects such as tables, triggers and stored procedures (Oppel and Sheldon, 2008). The SQL keywords most often associated with DDL statements are provided.
      - CREATE
      - ALTER
      - DROP
    - DML is used to access and manipulate data in existing database objects (Oppel and Sheldon, 2008). The SQL keywords most often associated with DML statements are provided.
      - SELECT
      - INSERT
      - UPDATE
      - DELETE
  - Functions in SQL

There are a multitude of functions used in SQL (Whitehorn and Marklyn, 2007). Some of these are presented.

    - Statement Functions
      - FROM
      - WHERE
      - BETWEEN
      - AND
      - OR
      - IN
      - LIKE
      - DISTINCT
      - ORDER BY
      - GROUP BY
    - Statistical Functions
      - SUM
      - COUNT
      - AVG
      - MIN
      - MAX

## Strategies for Enhancing a Database

There are two main ways through which a database can be made faster; improving the hardware and/or the software (Whitehorn and Marklyn, 2007). Excerpts from Whitehorn and Marklyn (2007) are used to briefly discuss the hardware and software considerations.

- Hardware Considerations
  - CPUs: Add more CPUs to the box, move to a box with faster CPUs, turn the database server into a cluster and/or add more nodes if already clustered.
  - Memory: Match the size of the database with that of the memory. This memory refers to RAM (Random Access Memory).
  - Disks: Disks should be in stacks that offer adequate speed and redundancy to match the database for adequate read performance.
  - Data volume and disk capacity: The volume and capacity of the disks should be sizeable to match the database and enhance the speed of reading the data.
- Software Considerations
  - Indexing: Indexes can speed up the access to data by several orders of magnitude. An RDBMS can efficiently manipulate any set of sorted values and therefore, find data much more rapidly. A database engine searches a sorted list through several ways but the most common way is the binary chop. There are two different flavors of index including clustered and non-clustered. The clustered index works by actually moving the rows on disk so that they are physically stored in sorted order. This speeds up access to the data. Though a little slower than clustered indexes, non-clustered index also speed up access to the data. However, their big advantage is there can be as many as desired on a single table. All RDBMS allow the selection of fields/columns to be indexed. The most effective selection is the primary key followed by heavily used columns and then foreign keys.
  - Query analysis and optimization: Many database engines come with tools such as query analyzers and query optimizers. These can be used to serve as investigative tools that determine the optimal execution plan for queries. These can then be implemented to enhance the software for the RDBMS.
  - De-normalization: This is the process of converting a normalized database to one where some or all of the tables are not in 3NF. This is appropriate to enhance speed particularly in large databases. There are several types of de-normalization namely mirroring tables, splitting tables, repeating groups, deriving columns, and the creation of a redundant data column.

### **3.2.4 Validation of Research**

Validation is a process that evaluates the correctness or credibility of a description, conclusion, explanation, interpretation, or other sort of account (Maxwell, 2005). Validation is the process of establishing validity. Validity is the term most often used to judge the quality or merit of a particular study (Maxwell, 2005). Validity is generally acknowledged to be a key issue in research design (Maxwell, 2005).

Individual data collection measures may have procedures for establishing their validity. This section concerns research validity. Research validity is the validity of a whole study in contrast to the validity of a single measure or instrument (Gliner and Morgan, 2000). Research validity depends on the relationship of research data and conclusions to reality (Maxwell, 2005). There are several dimensions and threats to validity and also, approaches for validity testing.

#### **3.2.4.1 Dimensions and Threats to Validity**

Gliner and Morgan (2000) and Creswell (2009) divide research validity into four main dimensions and/or threats. These are briefly defined and discussed.

- 1. Internal Validity**

This is the extent to which the results of a study can be attributed to the treatments rather than to flaws in the research design. Internal validity also refers to the degree to which one can draw valid conclusions about the causal effects of one variable on another (Gliner and Morgan, 2000).

Threats to internal validity are experimental procedures, treatments, or experiences of the participants that threaten the researcher's ability to draw correct inferences from the data about the population in an experiment (Creswell, 2009).

- 2. External Validity**

This deals with the question of generalizability. It has two aspects, population and ecological. Population refers to sample representativeness while ecological refers to the naturalness of the research setting and process (Gliner and Morgan, 2000). Threats to external validity arise when experimenters draw incorrect inferences from the sample data to other persons, other settings, and past or future situations. Essentially, these threats arise because of the characteristics of individuals selected for the sample, the uniqueness of the setting, and the timing of the experiment (Creswell, 2009).

- 3. Measurement Validity and Generalizability of the Constructs**

This is an assessment of how well an instrument measures a construct for a given purpose in a given population (Gliner and Morgan, 2000). Threats to measurement and construct validity occur when investigators use inadequate definitions and measures of variables (Creswell, 2009).

#### 4. Measurement Reliability and Statistics

This is the extent to which a measurement is consistent. There are four types of reliability indexes which include test-retest, parallel forms, internal consistency, and interrater. Each provides different information about the reliability or consistency of a measure or test (Gliner and Morgan, 2000).

Threats to measurement reliability and statistics arise when experimenters draw inaccurate inferences from the data because of inadequate statistical power or the violation of statistical assumptions (Creswell, 2009).

#### 3.2.4.2 Approaches for Validity Testing and Validation

Validity has to be assessed in relationship to the purposes and circumstances of the research rather than being a context-independent property of methods or conclusions (Maxwell, 2005). Thus, a validation approach must be appropriate and applicable to a research study and its deliverables. Maxwell (2005) presents a number of approaches for validity testing and validation which are intended to address the different threats and/or dimensions to validity. These are briefly discussed.

##### 1. Intensive Long-term Involvement

Repeated observations and interviews and also, the sustained presence of the researcher in the setting studied can aid in ruling out spurious associations and premature theories. They also allow a greater opportunity to develop and test alternative hypotheses during the course of the research (Maxwell, 2005).

##### 2. Intervention

In field research, the presence of the researcher is always in some way, an intervention. The effects of the researcher's presence can therefore be used to develop or test hypotheses about the group or topic being studied. In studies that lack a formal treatment, this experimental manipulation may be useful. Where this approach is utilized, it is imperative the researcher provides a full account of the process by which changes occurred from the specific intervention (Maxwell, 2005).

##### 3. Respondent Validation

Respondent validation is systematically soliciting feedback about research data from the respondents or specific sample studied. Maxwell (2005) considers this approach most important for ruling out the possibility of misinterpreting the meaning of participants' responses. This approach can also effectively serve to identify the researcher's biases and misunderstandings of what he/she observed or recorded (Maxwell, 2005).

4. Rich Data

Rich data refers to data that are detailed and varied enough that they provide a full and revealing picture of the research topic. For example, in observation studies, rich data are the product of detailed and descriptive recording of relevant events. Meanwhile, in interview studies, rich data will typically include verbatim transcripts and recording (Maxwell, 2005).

5. Triangulation

Triangulation involves collecting information from a diverse range of individuals and settings, using a variety of methods. This approach reduces the risk of chance associations and of systematic biases due to a specific method, and allows a better assessment of the generality of the researcher's explanations and conclusions (Maxwell, 2005).

6. Comparison

Explicit comparisons of collected data can be very useful in assessing validity threats particularly in detailed multi-case and multi-site studies. This is important considering that in-depth studies in single settings and of relatively homogeneous samples often incorporate less formal comparisons that contribute to the interpretability of the results. Other forms of comparison often used in research include those between intervention and control groups and those of the same setting but at different times (Maxwell, 2005).

7. Searching for Discrepant Evidence and Negative Cases

A key part of the logic of validity testing is identifying and analyzing discrepant data and negative cases. Important defects in an account can be determined from instances that cannot be accounted for by a particular interpretation or explanation. This validation approach requires the researcher to rigorously examine both the supporting and the discrepant data to assess whether it is more plausible to retain or modify the conclusion (Maxwell, 2005).

8. Quasi-Statistics

Quasi-statistics refer to the use of simple numerical results that can be readily derived from study data. Quasi-statistics allow the researcher to test and support claims that are inherently quantitative. This approach also enables the researcher to assess the amount of evidence in the data that bears on a specific conclusion, such as the number of discrepant instances that exist and the different sources from which they were obtained (Maxwell, 2005).

### **3.3 Research and Validation Approach**

The objective of this research is to improve DFCS implementation. I determined a number of deliverables to serve towards this purpose. The deliverables, provided in *Section 1.2.2*, were to be produced through a defined research approach. This approach was also to serve in validating the deliverables. One could deduce from the deliverables that the research was primarily qualitative in nature.

A number of validation approaches were discussed in *Section 3.2.4.2*. Many of these were infeasible or inapplicable to this research. Intensive long-term involvement and intervention were infeasible on the basis of time and also inapplicable because researcher presence in the study setting may not have been fruitful given that DFCS is an emerging area with currently limited application. Also, as this research is mostly qualitative, the use of quasi-statistics was inapplicable. Additionally, this research mostly involved data collection and as such, even data that are discrepant were to be accumulated. On this basis, there could not be negative cases. Thus, searching for discrepant evidence and negative cases were inapplicable for validation in this research.

The research approach involved the collection of data from different AEC design professionals in different settings with regards to different DFCS measures. This coupled with the fact that data was to be indiscriminately collected made comparisons inapplicable as a validation approach for this research. Furthermore, the research scope did not involve testing strategies or experimenting with changes on any ongoing capital projects. There was therefore limited basis for comparison. It is also important to note that testing on construction projects was within reason, infeasible for this research.

Using rich data for validation was also inapplicable for this research. This was because the research was targeted at obtaining certain specific information for a multitude of DFCS measures. Essentially, this validation approach was inapplicable because this research was based more on breadth than depth. Additionally, if the rich data approach was utilized despite the dissuasive breadth of the research, then it would likely have become infeasible with regards to scope and time.

Respondent validation is useful for clarifying participants' responses. The effectiveness of this approach in validating the research was limited for a number of reasons. Firstly, this research sought to obtain relatively short specific information on numerous DFCS measures. The selected data collection methods would adequately capture this information. Additionally, one data collection method, the survey, was likely to be self-reported. This significantly minimized the need for respondents' clarification. Maxwell (2005) stated that participants' feedback is not more inherently valid than their responses. For this reason, the value of this validity testing approach was considered minimal. Another

consideration was feasibility with regards to time. I did not believe this approach would have justified its use of time as one could neither be certain of respondent feedback rate nor time. Lastly, this approach typically does not add new information and since this was primarily data collection type research, this would not have been of value. For these many reasons, respondent validation was not to be utilized in this research.

The remaining validation approach, triangulation, was considered both applicable and feasible for this research. Triangulation involves collecting information from a variety of sources and methods to reduce the risk that conclusions will reflect only the systematic biases or limitations of a specific source or method (Maxwell, 2005). Surveys and interviews were selected as appropriate data collection methods for this research. Where two separate methods are used for research and for validation of certain data, this is termed methodological triangulation. In the interest of performing methodological triangulation, surveys and interviews were to be used separately for research and validation. Interviews can be effectively used to check the accuracy of other data collection methods (Maxwell, 2005). Additionally, when questions pertain to specific events and/or actions, interviews can be very useful for triangulation (Maxwell, 2005). For these two reasons, interviews were to be primarily used for validation while surveys were to be primarily used for research.

Another type of triangulation that was to be utilized is data triangulation. Expectedly, this is when two separate data sources are used for research and for validation of certain data. Therefore, the survey respondent who provided certain data was not to be the interviewee that validated the data. This also applied to me, the researcher. I was not to validate my own individual research work. Thus, my individual research data was to be validated through the surveys or interviews of AEC design professionals.

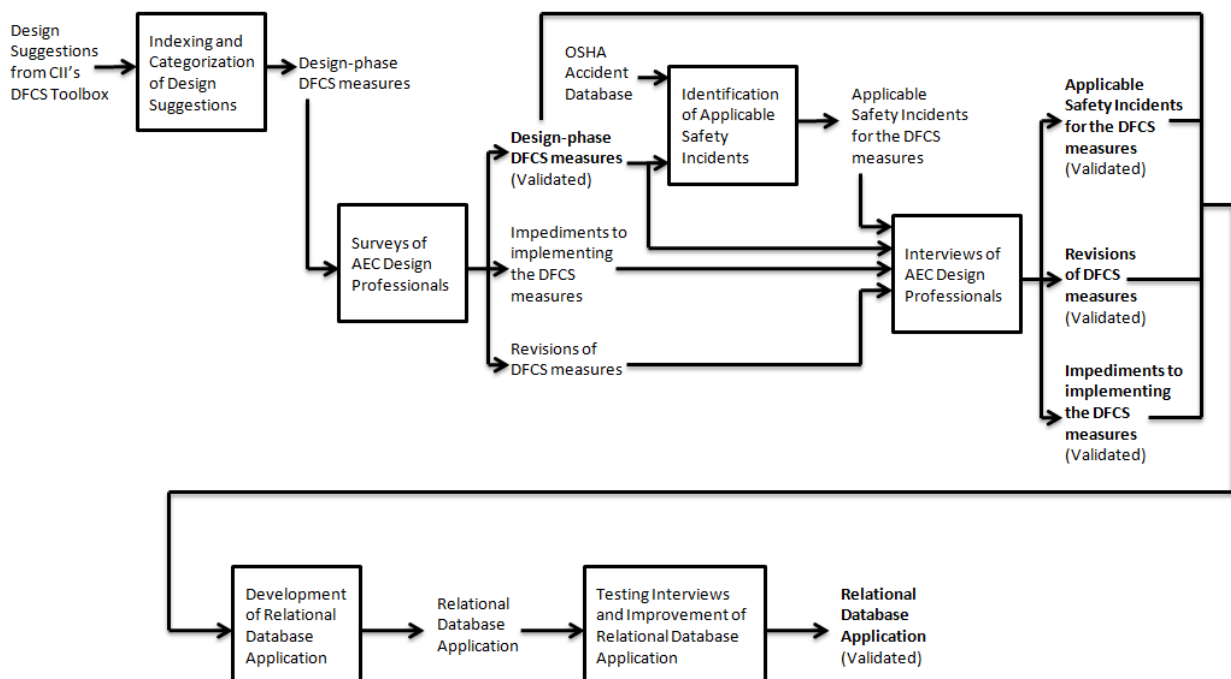
Marshall and Rossman (2006) emphasized the need for examining data collection methods and fitting them to research questions and/or deliverables. It was also stated that researchers must consider their own personal abilities in carrying out any particular approach or method (Marshall and Rossman, 2006). On this basis, the research approach was further defined. Where data was to be sorted, interpreted or manipulated, I was to execute the research tasks. This also applied to tasks where data was to be utilized for other functions such as in the development of tools.

The research deliverables listed and discussed in *Section 1.2.2*, cascade in a sequential manner. As such, a waterfall approach was considered very appropriate for the research. With this and the aforementioned decisions or guidelines, I determined the research tasks and their placement based on feasibility with regards to scope and time. *Table 19* indicates the data collection and research methods from *Section 3.2* and their functions in producing and validating the deliverables.

	<b>Research Approach and Tasks</b>	
1.	<u>Research</u> : Indexing and Categorization of Design Suggestions from CII's DFCS Toolbox	
2.	Surveys of AEC Design Professionals To serve the following functions:	
	a.	<u>Validation</u> : Indexing and Categorization of Design Suggestions from CII's DFCS Toolbox
	b.	<u>Research</u> : Identification of impediments to successful implementation of DFCS measures that apply in the capital project design phase
	c.	<u>Research</u> : Revised DFCS recommendations based on the impediments to implementing the DFCS measures
3.	<u>Research</u> : Identification of Applicable Safety Incidents from the OSHA Database	
4.	Interviews of AEC Professionals To serve the following functions:	
	a.	<u>Validation</u> : Impediments to successful implementation of DFCS measures that apply in the capital project design phase
	b.	<u>Validation</u> : Revised DFCS recommendations based on the impediments to implementing the DFCS measures
	c.	<u>Validation</u> : Applicable Safety Incidents from the OSHA database
5.	<u>Research</u> : Development of Relational Database Application	
6.	<u>Validation</u> : Testing Interviews and Improvement of Relational Database Application	

**Table 19:** Research Approach and Tasks

*Figure 21* graphically presents the research approach indicating which products were to be utilized, produced and validated through the research tasks.



**Figure 21:** Research and Validation Approach

### 3.4 Research Feasibility

Feasibility requires that a researcher conducts a project with the financial resources available, with sufficient time and energy to complete the work and with the emotional capacity of researching the matter (Rubin and Rubin, 2005; Engel and Schutt, 2008 and Marshall and Rossman, 2006). Rubin and Rubin (2005) also indicated that many research limitations are practical such as distance or proximity to research subjects. Scope was also discussed as a research element that should be controlled to ensure feasibility. Research questions and approaches can thus be adjusted or modified in the interest of feasibility (Rubin and Rubin, 2005). Rubin and Rubin (2005) also stressed the importance of the researcher's capability in conducting research objectively.

Engel and Schutt (2008) also note that the individual researcher must take into account the constraints faced due to personal schedules and other commitments as well as his/her skill level. Additionally, a feasible research project is one where the researcher has access to the appropriate research subjects (Rubin and Rubin, 2005; and Engel and Schutt, 2008). Based on the aforementioned features of a feasible research project, the developed research and validation approach was determined to be feasible. This section discusses this DFCS research with regards to its feasibility.

#### 3.4.1 Availability of Time

In considering the feasibility of this research with regards to the availability of time, each of the research tasks was demonstrably executed. Based on this, I estimated the length of time that would be required to execute each research task. An additional but necessary research task was included. This was the documentation, submission and presentation of research work and dissertation. This would also require some time. The time estimation is seen in *Table 20*.

	Research Tasks	Estimated Time Requirements (Months)
1.	Indexing and Categorization of Design Suggestions from CII's DFCS Toolbox	1
2.	Surveys of AEC Design Professionals (Development + Execution)	1.5
3.	Identification of Applicable Safety Incidents from OSHA Database	1
4.	Interviews of AEC Design Professionals (Development + Execution)	2
5.	Development of a Relational Database Application	1.5
6.	Testing Interviews and Improvement of Relational Database Application	1
7.	Documentation, Submission and Presentation of Research Work and Dissertation	2
	<i>Total Time Requirement</i>	<i>10 months</i>

**Table 20:** Estimated Time Requirements for the Research

As the research tasks were mostly to be executed sequentially and not concurrently, the total time needs for the research was approximated as the total time required for all the research tasks. At 10 months, the research fit within the timeframe of typical PhD research. This was however not to be a rigid timeline. The actual time requirement was expected to prove either slightly less or more. Conclusively, this research was considered feasible with regards to my availability of time.

### **3.4.2 Availability of Financial Resources**

Marshall and Rossman (2006) identified major costs associated with research activities to include local travel, equipment, office supplies, books and subscriptions, printing and duplicating, and contracted services. With regards to local travel expenses, I own a vehicle. As such, the expense was to be in fuel cost. As for equipment, I had laptop computers with the necessary software for executing and/or documenting the research tasks. I also had access to office supplies. As for books and subscriptions, I had access to my university's libraries and online subscriptions. However, there could have been need for others and this would have come at an additional cost.

Also, while I owned a color laser printer and had access to printing and duplicating equipment at my university, there could still have been need for additional financial resources to serve the function. Lastly, while contracted services were not indicated for this research, they were to be utilized when and if required. I took all the aforementioned costs into account as I estimated the financial requirements for executing each of the research tasks.

Those research tasks I was to be executing were assumed to come at no cost. Only additional costs necessary to execute each research task were included in the financial requirements for the research. Here too, the documentation, submission and presentation of research work and dissertation is included as a research task. It would after all come at a cost. Contingencies were also included. The cost estimates for each of the research tasks are presented in *Table 21*. Based on the total financial requirement estimated, this research was determined to be feasible. I had availability of financial resources to cover for the estimated total amount of \$1,000.

### **3.4.3 Accessibility of Data Sources**

This research was determined to be feasible with regards to accessibility of data sources. The data sources for the research tasks included the CII's DFCS Toolbox, AEC design professionals, OSHA's Accident Database and also, DFCS literature.

The CII DFCS Toolbox had already been utilized as a data source as all the design suggestions were extracted and its operational features were assessed. With regards to accessing AEC design professionals, accessibility to this data source was also feasible. Firstly, I had access to the professionals' contact and background information through the internet, search engines and professional networking sites. Secondly, the particular research tasks were to be designed to elicit useful responses and to yield high response rates. Such strategies were to include the introductory email and provision of information such as affiliation and other important details. Also, practical limitations such as proximity were to be taken into account in the selection of the interview sample. Additionally, the feasibility of accessing this data source was to be demonstrated through pilot surveys and interviews.

OSHA's accident database is publicly accessible via the OSHA Statistics and Data website (<http://www.osha.gov/oshstats/index.html>). As such, this data source was accessible and could be effectively utilized in completing its associated research task. Thus, access to this data source was feasible. Lastly, there was adequate access to the research-related literature. As demonstrated throughout the research work, utilizing DFCS literature as a data source was feasible.

#### **3.4.4 Feasible Research Scope**

The scope of this research was considered feasible. All the research tasks were demonstrated to a small extent and based on the resources and effort utilized; I found the scope to be appropriate.

The primary concern with regards to the scope of this research had to do with the number of design-phase DFCS measures for which data was to be collected. This was to be determined by the end of the first research task. Where 120 design suggestions met the criteria of being design-phase DFCS measures, 20 survey versions were to be developed and where 180 met the criteria, 30 survey versions were to be developed. While this means a larger survey sample could be required, it does not make the scope less feasible as the research tasks could be designed and developed to accommodate such a scenario. For example, those design-phase DFCS measures with priority for evaluation through the research interviews could be those not earlier validated by data triangulation. By limiting the number of interviews and prioritizing the DFCS measures, the scope could be controlled.

The scope of research was also to be controlled to prevent scope creep. The focus of this research was on yielding the specified deliverables. Anything beyond or other than the deliverables was to be documented as recommendations for future research. After all, the deliverables were determined with feasibility taken into consideration.

	<b>Research Tasks</b>	<b>Financial Requirement</b>	<b>Basis / Reason</b>
1.	Indexing and Categorization of Design Suggestions from CII's DFCS Toolbox	\$0	I already collected the design suggestions from CII's DFCS Toolbox. I also had continued access to the software. And, I was to be carrying out the indexing and categorization. Thus, there was no anticipated financial requirement for this research task.
2.	Surveys of AEC Design Professionals (Development + Execution)	\$100	The survey was likely to be administered via a survey website. The cost was estimated at \$20 a month for a basic subscription. A 3 month subscription was intended but other costs were anticipated. Thus, the financial requirement indicated.
3.	Identification of Applicable Safety Incidents from OSHA Database	\$0	The OSHA database is publicly accessible via the internet and since I was to be identifying the applicable safety incidents, there was no anticipated additional financial requirement for this research task.
4.	Interviews of AEC Design Professionals (Development + Execution)	\$320	As there was to be several interviews, I had assumed some were to be face-to-face interviews and others remote interviews. The cost for the remote interviews was considered negligible as I already had remote capabilities. As for the face-to-face interviews, though my interview sample was to be situated in my metropolitan area, transportation would be necessary to reach the participant's preferred locations. As I had a vehicle, I assumed that a half tank of gas at \$25 and an additional \$10 would cover both the drive and parking. For other costs such as the printing of interview guides, an additional \$5 was considered to be adequate. This came to the non-conservative total of \$40 per interview. Therefore, the financial requirement for this research was estimated at \$320, assuming 8 face-to-face interviews. The cost of the participants' time was not included as no financial incentive was to be offered for the interviews.
5.	Development of Relational Database Application	\$50	I was to execute this research task by myself and where necessary, with assistance. I also had the software necessary to execute the research task on my computer. I thus anticipated \$50 in case I eventually sought assistance.
6.	Testing Interviews and Improvement of Relational Database Application	\$200	As this research task was to include a few face-to-face interviews, the non-conservative estimate of \$40 per interview was also used. Besides this, certain improvements to the relational database application could have required some outside assistance. This would depend on the outcome of the interviews and my capabilities. For this reason, an additional \$80 was included to cover for it. This came to the estimated total of \$200.
7.	Documentation, Submission and Presentation of Research Work and Dissertation	\$180	This primarily included printing and binding costs of the research documentation. Based on a document length of 300 pages and the printing of 6 copies, I estimated the cost of this task. Furthermore, up to 30 copies of the presentation slides were to be printed. Based on these, I arrived at \$180 as the estimated financial requirement.
	Contingencies	\$150	This was included to cover for miscellaneous and unforeseen costs that could be incurred through the course of the research.
	<i>Total Financial Requirement</i>	<u><i>\$1,000</i></u>	

**Table 21:** Estimated Financial Requirements for the Research

## **4.0 Research Methodology and Results**

### **4.1 Research Execution and Outcomes**

In this section, the research tasks and their steps are discussed with regards to their objective, procedure, and results.

#### **4.1.1 Indexing and Categorization of Design Suggestions from CII's DFCS Toolbox**

##### **4.1.1.1 Objective**

The objective of this research task was to identify DFCS measures applicable to the design phase of a capital project. Safety researchers sponsored by the Construction Industry Institute (CII) accumulated 430 design suggestions for minimizing or eliminating certain construction safety hazards (CII, 1996; and Gambatese et al, 1997). None of the design suggestions were discarded based on cost, schedule, relative risk reduction, or any other design or construction performance criteria (Gambatese et al, 1997). Thus, many are not applicable to the project design phase. Furthermore, many of the design suggestions prescribe means, methods, techniques, sequences or procedures for the contractor and are therefore applicable to the project construction phase.

The design suggestions address different AEC design disciplines and were each assessed to identify those applicable to designers and the project design phase. The criteria for DFCS measures were utilized in indexing and categorizing the 430 suggestions.

##### **4.1.1.2 Procedure and Results**

This research task was executed through a number of steps based on the criteria for DFCS measures and compatibility with the overall research objectives.

1. DFCS suggestions that prescribe means, methods, techniques, sequences or procedures for the contractor were excluded.

DFCS suggestions or measures that prescribe means, methods, techniques, sequences or procedures for the contractor will infringe on clauses in the model contracts used by design professionals in the United States and thus expose them to liability in the event of a related safety incident. For architects, this is indicated in Section 3.3.1 of the AIA A201 contract document. For engineers, this is indicated in Section 6.01.H of the EJCDC E-500 contract document. Such DFCS suggestions were thus excluded as they are essentially construction suggestions for worker safety. The complete list of design suggestions in this category is provided in *Appendix B1*. Three examples are provided:

- Consider alternative methods for pouring concrete when specifying concrete pours below or next to overhead power lines, such as the use of a pumping truck.
  - Schedule sidewalks, slabs, and roadways around elevated work areas to be constructed as early as possible to serve as solid footing for scaffolding and ladders.
  - To reduce fall hazards design and schedule piping materials to be painted and/or insulated prior to erection or installation.
2. DFCS suggestions that pertain to temporary construction or project features were excluded.

DFCS entails addressing the safety of construction workers in the design of the permanent features of a project (Gambatese et al, 2005). Thus, DFCS suggestions must not pertain to temporary features used in the construction or completion of a project such as scaffolds. The implementation of such design suggestions could expose the design professional to liability in the event of a related safety incident. As such, these design suggestions are essentially construction suggestions for worker safety. Accordingly, they were excluded. The complete list of design suggestions in this category is provided in *Appendix B2*. Three examples are provided below:

- Ensure that proper warning signs, controls, and alarms are standardized throughout the project to alert workers about hazards.
  - Use durable thermoplastic markings or buttons rather than shorter-lived paint for pavement markings.
  - Provide clear signage for emergency showers and eye-wash basins in areas where personnel might come in contact with highly toxic or poisonous materials.
3. DFCS suggestions that pertain to other contractor responsibilities were excluded.

Model contracts used by architects and engineers in the United States clearly stipulate that the design professional not infringe on contractor responsibilities during the construction phase or otherwise. This is with regards to performing or furnishing any of the project work, for safety or security at the site, or for safety precautions and programs incident to the contractor's work. Implementing such DFCS suggestions could expose the designers to liability in the event of a related safety

incident. Hence, design suggestions that pertain to other contractor responsibilities were excluded. The complete list of design suggestions in this category is provided in *Appendix B3*. Three examples are provided below:

- Where job site access is limited, consideration should be given to alternating work schedules for short-term interruption of work tasks to allow additional clearance for crane set-up and use.
- Prohibit the manual placement of metal decking or forms if wind speeds exceed 25 mph.
- Minimize construction visitation and public access through or adjacent to the project site, as these can result in distractions that can create hazards for workers.

4. DFCS suggestions that do not pertain to the safety of construction workers were excluded.

Toole and Gambatese (2008) define DFCS as a process in which engineers and architects explicitly consider the safety of construction workers during the design process. Therefore, design suggestions that only pertain to maintenance workers, inspection workers, and/or project users and occupants were excluded. The complete list of design suggestions in this category is provided in *Appendix B4*. Three examples are provided below:

- Provide sewers with adequate access-ways to allow for ease of inspection and maintenance operations.
- To contain hazardous and flammable materials, isolate from adjoining areas the storage areas for combustible and toxic materials, such as paper, explosives, tires, celluloid, excelsior, petroleum, plastics, etc.
- Design open drainage pipes for storm sewers to allow for easy access for the removal of debris.

5. DFCS suggestions that pertain to designer responsibilities and processes that are not part of project design were excluded.

DFCS entails addressing the safety of construction workers in the design of the permanent features of a project (Gambatese et al, 2005). On this basis, DFCS suggestions that cannot be reflected in project design were excluded. While such suggestions are implementable without exposure to additional liability, they go beyond the criteria that

define DFCS. The complete list of design suggestions in this category is provided in Appendix B5. Three examples are provided below:

- Schedule the release of engineering drawings such that sufficient time is allowed for materials to be purchased, delivered, and installed.
- Note on the contract drawings the existing and new floor design loads to aid the constructor in determining material stockpile locations and heavy equipment maneuverability.
- Specify testing procedures for complicated designs or specialized mechanical, electrical, or piping systems, to avoid faulty assumptions being made by the constructor.

6. DFCS suggestions that are currently mandatory by OSHA standards were excluded.

DFCS suggestions that are already mandatory by OSHA standards very likely pertain to the project construction phase. Furthermore, the fact that they are mandatory makes their value in this research limited. The research is targeted at encouraging the minimization or elimination of construction hazards through project design measures. Where OSHA already mandates certain DFCS suggestions, there is negligible need for encouraging their implementation. After all, their non-implementation exposes the parties involved to fines and liability in the event of a related safety incident. Therefore, such suggestions were excluded. The complete list of design suggestions in this category is provided in *Appendix B6*. Three examples are provided below:

- Maintain a minimum clearance between the project and overhead power lines as outlined in Section 1926.950 of the Code of Federal Regulations.
- Allow for a large, unobstructed, open area (limited access zone) below elevated masonry work to minimize the risk of workers being struck by falling objects. See Section 1926.750 of the Code of Federal Regulations.
- Design the foundation for the soil variations within the site. Consider the soil classifications outlined in Section 1926.650 of the Code of Federal Regulations.

7. DFCS suggestions that are either currently required by building codes or that indicate adherence to building codes were excluded.

DFCS suggestions that are already mandatory by building codes very likely pertain to occupant safety, which is the primary safety concern of

design professionals. Also, the fact that they are mandatory makes their value in this research limited. Where building codes already require certain DFCS suggestions, there is little need for encouraging their implementation. After all, their non-implementation exposes the design professionals involved to liability in the event of a related safety incident. Therefore, such suggestions were excluded if indicated as such. The DFCS suggestions were not evaluated against building codes. Only those that specified adhering to building codes were excluded. The complete list of design suggestions in this category is provided in *Appendix B7*. Three examples are provided below:

- Ensure that the building height and area per floor meet all local building code requirements for the type of construction used.
- Design piping system components to meet all national, state, and local building code requirements and address the existing construction conditions to ensure worker safety.
- Ensure that tanks and vessels meet all local, state, and federal design code requirements.

8. The remaining DFCS suggestions were compiled.

The remaining DFCS suggestions, after all exclusions, were compiled. These are the DFCS measures identified to be applicable to the project design phase. In further research tasks, these were the CII design suggestions that were utilized. Six examples of such DFCS measures are provided below:

- Design window sills to be 42 inches minimum above the floor level. Window sills at this height will act as guardrails during construction.
- Locate exterior stairways and ramps on the sheltered side of the structure to protect them from rain, snow, and ice to minimize fall hazards.
- On spread and continuous footings, and mat foundations, design the top layer of reinforcing steel to be spaced at no more than 6 inches on center, each way, to provide a continuous, stable walking surface before the concrete is poured.
- Design structural member depths to allow adequate head room clearance around stairs, platforms, valves, and all areas of egress.
- Provide grounding circuits to all 480 volt lighting fixtures.

- Locate underground utilities and other below-grade features in areas easily accessible for excavation. Allow sufficient area around excavations for stockpiling the soil.
9. The compiled DFCS suggestions were categorized by their appropriate design disciplines that included architects, civil/structural engineers, and mechanical/electrical/plumbing engineers.

This step was necessary to enable the next research task, the survey. To collect useful data for the DFCS measures, each was assigned to the AEC design professional it was most applicable to.

CII (1996) indicated the design disciplines addressed by the over 400 design suggestions. Architects, Civil/Structural engineers, and MEP engineers constitute the main disciplines addressed by the suggestions. Accordingly, they constituted the sample.

I utilized my background in architecture and civil engineering to execute this step. Categorization for a number of the compiled DFCS measures is provided below:

- Architects
  - Locate exterior stairways and ramps on the sheltered side of the structure to protect them from rain, snow, and ice to minimize fall hazards.
  - Orient the project to allow for the construction of temporary roads, fire lanes, and approach roads during construction.
  - Use consistent tread and riser dimensions throughout the stairway run and the project.
  - Design parapets to be 42 inches tall. A parapet of this height will provide immediate guardrail protection and eliminate the need to construct a guardrail during construction or future roof maintenance.
  - Provide inserts in window jambs for guardrail attachment.
- Civil / Structural Engineers
  - Design structural member depths to allow adequate head room clearance around stairs, platforms, valves, and all areas of egress.
  - Design beam-to-column double-connections to have full support for the beams during the connection process.
  - In order to allow sufficient walking surface, use a minimum beam width of 6 inches.
  - Use masonry blocks of consistent size and shape.
  - Use a single size, or a minimum number of sizes possible, of bolts, nails, and screws. If more than one size is required, specify sizes which vary greatly and are easily distinguishable.

- MEP Engineers – Mechanical Engineers
  - Avoid locating mechanical equipment in or directly adjacent to passageways as these can become major obstructions for those passing by the area.
  - Provide ventilation systems around fueled equipment operating indoors to maintain the air quality.
  - Locate valves such that they can be operated easily, or so that a standard type of operating device can be installed. Consider using remote valve operators.
  - To reduce fall hazards, locate rooftop mechanical/HVAC equipment away from skylights.
  - Locate underground utilities and other below-grade features in areas easily accessible for excavation. Allow sufficient area around excavations for stockpiling the soil.
  
- MEP Engineers – Electrical Engineers
  - Ensure that the withstand rating is adequate for the available fault current.
  - Provide grounding circuits to all 480 volt lighting fixtures.
  - Locate electrical circuit breaker boxes in sight of the equipment which they affect to ensure easy access and minimize confusion.
  - Design the ventilation system and lighting fixtures in a mechanical room to be operated by the same switch to ensure adequate ventilation whenever workers are in the area.
  - Isolate live conductors from accidental contact by overhead placement, secure enclosures, locked panels, etc.
  
- MEP Engineers – Plumbing Engineers
  - Minimize flanges in piping under high pressure, or which contains explosive or lethal gases.
  - Route piping to avoid head knockers (6 ft. - 6 in. minimum above grade) and tripping hazards.
  - Direct safety relief valve exhausts away from passageways and work areas.
  - When terrain changes grades, route sewer lines to avoid the need for deep trenches.
  - Ensure that the shut-off head on all pumps is consistent with the associated piping.

At the completion of this research step, the total number of DFCS suggestions that were identified as being situated in the project design-phase was 317 out of the 430 suggestions provided in the CII's DFCS Toolbox. 134 were applicable to architects while 74 were applicable to civil/structural engineers and 109 were applicable to MEP engineers. This is as seen in *Table 22*.

AEC Design Professionals		Number of DFCS Measures (Design-phase Measures)
Architects		134
Civil/Structural Engineers		74
MEP Engineers		109
	<i>Mechanical</i>	25
	<i>Electrical</i>	33
	<i>Plumbing</i>	51
TOTAL		317

**Table 22:** Categorization and Numbers of the Design-Phase DFCS Measures by AEC Design Profession

However, it must be noted that there were a few cases where certain compiled DFCS measures were considered applicable to more than one AEC design professional. In such cases, the DFCS measures were double-counted. Three examples are provided below:

**Architects and Mechanical Engineers**

- To reduce fall hazards, locate rooftop mechanical/HVAC equipment away from skylights.

**Architects and Electrical Engineers**

- Avoid locating electrical rooms under pipes carrying liquids that could pose a shock hazard.

**Architects and Plumbing Engineers**

- Design the covers over sumps, outlet boxes, drains, etc. to be flush with the finished floor to eliminate these features as tripping hazards.

The categorized DFCS measures were the output of this research task that was utilized in the next research task, the surveys of AEC design professionals.

#### **4.1.1.3      Unexpected Findings and Implications for Next Research Tasks**

The unexpected finding of this research task was the number of DFCS measures that were categorized as being situated in the project design phase. At 317 measures, this had a significant implication on the following research tasks. As I was to utilize all the 317 to elicit data through the surveys, this meant I had to have a very large sample size. Furthermore, receiving multiple responses for each of the DFCS measures became less feasible. I had earlier anticipated identifying between 120 and 150 DFCS measures to be situated in the design phase.

Further on, the interviews of AEC design professionals was also intended to elicit and validate data for all the DFCS measures. As a result of the large number of DFCS measures, this also became less feasible. Hence, categorization and

logical sequencing based on the survey responses was determined as the approach towards decreasing the number of DFCS measures for which data was to be elicited and validated through the interviews.

#### 4.1.2 Surveys of AEC Design Professionals

##### 4.1.2.1 Objective

The surveys of AEC design professionals were used for three main purposes. Firstly, they were used in validating the product of the first research task, DFCS measures applicable to the project design phase. Secondly, the surveys were used in obtaining the impediments to successful implementation of these DFCS measures. Lastly, the surveys were intended to obtain revisions or the basis for revisions of the DFCS measures in the interest of improving their use and enhancing their effectiveness.

##### 4.1.2.2 Procedure and Design

The survey design and administration process was thoroughly discussed in *Section 3.2.1.3*. In developing this survey, I took all the discussed issues and guidelines into consideration. Additionally, I used the survey developed by Gambatese et al (2005) as an additional guideline. This is because the survey and study were for the same research topic as mine, DFCS. Furthermore, the face-to-face survey was used to collect general comments on six proposed DFCS modifications. This section presents and discusses the development and features of the survey that was administered to AEC design professionals based on the steps described by Bethlehem (2009), CSU (2010) and Punch (2003).

1. The data collection questions were developed.

For each DFCS measure, three questions were to be asked. These are provided in *Table 23*.

	Question Function	Data Collection Questions
1.	To validate the DFCS measures determined to be applicable to the project design phase.	Is this measure applicable to the design phase of a project?  Why or why not?
2.	To obtain the impediments to successful implementation of the DFCS measures determined to be applicable to the project design phase.	Can this measure be successfully implemented in the project design phase?  Why or why not?
3.	To obtain revisions of the DFCS measures so as to increase their implementation on projects and possibly enhance their effectiveness in improving safety.	Do you find a revision could improve this measure to increase its implementation on projects?  If Yes, please provide your revision of the measure.

**Table 23:** Survey Data Collection Questions for DFCS Measures

2. The type of administration method or form for the survey was determined.

Based on the comparison of major survey methods in *Table 15*, I found that internet/electronic surveys were most adequate for this research. This was in the interest of feasibility with regards to resources and time. According to Czaja and Blair (2005), internet/electronic surveys are very low in cost and require a relatively short data collection period. Also, the geographic distribution of the sample may be wide. Furthermore, with regards to this research and the type and depth of information that was sought through the surveys, internet/electronic surveys were determined to be appropriate. This was also based on the determinations by Czaja and Blair (2005) in *Table 15*.

3. The survey questionnaire was created.

In developing the questionnaire, I considered the features identified by Punch (2003) and CSU (2010). The characteristics of the survey for this research are stated and briefly discussed.

- Qualitative Survey: As the research is primarily qualitative, the survey was also qualitative.
- Open-ended Questions: Even though surveys with close-ended questions tend to have a higher response rate than those with open-ended, I opted to use open-ended questions. Given that DFCS is an emerging area and also that more information is preferable, limiting respondents' answers through close-ended questions seemed inappropriate.
- Funneling Question Format and Order: This format was selected to provide a better flow when asking questions about each DFCS measure. For each DFCS measure, questions were placed in sets with shorter/easier questions at the beginning and more complex/difficult questions at the end.

4. The sample and its features were determined.

- Sample Selection

Due to the research topic, purposive sampling was utilized. DFCS involves addressing safety through design. Therefore, DFCS measures pertain to design professionals. Thus, for each measure, data must be collected from the professional it is most applicable to. CII (1996) indicated the design disciplines addressed by the design suggestions. The various design disciplines were addressed 641 times by the 430 design suggestions (CII, 1996). This is indicated in *Table 24*.

	<b>Design Discipline</b>	<b>No. of Times Addressed</b>	<b>% of Recorded Suggestions</b>
1.	Structural	141	32.8
2.	Architectural	127	29.5
3.	Piping/Plumbing	84	19.5
4.	Electrical/Instrumentation	69	16.0
5.	Mechanical/HVAC	69	16.0
6.	Construction Management	62	14.4
7.	Civil	48	11.2
8.	Tanks/Vessels	17	4.0
9.	Traffic/Transportation	16	3.7
10.	Geotechnical	5	1.2
11.	Coatings/Insulation	3	0.7
	<b>Total</b>	<b>641</b>	

**Table 24:** Design Disciplines Addressed by the Design Suggestions (Source: CII, 1996)

From *Table 24*, it is apparent many of the design disciplines are sub-disciplines. Based on the main disciplines addressed by the suggestions, certain AEC design professionals were included in the sample. Also, in the interest of generalizability, these professionals were selected from industry and from academia. The professionals were to preferably have experience of at least five years. This was to ensure they had the exposure to provide useful information on the DFCS measures. The composition of the sample or panel of experts is provided.

- Industry and Academia
  - Architects
  - Civil, Structural and Construction Engineers
  - Mechanical/Electrical/Plumbing (MEP) Engineers
- Sample Sizing

The size of the sample was determined based on the number of DFCS measures identified to be applicable to the project design phase. The indexing and categorization of design suggestions from CII's DFCS Toolbox yielded 317 DFCS suggestions that were identified as being situated in the project design-phase. These DFCS suggestions were split into different survey versions. Each of these versions was then required to have at least one respondent. As such, the size of the sample remained variable until the completion of the research task. This was a form of quota sampling that was also applied to the number of professionals from each design discipline. So where additional mechanical engineers were required to provide data for mechanical engineering related DFCS measures, the sample size was expanded appropriately.

The best case scenario would have been at least two respondents for each survey version. The benefit of this approach is validation of the collected information through data triangulation. However, given the large number of DFCS measures for which data was to be collected, this was ultimately not feasible.

- Approaching and Gaining Access to the Selected Sample

To gain access to the selected sample, the internet, search engines and professional networking sites were used. As the selected survey method was internet/electronic surveys, the email addresses of the selected sample of AEC design professionals were required.

In identifying individual AEC design professionals from industry, I searched for design firms using the location of Pittsburgh, PA and expanded to within and beyond the metropolitan area. In each design firm, I read through the background and experience of the professionals. Some were indicated directly on the firm website while others were presented in curriculum vitae links.

I focused on all levels of employees, from the principals to the associates and other employees. Those design professionals that met my sample criteria were then selected and their email addresses obtained. Where their email addresses were not listed on their company websites, I used professional networking sites to obtain them. In the case of selecting AEC professionals from academia, a similar but easier approach was utilized. This was considering that universities and colleges typically provide the professional information and email addresses of their faculty. Once selected, the name, affiliation, email address and location of all the AEC professionals were recorded.

5. The designed survey was subjected to pilot testing or pretesting.

Punch (2003) stated that pilot testing is necessary for survey questionnaires that have not already been used and field tested. This applied to the designed survey.

As stated earlier, internet/electronic surveys were selected for this research. There are two types of internet/electronic surveys, email and web (Krysik and Finn, 2010). Email surveys are essentially text messages that are either included in an email message or attached to it as a separate word processing or spreadsheet document (Krysik and Finn, 2010). Web surveys meanwhile are situated on a web page or site to which the respondent is linked. In both cases, an email is used to request and/or enable participation. With regards to prior DFCS research surveys, Gambatese et al (2008) administered e-mail surveys to an expert panel to

validate whether certain design suggestions identified as effective by Behm (2005) could prevent specific accidents.

For the pilot survey, I chose to use email surveys. This was to offer freedom for commentary on any part of the survey particularly the questions themselves. After all, pilot testing is to improve the quality of the questions and the survey in collecting complete and useful information and also, to increase response rates. Also, a survey needs to be tested for length, for time and difficulty to complete (Punch, 2003). The two different versions of the pilot surveys are provided in *Appendix C*.

- Format and Structure of the Pilot Survey
  - The survey was a Microsoft Word document
  - The survey had a cover letter that provided the following information
    - The research topic
    - The research purpose
    - The intended use of the collected information
    - The basis for selecting the respondents
    - The anonymity of survey responses
    - The expected length of survey completion
    - Instructions for returning the survey questionnaire and the email address
    - Researcher's name and contact details
    - Research advisor's name and contact details
  - The survey had 3 sections
    - Section 1: General Information  
This section provided blank spaces for the following information:
      - Profession
      - Job Title / Position
      - Years of Experience
    - Section 2: Design Measures  
This section asked respondents to answer questions on the DFCS measures. The DFCS measures and questions were organized into a table with the former as the rows and the latter as the columns. The blank intersecting spaces were provided for the answers.
    - Section 3: Other Questions  
This section asked a number of questions on the survey itself and on the participation of the respondent. For each question, a blank space was provided for the respondents' answers. These three questions were asked.
      - How long did it take you to complete the survey?

- Would you like your participation in the study to be confidential?
  - Do you have any general comments or suggestions?
- Execution of Pilot Survey
  - Survey Versions
 

I created 6 total versions of the survey for two different disciplines and with different lengths.

    - Architects: 3 surveys with 6, 7 and 8 DFCS measures for which data was to be collected. The version with 8 measures is provided in *Appendix C1*.
    - Civil Engineers: 3 surveys with 6, 7 and 8 DFCS measures for which data was to be collected. The version with 8 measures is provided in *Appendix C2*.
  - Sample Selection and Contact
    - I used purposive and convenience sampling to select 6 AEC professionals in my university (Carnegie Mellon University). 3 were architects while 3 were civil/structural engineers. I applied these two criteria.
      - A minimum of 5 years in working experience
      - Some background in not just design but construction projects
    - I contacted the sample via email. In the email, I introduced myself and stated my status. I also stated the name of my advisor. I then requested input in my research pertaining to DFCS. I then stated that the survey is to be a pilot survey that should take no more than 10 minutes. Thus, this is a participating pretest. I also indicated the basis for the sample selection, AEC professional with experience in design and construction. Lastly, I requested that I be notified if the email recipient was willing to participate. Greetings and thanks were also included. This was done to get the commitment of the sample prior to sending the email. This was expected to make it harder for them to ignore or not complete the attached survey.
- Email and Survey Responses
  - Where the email recipients responded and agreed to participate, I expressed my appreciation and attached the survey document to my response email.
  - I then awaited and collected the survey responses. *Table 25* indicates the responses of the selected sample to my email and survey.

<b>Selected Sample</b>	<b>Survey Versions (Number of DFCS measures included)</b>	<b>Responded to Email and Agreed to Participate?</b>	<b>Responded to Survey?</b>	<b>Nature of Survey Response</b>	<b>Improvement to Survey Design based on Responses</b>
<i>Architect 1</i>	6	Yes	Yes	Respondent requested a face-to-face survey administration which answered all the questions on the survey and highlighted a number of survey design issues.	The survey questions were revised for clarity and comprehension. Their order was also adjusted.
<i>Architect 2</i>	7	No	-	-	-
<i>Architect 3</i>	8	Yes	Yes	Respondent believed DFCS violated AIA A201 and did not complete the survey at all. The respondent indicated this in email correspondence.	A brief discussion on liability for worker safety was included at the beginning of the survey. This indicated how designers could consider construction safety without assuming liability.
<i>Civil Engineer 1</i>	6	Yes	Yes	Respondent provided input in the email and not the survey. Responses however pertained to each of the DFCS measures.	The ease of survey response was increased. This was to ensure that survey questions were answered and also, responded to on the survey itself.
<i>Civil Engineer 2</i>	7	Yes	Yes	Respondent provided answers to all of the questions asked on the survey.	The length of the survey was set at a maximum of 6 DFCS measures. Also, the expected time of survey completion was adjusted from 10 minutes to 10-15 minutes. Also, the survey questions were revised to remove redundancies.
<i>Civil Engineer 3</i>	8	Yes	No	-	-

**Table 25:** Pilot Survey Responses

- Improvements and Changes to Research Survey

- Question Revisions and Change in Order  
CSU (2010) states that pilot tests should specifically assess question variation, meaning, flow, order, skip patterns, and timing. A respondent provided input on his comprehension of the data collection questions. He also indicated this on his survey response. Another respondent answered “No” to all the questions regarding revision of the DFCS measures while another did not answer them at all. This suggested that the data collection question needed to be more comprehensible and also have more clarity. The questions were thus collectively revised and their order adjusted for a better flow. The revisions are seen in *Table 26*.

	Question Function	Revised Data Collection Questions
1.	To validate the DFCS measures determined to be applicable to the project design phase.	Is this measure applicable to the design phase of a project?  Why?
2.	To obtain revisions of the DFCS measures so as to increase their implementation on projects and possibly enhance their effectiveness in improving safety.	Do you feel this measure can improve construction worker safety?  Why?
3.	To obtain the impediments to successful implementation of the DFCS measures determined to be applicable to the project design phase.	Would you implement this measure in your design?  Why?

**Table 26:** Revised Survey Data Collection Questions for DFCS Measures

- Inclusion of Discussion on Liability for Construction Worker Safety  
One respondent felt the involvement of design professionals in construction safety even through DFCS would constitute a violation of model contracts, specifically AIA A201. Despite multiple correspondences, this belief could not be allayed. The respondent might have believed I was unaware of the stipulations in the model contracts. To ensure this did not occur in the administration of the research survey, the appropriate model contract language was provided and briefly discussed with regards to the implementation of DFCS. Where a survey was intended for architects and engineers, Section 3.3.1 of the AIA A201 and Section 6.01.H of the EJCDC E-500 contract documents were respectively presented and briefly discussed with regards to how DFCS does not result in their violation and the resulting increased liability exposure. All further elicitation documents including surveys and interview guides included this discussion section.

- **Setting Survey Length and Adjusting the Expected Time of Survey Completion**

According to Czaja and Blair (2005), the internet/electronic survey completion time should be less than 15 minutes. A respondent completed a survey version that asked questions on 7 DFCS measures. The respondent indicated that it took 15 minutes to complete. Furthermore, the respondent answered “No” to one of the questions for all the DFCS measures. Perhaps with fewer questions, the respondent would have provided alternate, more accurate and/or more complete answers. On this basis, the standard research survey asked questions on a maximum of 6 DFCS measures. Also, in the survey email and cover letter, the expected time of survey completion was adjusted from 10 minutes to 10-15 minutes.

- **Enhancing Ease of Survey Response: Web Survey**

A respondent found it more convenient to write comments for each of the DFCS measures in the body of his email response. This highlighted the need to make responding to the survey easier. And this could be done by using the other type of internet/electronic survey, web surveys. The major advantages of web surveys over email surveys are they can employ interactive features and they have a simplified submittal process (Krysik and Finn, 2010). Email surveys bear the risk that they may not be sent at all or they may be returned to the wrong email address (Krysik and Finn, 2010). They are also less convenient for respondents as they have to download, complete, attach and then send the survey as compared to just accessing it via a link, completing it and clicking on a submit button. The email survey was used in the pilot to allow commentary on all parts of the survey. In the case of the research survey, this allowance was not advisable since it was fully directed at obtaining answers. This further made the web survey a more effective option. Krysik and Finn (2010) stated that the development of survey websites such as SurveyMonkey and Web Surveyor has greatly simplified the web survey process. To determine which survey website to utilize, a comparative analysis conducted by Wright (2005) was considered. This is seen in the CAT in *Table 27*. I used two main criteria in selecting the survey website to use for my research survey. These included cost and familiarity.

Company Name/Product	Features	Pricing	Service Limitations
Active Websurvey	Unlimited surveys; software automatically generates HTML codes for survey forms	Information unavailable on website	Customer required to purchase software; limited to 9 question formats
Apian Software	Full service web design and hosting available	\$1195 up to \$5995 depending on number of software users; customer charged for technical support	Customer required to purchase software
CreateSurvey	Standard features; educational discount	\$99 a month for unlimited surveys and responses; free email support	Survey housed on company server for a set amount of time
EZSurvey	Unlimited surveys; mobile survey technology available; educational discount	\$399 for basic software; additional software is extra; telephone training is \$150 an hour	Customer required to purchase software
FormSite	Weekly survey traffic report; multiple language support	\$9.95 up to \$99.95 per month depending on desired number of response	Survey housed on company server for only a set amount of time; limited number of response per month
HostedSurvey	Standard features; educational discount	Charge is per number of responses; first 50 response are free, then around \$20 every 50 responses.	Survey housed on company server for only a set amount of time
InfoPoll	Standard features; Software can be downloaded for free	Information unavailable on website; limited customer support; training available for a fee	Software can be downloaded free, but works best on InfoPoll server; customers appear to be charged for using InfoPoll server
InstantSurvey	Standard features; supports multimedia	Information unavailable on website; free 30 day trial	Survey housed on company server for only a set amount of time
KeySurvey	Online focus group feature; unlimited surveys	\$670 per year for a basic subscription; free 30 day trial	Survey housed on company server for only a set amount of time; limited to 2000 responses
Perseus	Educational discount; mobile survey technology available	Information unavailable on website; free 30 day trial	Survey housed on company server for only a set amount of time
PollPro	Standard features; unlimited surveys	\$249 for single user; access to PollPro server is an additional fee	Customer required to purchase software
Quask	Supports multimedia	\$199 for basic software; access to Quask server for an additional fee	Customer required to purchase software; more advanced features only come with higher priced software
Ridgecrest	Standard features; educational discount	\$54.95 for 30 days	Survey housed on company server for only a set amount of time; limited to 1000 responses for basic package
SumQuest	Standard features; user guidebook for creating questionnaire available	\$495 to purchase software; free unlimited telephone support	Customer required to purchase software
SuperSurvey	Standard features	\$149 per week for basic package.	Survey housed on company server for only a set amount of time; 2000 response per week limit
SurveyCrafter	Standard features; educational discount	\$495 for basic software package; free and unlimited technical support	Customer required to purchase software
SurveyMonkey	Standard features; unlimited surveys	\$20 a month for a basic subscription; free email support	Survey housed on company server for a set amount of time; limited to 1000 initial responses
SurveySite	Company helps with all aspects of survey design, data collection and analysis; online focus group feature	Information unavailable on website	Company staff rather than customer create and conduct survey
WebSurveyor	Standard features; unlimited surveys	\$1,495 per year for software license	Customer required to purchase software
Zoomerang	Standard features; educational discount	\$599 for software	Customer required to purchase software

**Table 27:** Comparison of Online Survey Software and Services (Source: Wright, 2005)

As seen in *Table 27*, SurveyMonkey and HostedSurvey were the two survey websites with the least cost. However, considering I needed to develop tens of survey versions, a time-based payment system was determined to be more appropriate than one based on number of surveys or responses. With this taken into consideration and along with the fact that I was to administer much fewer than 1000 surveys, SurveyMonkey was the more cost-effective survey website for my research. Additionally, I was already very familiar with filling surveys administered through SurveyMonkey and with the design flexibility they offered. For these reasons, I used SurveyMonkey to administer my research web surveys.

- Other Determinations from Pilot Surveys
  - Requests for face-to-face surveys were to be accommodated if respondents were proximally situated. One pilot survey respondent felt this would enable him to provide better responses. The pilot face-to-face survey served this function while providing detailed and useful input for enhancing the effectiveness of the research survey. In the interest of collecting more complete information, such requests were to be accommodated.
  - Snowball sampling was also to be accommodated. Where a survey respondent gave a referral to another potential participant, that participant could be included in the sample set. One pilot survey respondent provided the name, email and affiliation of another AEC design professional he felt could be helpful in this research. I appropriately included this referred professional in my survey sample.

6. The survey was administered and the data was collected.

The research survey and its process of administration were designed with the aim of collecting useful information and achieving the highest possible survey response rates. The improvements determined from pilot testing were implemented in the design of the research survey. A version of the research survey is provided in *Appendix C3*. The interface, layout, information and questions presented are typical of all the research web survey versions.

- Format and Structure of the Research Survey
  - The research survey was a web survey that was hosted on a survey website, SurveyMonkey. SurveyMonkey ([www.surveymonkey.com](http://www.surveymonkey.com)) provided the authoring tools and details that I used in developing the format and structure of the research survey.

- The survey had a cover page that provided the following information. SurveyMonkey allowed a cover page to be designed and included in the survey.
  - The research topic
  - The research purpose
  - The intended use of the collected information
  - The basis for selecting the respondents
  - The anonymity of survey responses
  - The expected length of survey completion
  - Instructions for completing and submitting the survey questionnaire
  - Researcher's name and contact details
  - Research advisor's name and contact details
  - A "Begin Survey" button
  
- The survey had 7-8 data collection web pages depending on the number of DFCS measures for which data was to be collected. There were however, 11-12 web pages in total. Each page had a "Next" button and a "Previous" button except the first and last pages which only had a "Next" button and a "Previous" button respectively. Each page also had an "Exit this Survey" button.
  - Discussion Section: Liability for Worker Safety  
In this section, the issue of liability for worker safety and how DFCS can improve safety without violating model contract language was briefly discussed. SurveyMonkey allowed for the entry of "Descriptive Text" in the survey.
  
  - Section 1: General Information  
This section was intended for confirmation of the participant's background and also to serve as an icebreaker. This section provided text boxes for entry of the following information:
    - Profession
    - Job Title / Position
    - Years of Experience
  
  - Section 2: Design Measures  
This section asked respondents to answer questions on the DFCS measures. The DFCS measures and questions were organized into separate pages. For each DFCS measure, the questions were open-ended but had a small close-ended element. This was for the

Yes/No/Other answers. The “Other” option had a text box to enable further information entry. This question type was of the “Multiple Options (Only One Answer)” offered by SurveyMonkey. These options were then followed by a comment box which allowed for the open-ended entry. For the close-ended element, answers were required before the respondent was able to proceed to another survey section. SurveyMonkey provided for this feature by returning the respondent to the skipped question and highlighting it. This was intended to assure of more complete survey responses. Adjustments to the answer input sections of the questions for each DFCS measure are seen in *Table 28*.

	<b>Survey Questions for each DFCS Measure</b>	<b>Question and Answer Format on the Web Surveys</b>
1.	Is this measure applicable to the design phase of a project?  If No (or Not Yes), why?	Is this measure applicable to the design phase of a project? <input type="radio"/> Yes <input type="radio"/> No <input type="radio"/> Other <div style="border: 1px solid black; width: 150px; height: 15px; margin-left: 100px;"></div> Why? <div style="border: 1px solid black; width: 300px; height: 50px; margin-top: 5px;"></div>
2.	Do you feel this measure can improve construction worker safety?  If No (or Not Yes), why?	Do you feel this measure can improve construction worker safety? <input type="radio"/> Yes <input type="radio"/> No <input type="radio"/> Other <div style="border: 1px solid black; width: 150px; height: 15px; margin-left: 100px;"></div> Why? <div style="border: 1px solid black; width: 300px; height: 50px; margin-top: 5px;"></div>
3.	Would you implement this measure in your design?  Why or why not?	Would you implement this measure in your design? <input type="radio"/> Yes <input type="radio"/> No <input type="radio"/> Other <div style="border: 1px solid black; width: 150px; height: 15px; margin-left: 100px;"></div> Why? <div style="border: 1px solid black; width: 300px; height: 50px; margin-top: 5px;"></div>

**Table 28:** Question and Answer Format on the Research Web Surveys

- Section 3: Other Questions

This section asked one question on the DFCS study and two on the participation of the respondent. For the first question, on the DFCS study, a text box was provided for the respondents' answers. For the second and third questions, on the respondents' participation, "Yes" or "No" options were provided. The questions are provided below:

- Do you have any general comments or suggestions on DFCS or on the study?
- Would you like your participation in the study to be confidential? Yes or No?
- Would you be willing to further participate in the study? Yes or No?

- Confirmation Section: Submission Confirmation

This section confirmed completion and submission of the survey. It also expressed gratitude and appreciation for the participation of the respondents. The respondent exited the survey from this page.

- Execution of Research Survey

- Survey Versions

I created 56 versions of the research survey. Their number was to include questions for a maximum of 6 DFCS measures determined to be applicable to the project design phase and for a minimum of 5 DFCS measures. The measures were to be preferably dissimilar in terms of the project feature they addressed. This would more likely retain the interest of the respondents and also prevent multiple similar responses from being entered. There were 317 of such measures identified from the first research task. These versions were categorized for architects, civil/structural engineers, and MEP engineers. The details are provided in *Table 29*.

AEC Design Professionals		Number of DFCS Measures and Survey Versions	
		<u>Design-phase DFCS Measures</u>	<u>Survey Versions</u>
Architects		134	23
Civil/Structural Engineers		74	13
M/E/P Engineers		109	20
	<i>Mechanical</i>	25	5
	<i>Electrical</i>	33	6
	<i>Plumbing</i>	51	9
TOTAL		317	56

**Table 29:** Design-phase DFCS Measures and Survey Versions by AEC Design Professional

- Sample Selection and Contact

The sample of industry and academia AEC design professionals selected using the internet, search engines and professional networking sites were elicited for data through the web survey. With the key sample criterion of a 5 year length of work experience, the name, affiliation, email address and location of all AEC professionals were recorded. As discussed earlier, this purposive sampling was most appropriate for this research. The sample size remained variable with the single requirement that each survey version be completed by at least one respondent.

The survey samples were contacted via email. In the email, I introduced myself and stated my status. I also provided the name of my advisor. I also stated the basis for the sample selection as being an AEC professional with experience in design and possibly, construction. I then requested input in my research pertaining to DFCS via the web survey. I also indicated that roughly 10-15 minutes would be required to complete the survey. Lastly, I requested a response or notification if the email recipient was willing to participate. I also included greetings and thanks while expressing the high value of the professionals' inputs to my research. Where possible, I tailored my emails to the particular professionals I was contacting. This was intended to make the professional more willing to participate. A sample of the sent email is provided in *Appendix G1*.

- Email and Survey Responses

Where the email recipients responded and agreed to participate, I expressed my appreciation and included the web link in my response email. I also stated that the survey was user-friendly and should not be of much inconvenience to complete. This was to encourage the professional to respond soon. I then awaited and later collected the survey responses. Also, where the email recipients indicated willingness to participate but did not complete the survey more than a week after receiving the survey link, I sent the survey link to another AEC design professional in the sample. I did not send reminder emails so as not to make the respondents uncomfortable and cause them to make random or rushed data entries. SurveyMonkey allowed for identifying which surveys had been responded to and to what extent, along with the respondents' answers. As a matter of note, no face-to-face surveys were requested by any of the respondents.

- Data Collection Schedule

Czaja and Blair (2005) indicated that the data collection period for internet/electronic surveys is typically 1 to 3 weeks. In determining whether this was an adequate period of data collection for my research survey, I considered that of my pilot surveys. The period of response for the pilot surveys is indicated in *Table 30*.

Selected Sample	Survey Versions (Number of DFCS measures included)	Email Response Period (Days)	Survey Response Period (Days)	Total Data Collection Period (Days)
<i>Architect 1</i>	6	0	17	17
<i>Architect 2</i>	7	-	-	-
<i>Architect 3</i>	8	0	2	2
<i>Civil Engineer 1</i>	6	0	3	3
<i>Civil Engineer 2</i>	7	0	12	12
<i>Civil Engineer 3</i>	8	0	-	-

**Table 30:** Pilot Survey Response Periods

Based on the pilot survey responses, it seemed 3 weeks was an appropriate timeframe. However, due to the large number of survey versions that needed to be completed by at least 1 respondent, a substantially large number of email recipients were ultimately contacted. Thus, the 3 weeks increased to 14 weeks.

## 7. The collected survey data was analyzed.

SurveyMonkey provided server space for storing collected survey data and also, simple automated analysis for evaluating the collected data (Wright, 2005). In this research, collected survey data was tabulated with the DFCS measures as the rows, and the data collection questions as the columns.

As stated earlier, at least one complete response was to be received for each survey version; this was to validate or enable the validation of data for the DFCS measures included in the version. As this research mainly involved the collection of qualitative data, this was imperative. On the basis of the number of responses and their similarities and dissimilarities, the extent to which the answers were validated, the functions of the data collection questions were achieved, and the next stage of analysis for the data, were determined. This is depicted in *Table 31*.

For the Yes/No/Other answers, these were tallied for the questions on each DFCS measure. As for the answers provided in the open-ended question segments, they were read, distilled and summarized into keywords. The identified impediments to implementation of DFCS measures were used as the summarizing keywords. For example, where a respondent stated that high expenses may be realized from implementing a certain DFCS measure, the keyword would simply be “increased cost”. Where two respondents identified cost as an impediment to implementing a certain DFCS measure, cost is validated as an impediment of that

measure through data triangulation. Also, where no impediment was identified for a DFCS measure, it was documented accordingly. To demonstrate application of the approach depicted in *Table 31* on actual research data, the data collected through the pilot surveys were analyzed. This is seen in *Table 32*.

Using the revised data collection questions, a similar analysis to that in *Table 32* was conducted on data collected for all DFCS measures considered applicable to the project design phase. The tabulation of the analyzed data constituted the survey findings from which decisions were made with regards to further research tasks.

	Question Function	Closed-Ended Segment of Data Collection Question	Possible Survey Responses (Number)	Outcome with regards to Validity	Open-Ended Segment of Data Collection Question	Possible Survey Responses (Number)	Outcome with regards to Validity
1.	To validate the DFCS measures determined to be applicable to the project design phase.	Is this measure applicable to the design phase of a project?	No/Other (2)	Validated	Why?	(0) Response	No basis for Validation
			No/Other (1)	Not Validated		(1) Response	Not Validated
			Yes (1) and No/Other (1)	Validated		(2) Opposite Responses	Not Validated
			Yes (1)	Validated		(2) Dissimilar Responses	Not Validated
			Yes (2)	Validated		(2) Similar Responses	Validated
2.	To obtain revisions of the DFCS measures so as to increase their implementation on projects and possibly enhance their effectiveness in improving safety.	Do you feel this measure can improve construction worker safety?	No/Other (2)	Validated	Why?	(0) Response	No basis for Validation
			No/Other (1)	Not Validated		(1) Response	Not Validated
			Yes (1) and No/Other (1)	Not Validated		(2) Opposite Responses	Not Validated
			Yes (1)	Not Validated		(2) Dissimilar Responses	Not Validated
			Yes (2)	Validated		(2) Similar Responses	Validated
3.	To obtain the impediments to successful implementation of the DFCS measures determined to be applicable to the project design phase.	Would you implement this measure in your design?	No/Other (2)	Validated	Why?	(0) Response	No basis for Validation
			No/Other (1)	Not Validated		(1) Response	Not Validated
			Yes (1) and No/Other (1)	Not Validated		(2) Opposite Responses	Not Validated
			Yes (1)	Not Validated		(2) Dissimilar Responses	Not Validated
			Yes (2)	Validated		(2) Similar Responses	Validated

**Table 31:** Validation Analysis of Collected Survey Data

	<b>DFCS Measures</b>	<b>Is this measure applicable to the design phase of a project?</b>  <b>Why or why not?</b>	<b>Can this measure be successfully implemented in the project design phase?</b>  <b>Why or why not?</b>	<b>Do you find a revision could improve this measure to increase its implementation on projects?</b>  <b>If Yes, please provide your revision of the measure</b>
	<u>ARCHITECTS</u>			
1.	Design a permanent guardrail that surrounds each skylight.	Yes (1)	Yes (1)	No (1)
2.	Design window sills to be 42 inches minimum above the floor level. Window sills at this height will act as guardrails during construction.	Yes (1)	No (1)  Decreased project quality and diminished design creativity (1)	No (1)
3.	Design scaffolding tie-off points into exterior walls of buildings for construction purposes.	Yes (1)	No (1)  Decreased project quality and diminished design creativity (1)	No (1)
4.	On sloped sites, orient the project layout or grade the site accordingly to minimize the amount of work on steep slopes.	Yes (1)	Other (1) [Maybe] Depends on site and environment  Decreased project quality and diminished design creativity (1)	No (1)
5.	In multi-story buildings, design each floor plan to have a smaller area than the story below to prevent objects and workers from falling more than one story.	Yes (1)	No (1)  Decreased project quality and diminished design creativity (1)	No (1)
6.	Locate exterior stairways and ramps on the sheltered side of the structure to protect them from rain, snow, and ice to minimize fall hazards.	Yes (1)	No (1)  Decreased project quality and diminished design creativity (1)	Other [Not sure] (1)  Locate exterior stairways and ramps on <u>undercover</u> sides of the structure to protect them from rain, snow, and ice to minimize fall hazards.
	<u>CIVIL ENGINEERS</u>			
7.	Use a single size, or a minimum number of sizes possible, of bolts, nails, and screws. If more than one size is required, specify sizes which vary greatly and are easily distinguishable.	Yes (1)	Yes (1)	No (1)
8.	Consider alternative steel framing systems which reduce the number of elements and where beams are landed on supports rather than suspended between them.	Yes (1)	No (1)  Increased cost (1) Decreased project quality and diminished design creativity (1)	No (1)
9.	In order to allow sufficient walking surface, use a minimum beam width of 6 inches.	Yes(1)	Other (1) [Maybe]  Decreased project quality and diminished design creativity (1)	No (1)
10.	Align or locate post-tensioning cables such that if failure of a jack, cable, or fitting occurs during tensioning, the cable is not directed towards an active work area.	No (2)  More to do with construction and scheduling than design (2)	-	-
11.	Design wood piles such that they are below the water table, and do not specify creosote for protection of the piles from environmental deterioration.	Yes (1)	Yes (1)	No (1)

	DFCS Measures	Is this measure applicable to the design phase of a project?  Why or why not?	Can this measure be successfully implemented in the project design phase?  Why or why not?	Do you find a revision could improve this measure to increase its implementation on projects?  If Yes, please provide your revision of the measure
12.	On spread and continuous footings, and mat foundations, design the top layer of reinforcing steel to be spaced at no more than 6 inches on center, each way, to provide a continuous, stable walking surface before the concrete is poured.	Yes (2)	Other (2) [Maybe]  Increased cost (2)	No (1)
13.	Provide the constructor with floor and roof design loads for use in determining material stockpile locations and heavy equipment maneuverability.	Yes (1)	Yes (1)	No (1)

**Table 32:** Analyzed Data from Pilot Survey Responses

### 4.1.2.3 Results and Data

#### **Response Rates and Characteristics of Survey Respondents**

To have at least one complete response to each survey version, a sample size of 644 was ultimately required. Out of the 644 total email recipients, 90 responded that they were willing to complete the survey. And out of these, 67 completed the surveys. This corresponded to an overall survey response rate of 10.4%. Low response rates are characteristic of surveys (Marshall and Rossman, 2006). *Table 33* provides the number of email recipients by AEC design profession, the number of email respondents and the response rates. As there were 56 survey versions and 67 respondents, a number of survey versions had multiple respondents. This was largely due to the fact that I continuously expanded the survey sample across all AEC design professions until I received responses to all the survey versions. And, this was regardless of the profession category with the incomplete survey versions.

A criterion in the selection of the survey sample was at least 5 years of working experience. The survey respondents averaged 20 years of experience. The least was 3 years while the most was 37 years of experience. Only 3 survey respondents indicated less than 5 years and they all indicated 3 years of work experience. They indicated professions that included Professor of Architecture, Structural Engineering, and Electrical Teacher. They also indicated job titles of Assistant Professor, Senior Engineer, and Instructor, respectively. On the basis of the indicated professions and job titles, I did not disqualify or eliminate their responses as I felt they must have a significant level of knowledge to occupy their positions. There is also the possibility that their indicated years of experience was with regards to occupying their current position at their work places, and not their total years of experience. After all, the question about years of experience followed the question about job title. *Table 34* provides the number of survey respondents and the average years of experience of the respondents by their AEC design profession and in total.

The entered profession information of the survey respondents is provided in *Appendix D*. These include profession, job title, and years of experience.

Survey	Number of Email Recipients						Number of Email Respondents
	Architects	Civil Engineers	MEP Engineers			TOTAL	
			Mechanical	Electrical	Plumbing		
	175	65	46	135	223	644	90
Number of Completed Surveys	29	14	5	9	10	67	
Number of Survey Versions	23	13	5	6	9	56	
Number of Design-phase DFCS Measures	134	74	25	33	51	317	
				Email Response Rate			14.0%
				Survey Response Rate of Email Respondents			74.4%
				Survey Response Rate			10.4%

**Table 33:** Survey Response Rate and Recipients

AEC Design Professionals [Survey Respondents]	Number of Respondents	Average Years of Experience
Architects	29	20.5
Civil / Structural Engineers	14	16.8
MEP Engineers	24	22.7
<i>Mechanical Engineers</i>	5	23.3
<i>Electrical Engineers</i>	9	17.2
<i>Plumbing Engineers</i>	10	26.9
<b>Total Number of Respondents</b>	<b>67</b>	
	<b>Average Years of Experience of All Respondents</b>	<b>20.0</b>

**Table 34:** Years of Experience of the Survey Respondents

## Survey Responses on DFCS Measures

This section presents responses to a sample of the 317 DFCS measures included in the 56 survey versions. As seen in *Table 35*, there were a variety of responses given by the survey respondents to each of the three questions.

	DFCS Measures	Is this measure applicable to the design phase of a project?  Why?	Do you feel this measure can improve construction worker safety?  Why? [Revisions]	Would you implement this measure in your design?  Why? [Impediments]
	<b>Architects</b>			
Ex. 1	Use a uniform railing height throughout the project site.	Yes (1)	Yes (1)	Yes (1)
Ex. 2	For buildings with mechanical equipment in the top floor, design the roof of the area to have a hatch (e.g., 9 ft. x 9 ft.) for lowering large equipment into the mechanical room.	No (1)  9 x9 is a big hole in a roof. This can be coordinated with construction to insert. A removable panel can be designed, but not an operating hatch for an periodic access	No (1)	No (1)  Cost and low frequency of use
Ex. 3	Provide a covering, or extend the roof line over exterior stairs, ramps, and walkways to reduce the buildup of moss or the accumulation of ice in winter.	Other – Maybe yes – Maybe no (1) If the architect recognizes the issue during design, then yes. If the issue isn't noted until construction has begun, then, it is not related to the "design phase", but nonetheless is a design related issue.  Yes (1) This is a general design question that impacts long term safety	Other - Can't tell from the statement. (1) In general, one would expect that the statement relates to the future occupants of the building. However, if the issue is raised for temporary purposes during construction, then perhaps it is construction worker related. One would however expect, that if it is an issue for workers it may well also be an issue for future building occupants also.  Other – not critical (1) This is not critical for construction only long term use of the building.	Yes (1) Typically, if there is a chance for slip-fall conditions, the architect has a standard of care to consider design solutions to the issue.  Other – Maybe (1) When the budget permits and depending on the climate of the project. May not be reasonable in the areas that I work.
	<b>Civil / Structural Engineers</b>			
Ex. 4	Design structural member depths to allow adequate head room clearance around stairs, platforms, valves, and all areas of egress.	Yes (1)  Sounds like good practice.	Yes (1)  Construction worker safety as well as long term occupant/user safety.	Yes (1)
Ex. 5	Design the project such that the cut and cover method can be used for excavation rather than tunneling.	Other – not applicable to building design (1)	Other – not applicable to building design (1)	Other – not applicable to building design (1)
Ex. 6	For precast concrete members, provide inserts or other devices to attach lines or lanyards for fall protection.	No (1)	Yes (1)	No (1)  Designer is specifying construction method and procedure

	DFCS Measures	Is this measure applicable to the design phase of a project?  Why?	Do you feel this measure can improve construction worker safety?  Why? [Revisions]	Would you implement this measure in your design?  Why? [Impediments]
	<b>MEP Engineers</b>			
	<u>Mechanical Engineers</u>			
Ex. 7	Ensure that safety relief valves exhaust and drain away from passageways and work areas.	Yes (1)  Safety relief valves may release at any time. Care must be taken to ensure that these will not injure workers in the building.	Yes (1)  See previous response.	Yes (1)  This should be a measure that can easily be conveyed in a design through the specifications.
Ex. 8	Design new utilities under roadways and sidewalks to be placed using trenchless technologies or tunneling instead of trenching.	No (1)	Yes (1)	Yes (1)
	<u>Electrical Engineers</u>			
Ex. 9	Provide grounding circuits to all 480 volt lighting fixtures.	Yes (2)  No electrical device should be allowed to float with potential, even if it weren't a code requirement. This is a matter of both construction worker safety and operational safety after the Owner take occupancy of the building.  NEC Code requirement (NEC Article 250).	Yes (2)  See previous answer.	Yes (2)  Safety!
Ex. 10	Locate electrical circuit breaker boxes in sight of the equipment which they affect to ensure easy access and minimize confusion.	Yes (2)  I assume we're talking about permanently installed equipment.  It provides a standard level of maintenance and safety for the owner that all contractors must meet.	Yes (1) It improves safety for anyone who services equipment.  No (1) Likely minimal impact on construction worker safety, but more impact on owner maintenance safety and convenience.	Other – Sometimes (2)  I would whenever required by code or practical.  It depends on the equipment, distance of travel to operate the overcurrent device, and other factors.
	<u>Plumbing Engineers</u>			
Ex. 11	Ensure that the shut-off head on all pumps is compatible with the associated piping.	Yes (1)	Yes (1)	Yes (1)
Ex. 12	Provide relief valves between each pair of sectionalizing valves on lines containing liquids and subject to being both isolated and heated, such as heat exchangers, liquefied gas piping, etc.	Other – Depends (1)  Should be specific to each system	Other – Depends (1)  Again, depends on how well versed the designer is in system designing	No (1)  Not totally objective

**Table 35:** Survey Responses on a Sample of the 317 DFCS Measures

## **Respondent Commentary on DFCS and Discussion**

At the last page of the survey is the question; “Do you have any general comments or suggestions on DFCS or on the study?” Several of the survey respondents responded to this question. I categorized their responses based on the topics they addressed and included a brief discussion with regards to the matters raised.

### **1. Accidents are inevitable on the construction site**

- “Accidents are accidents, they can't all be prevented”.
- “It will simply never be safe on a construction site until magic wands are created. Construction sites are dangerous places”.

The fact of the matter is that accidents will occur. The important issue is trying to minimize their occurrence, and decrease the potential and severity of injury when they occur. Along with other safety strategies and protective measures, DFCS is intended to assist towards this end. Accidents and injury can have adverse impacts on the project and all project stakeholders, and thus, the need to decrease their occurrence.

### **2. DFCS is not practical as jobsite conditions change constantly**

- “Designing for construction safety is not a practical concept. You can design for interim life safety measures, but jobsite conditions change constantly”.
- “Some measures require knowledge of field conditions for a suitable solution”.

It is understood that jobsite conditions constantly change and knowledge of the field conditions is essential to identifying appropriate safety measures. However, this does not make DFCS impractical. Designers provide input to construction site safety through DFCS. The designer is to determine the DFCS measures that are appropriate to his or her project and construction site. Meanwhile, contractors are still expected to implement safety measures as appropriate to jobsite conditions. It must be clearly noted that DFCS is not intended to be the only safety strategy implemented on a project.

### **3. The implications on cost and insurance rates must be considered before and when implementing DFCS**

- “Contractors benefit from DFCS but who pays for it?”
- “The cost and need of DFCS is probably better determined by the actuarial studies that affect insurance rates to determine what cost is reasonable as a standard of care.”

- “For architects, the idea of planning in construction safety features might be new. Only some architects will help the contractor “phase” the work. This type of planning is usually done for an additional fee. Architects will not and should not want to do this planning work without additional compensation.”

Some DFCS measures have cost implications. However, this cost is mostly borne by the owner. Nonetheless, the designer has the ability to select DFCS measures that have minimal or negligible cost implications relative to the project cost. Even without additional compensation, the designer should be willing to implement DFCS. This is because safety incidents result in disruption to work and delay in project completion. This means extending the period of inspection of the project designer. This is also in the interest of preventing exposure to negative publicity from court cases and lawsuits due to poor safety performance, which could impact every project participant.

#### 4. Some of the DFCS measures were covered in code requirements

- “Most of the DFCS measures in this survey are from my knowledge already covered in codes.”
- “Many of the DFCS measures are code (NEC) requirements and have to be implemented during design.”
- “Some DFCS measures are code enforced and should be included on design documents.”

As noted in the earlier research task, some of the DFCS measures utilized in the survey are situated in code requirements. This was duly noted by some of the survey respondents. Also, these commentaries highlight that there might be little or no need of motivating the implementation of certain DFCS measures since they are already situated in code requirements.

#### 5. Construction safety is the contractors responsibility and the contractor has the most knowledge to better address the risks of safety hazards

- “I think AIA contracts are written explicitly to allow a contractor to take responsibility for safety of an active construction site. A good designer will think about safety of the building in a holistic way, which may include the construction period, but not exclusively the construction period. A construction worker is prepared with training, equipment, protective gear, and heightened awareness that are not to be found in a typical building user. So a designer can expect a construction worker to encounter and tolerate minimally hazardous situations in the process of erecting a building. An architect's main concern is that of the regular building user and inhabitant or

maintenance worker. While DFCS should be included as much as realistic and possible, an architect is not able to fully control all the circumstances on an active construction site and so can only incorporate features that facilitate the contractor being able to fully implement DFCS.”

- “There is a delicate balance between design and construction when considering that contractor's means and methods offer a competitive bidding strategy. Certainly the designer of record must approve any temporary condition of sequence of activities, but the contractor should have some flexibility in delivering the project using innovative techniques not thought of by the designer.”
- “Construction safety is tough to design for because it is challenging to know what equipment and personnel a contractor will have. It is better to produce a safe and constructible design and allow the contractor to request any changes that they would like to make to improve constructability, economy, safety, and speed. Without contractor input that is completing the work then it is risky to add these items in ones designs as it is unclear if they will be needed.”
- “CS typically relies more on the contractor’s means and methods than design.”
- “The design engineer can include measures in the design to minimize risks related to construction safety. Typically, though, the engineer is not on site enough during construction to enforce those measures. That is why there are the "means and methods" clauses in design contracts.”

These commentaries did not reflect a good understanding of the DFCS concept. DFCS involves addressing construction worker safety through passive ‘safer’ design of project features. Thus, the designer does not need to prescribe means and methods for the contractor. And, the designer does not need to be physically present on the construction site. DFCS is not to prevent the contractor from executing safety strategies situated in the construction phase. The contractor is certainly more knowledgeable about such safety strategies.

#### 6. The effectiveness of DFCS depends on the construction sequence.

- “Dangers to contractors are most prevalent during construction before the designed permanent elements that you have inquired about are put in place.”
- “I don't see the relevance of these design features to the construction process. They have more to do with the ongoing maintenance of the building and many of these features would not appear until later in the process. So what are the workers to do until then? They need to be responsible for their own safety. They need to assess that when deciding to build the project.”

This is one of the shortcomings of the DFCS concept. Where the permanent project features intended for construction worker safety are not constructed till the end of the construction phase, there will be a minimal to negligible impact on construction safety. Thus, until these features are constructed, the construction workers must utilize appropriate safety strategies and protective measures to avoid the related hazards. The design professional should not and must not indicate the sequence for constructing the DFCS features. This will expose the designer to liability in the event of a related safety incident.

7. DFCS may expose the design professional to additional liability.

- “It seems that the DFCS measures do not align or parallel IBC or NFPA 101 (Life Safety Code) provisions and may be in conflict with other architectural guidelines or construction parameters. As an unintended result, the design professional, by noting such items on the set of documents, might increase liability exposure from occupant use even though they are intended to decrease danger for construction practices.”
- “As an architect I refuse to have any input or comment on construction safety.”

By its definition, DFCS should not increase the exposure of the designer to liability. However, the design suggestions for construction safety from earlier research include several that are situated in the construction phase and thus have the potential to expose the designer to additional liability. Through the categorization task and the surveys, these were to be identified. Nevertheless, some design professionals will likely have an aversion to implementing DFCS since model contracts preclude architects and engineers from prescribing means and methods for the contractor, particularly with regards to safety. Many simply find it less risky to not be involved in safety at all.

8. Designers should have and exhibit concern for safety.

- “Anything that can be done to increase the health, safety, or welfare during design for the entire life cycle of a building is worth consideration.”
- “Even though architects are and should be relieved of construction worker safety through the contractor's means and methods, the architect nonetheless needs to understand how their designs are going to be built and they should not design “impossible conditions” for construction through overly short construction schedules, unreasonable liquidated damages, etc.”

- “Life safety is of critical importance in architecture.”
- “The design engineer can include measures in the design to minimize risks related to construction safety.”
- “Worker safety was always #1 concern.”
- “Professional 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.”

These commentaries signify the concern for safety of some AEC design professionals. Such designers are likely to be more willing to implement DFCS on their projects.

9. Several issues in project design supersede construction safety and DFCS in importance.

- “There is a range of issues that supersede the safety on a construction site. No one is interested in creating a hazard but we do not design buildings with the specific intent to perform during the construction phase. Cost, performance and items like disabled access are far ahead of the temporary time period that a project is under construction.”
- “Design must not be sublimated to the regulation of life safety and prescriptive codes often severely limit good design solutions. A performative code that allows design to accommodate life safety on a case by case basis is the best to do both.”
- “Incorporating DFCS can sometimes cause major design issues. Is it warranted?”

These commentaries indicate that certain design professionals find other issues to be more pressing in the design phase. This can be understood as projects are driven by value. However, it does not mean that the consideration of safety cannot occur after those issues have been addressed. One may design for performance and to minimize cost and then implement DFCS measures that do not adversely impact performance or significantly increase cost but decrease the likelihood of certain construction safety incidents.

10. Constructability should factor construction safety.

- “Many of the DFCS measures have validity as part of design for constructability, of which DFCS is one element.”
- “It is better to produce a safe and constructible design and allow the contractor to request any changes that they would like to make to improve constructability, economy, safety, and speed.”

Gambatese et al (2007) identify improved construction safety as a benefit of enhanced constructability. It is the responsibility of the AEC design professional to factor the safety constructability of a project and the contractor's responsibility to safely construct the project. Thus, the contractor remains free to request changes to enhance safety constructability. These commentaries echo the definition of DFCS by Toole (2007), safety constructability.

11. With increased information and education, safety could be increased through DFCS implementation.

- "As a designer, if provided more information on effectiveness of particular details, safety could be increased during the design phase."
- "Education is a key to further enabling DFCS from the design side. Just answering these questions has heightened my awareness of this issue. I believe that it is a natural instinct for any worthwhile design professional to want to accommodate these items, as it is obvious that they would not impact our aversion to input on a contractor's means and methods."

These commentaries highlight the DFCS impediment, lack of safety expertise. They also emphasize the importance of this research, which focuses on collecting information on DFCS measures with regards to their feasibility and effectiveness. Furthermore, they indicate that the education of AEC design professionals on DFCS and what it entails could also serve to increase its implementation.

12. DFCS would be more acceptable if there are other benefits and/or minimal adverse implications associated with its implementation.

- "If DFCS could be shown to have an economic advantage, engineers may find it more acceptable."
- "There may be insurance implications of more or less safety features. Insurance costs can be lessened with higher safety features, which might in turn offset the initial cost of the safety features."
- "Many of the questions asked are specified to protect the system, and construction worker and/or end user safety are additional benefits."
- "Several of the suggestions are good for people in addition to the construction workers and those measures could be implemented for reasons beyond DFCS."

Certain DFCS measures have cost and other advantages in addition to improving construction safety. Based on the commentaries, such measures have more potential to be

considered for implementation. Looking at the bigger picture, DFCS could indeed lessen insurance costs by resulting in fewer accidents and injuries. This also means fewer litigation and legal costs.

13. Certain DFCS measures were more applicable to operations and maintenance safety as opposed to construction safety.

- “Each of the DFCS measures seems more applicable to operations safety instead of construction safety.”
- “Some of the questions seem to be related to a later stage in a projects life.”
- “I'm not sure we're agreed on construction safety versus operation/maintenance safety.”

It is quite true that certain DFCS measures will have minimal impact on safety in the construction phase and a more prolonged and extended impact on safety in later project phases. This does not make the DFCS measures less viable for implementation. As a matter of fact, this should increase their viability since design professionals bear liability for occupant and maintenance worker safety. Such measures increase this set of beneficiaries to include construction workers.

14. Some of the DFCS measures are already utilized on projects.

- “It seems like a few of these DFCS issues have already been resolved - like the column web issue.”
- “Most of these DFCS measures are already used.”

According to some design professionals, certain DFCS measures in the survey were already used on projects. This could allude to earlier safety consciousness of the respondents and/or their firms. Also, the commentaries highlight that there might be little or no need of motivating the implementation of certain DFCS measures since they are already utilized.

#### **4.1.2.4      Interpretation of Results**

##### **Outcome of Objectives**

The outcomes with regards to each of the survey objectives were distinct. With regards to the first objective, the validation of the DFCS measures as being situated in the project design phase, this was accomplished. Out of the 317 DFCS measures included in the surveys, 234 were validated as being situated in the project design phase and 33 were identified as possibly being situated in the project design phase. 58 were identified as not being situated in the project

design phase and are provided in *Appendix B8*. This totals 325 DFCS measures because some had multiple responses that differed with regards to being situated in the project design phase. These were double counted in the appropriate categories. Three examples of such DFCS measures and their responses are provided in *Table 36*.

	DFCS Measures	Is this measure applicable to the design phase of a project?	Do you feel this measure can improve construction worker safety?	Would you implement this measure in your design?
		Why?	Why? [Revisions]	Why? [Impediments]
Ex. 1	Group floor openings together to create one larger opening rather than many smaller openings, as these can be more easily guarded.	No (1)  Other (1) Not a significant concern on projects	No (1)  Yes (1) Statistics	No (1)  Other (1) Depends. Multistory repetitive situation would warrant implementation
Ex. 2	Provide a non-slip surface treatment on ramps to help prevent slipping and falling.	Yes (1)  No (1) Minor construction detail	Yes (2)  Non-slip surface	Yes (2)  Minor impact on design
Ex. 3	Provide a covering, or extend the roof line over exterior stairs, ramps, and walkways to reduce the buildup of moss or the accumulation of ice in winter.	Other – Maybe yes – Maybe no (1) If the architect recognizes the issue during design, then yes. If the issue isn't noted until construction has begun, then, it is not related to the "design phase", but nonetheless is a design related issue.          Yes (1) This is a general design question that impacts long term safety	Other - Can't tell from the statement. (1) In general, one would expect that the statement relates to the future occupants of the building. However, if the issue is raised for temporary purposes during construction, then perhaps it is construction worker related. One would however expect, that if it is an issue for workers it may well also be an issue for future building occupants also.       Other – not critical (1) This is not critical for construction only long term use of the building.	Yes (1) Typically, if there is a chance for slip-fall conditions, the architect has a standard of care to consider design solutions to the issue.          Other – Maybe (1) When the budget permits and depending on the climate of the project. May not be reasonable in the areas that I work.

**Table 36:** Survey Responses on 3 DFCS Measures with Multiple but Different Responses

With regards to the second objective, obtaining the impediments to implementing the DFCS measures, this was also achieved where applicable. For some DFCS measures, impediments were identified while for others, they were not. The responses to the questions about the DFCS measure in *Example 3* of *Table 36* indicate the implementation impediment of cost. For all the DFCS measures, the indicated impediments were documented.

With regards to the third objective, obtaining revisions or the basis for revisions of the DFCS measures in the interest of improving their use and enhancing their effectiveness, this was achieved but for only two DFCS measures. 2 out of 317 DFCS measures represent an extremely low output. The survey question was “Do you feel this measure can improve construction worker safety?” and “Why?” The latter segment was intended to yield the basis for the revisions and/or the revisions. Some survey respondents only answered the first segment. But most

also responded to the second segment and did not provide the information necessary to revise the measures. There were a total of 240 responses to the second segment. However, only 2 of these were adequate to provide a basis for revisions. This was perhaps due to the fact that survey respondents are typically not willing to spend too much time answering the questions and thus, did not provide as much detail, including how the DFCS measures could be made to improve safety particularly if the respondent indicated that they could not. This was not unexpected since surveys do not allow the researcher to collect much detail relative to other data collection methods such as interviews. Seen in *Table 37*, the responses and revision data are provided along with the next course of action.

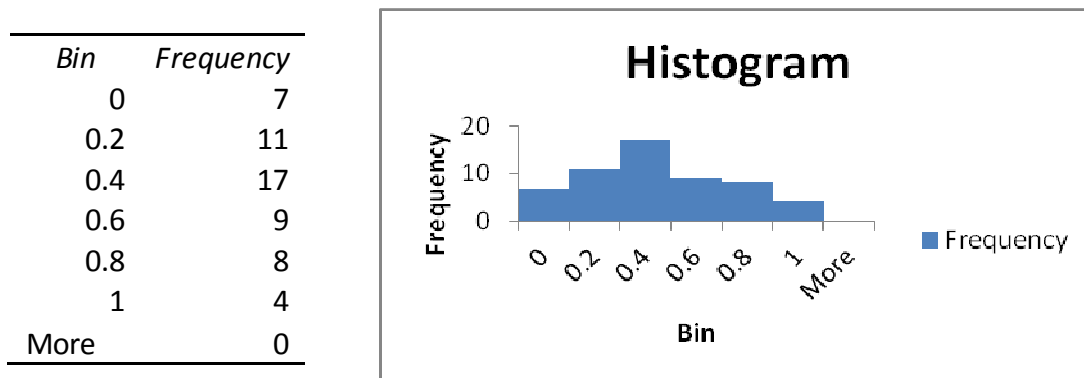
	DFCS Measures	Is this measure applicable to the design phase of a project?  Why?	Do you feel this measure can improve construction worker safety?  Why? [Revisions]	Potential Revisions	Course of Action
	<u>Architects</u>				
1.	Design window sills at a consistent level throughout the project.	Yes (1)  Window sill heights are a part of design.	Other – Depends (1)  If they were all at 48" and the walls were constructed to safety tolerances they could possibly be of benefit, but again they cant all be built at once and it would make for some poor and likely wasteful buildings.	[Design window sills at a height of 48 inches above the floor level throughout the project]	This revision was not included in the future research tasks because a similar DFCS measure was already included in the survey. This is:  "Design window sills to be 42 inches minimum above the floor level. Window sills at this height will act as guardrails during construction."
	<u>Civil / Structural Engineers</u>				
2.	Avoid steel beams of common depth connecting into the column web at the same location.	Yes (1)  Need to design the connections	No (1)  The beam depth doesn't matter. The connection matters. Using a four-bolt connection on one side and a three bolt connection on the other side (for example) may eliminate this. Or use seated connections, which eliminate the problem altogether.	[When designing beam-to-column connections with more than one beam connecting to the column, use a four-bolt connection on one side and a three bolt connection on the other side]  [Use seated connections for beam-to-column connections particularly where there are multiple beams connecting to the column]	These revisions are far apart from the DFCS measure. They are alternate DFCS measures to this one. As such, they were considered new DFCS measures yielded through this research. Thus, they were not revisions to be included in future research tasks.

**Table 37:** Survey Responses and Revision Data for the 2 DFCS Measures with a yielded Basis for Revision

Conclusively, the objectives of the survey were achieved as identified design-phase DFCS measures were validated, and their impediments and revisions yielded where applicable.

## Assessment of Respondent Entries on the DFCS Measures

An observation was made from the survey responses. There were 3 questions on each of the 5-6 DFCS measures included in each survey. Certain survey respondents answered Yes-Yes-Yes to the questions for several DFCS measures. It was important to assess these responses to see if they had a random distribution across all survey respondents. A random distribution suggests a higher validity of the entries by the survey respondents. Thus, the Yes-Yes-Yes responses were evaluated to identify whether they had a normal or a uniform distribution across all survey respondents. Towards this, the percentages of Yes-Yes-Yes responses out of the 5-6 DFCS measures included in each of the surveys were derived. These were used to develop the histogram seen in *Figure 22* and the summary statistics seen in *Table 38*.



**Figure 22:** Histogram of the Percentage of Yes-Yes-Yes Survey Responses for DFCS Measures per Survey

Yes-Yes-Yes Responses	
Mean	0.4
Standard Error	0.035897
Median	0.366667
Mode	0.333333
Standard Deviation	0.268629
Sample Variance	0.072162
Kurtosis	-0.09452
Skewness	0.509255
Range	1
Minimum	0
Maximum	1
Sum	22.4
Count	56
Confidence Level (95.0%)	0.072

**Table 38:** Summary Statistics for Percentage of Y-Y-Y Survey Responses for DFCS Measures per Survey

In *Figure 22*, the values (0.0, 0.2, 0.4, 0.6, 0.8, and 1.0) stand for the percentage of Yes-Yes-Yes (YYY) responses in each survey version. Thus, the values for each survey version ranged between 0.0 and 1.0. The bins were used in the

histogram to categorize the data pool and yield the frequency between the values. In *Table 38*, the mean value of 0.4 means that: “On average, each survey version had Yes-Yes-Yes responses for 40% of the DFCS measures included in the survey”.

In order to identify whether the Yes-Yes-Yes responses for DFCS measures had a normal or a uniform distribution across all survey respondents, the Pearson’s Chi-squared test for Normal and Uniform distribution was used. I determined bin sizes so that each bin had at least a frequency of 5. According to NIST (2011), for the chi-square approximation to be valid, the expected frequency should be at least 5. It was also noted that the test is not valid for small samples. There were two shortcomings. Firstly, one of the bins only had a frequency of 4. Secondly, from observation, 56 data points do not qualify as a sufficient sample size. The chi-squared test was nonetheless executed.

#### Chi-Squared Test for Normal Distribution of Yes-Yes-Yes Responses

H0 = the data follows the normal distribution

H1 = the data does not follow the normal distribution

Level of Significance =  $1 - 0.95 = 0.05$

Exp. number of samples in each bin = (Percentage of Curve Area in that Bin) x

Total number of samples

	Lower Bin Range	Upper Bin Range	Actual No.
Bin	BR	BR	Obs.
0	-0.1	0.1	7
0.2	0.1	0.3	11
0.4	0.3	0.5	17
0.6	0.5	0.7	9
0.8	0.7	0.9	8
1	0.9	1.1	4

Curve Area Left of Lower Bin Range	Curve Area Left of Upper Bin Range	Area in Bin		Expected Number of Observations
CDF i	CDF i+1	CDFi+1 - CDFi		Exp.
0.031	0.132	0.101	x 56	5.639
0.132	0.355	0.223	x 56	12.477
0.355	0.645	0.290	x 56	16.257
0.645	0.868	0.223	x 56	12.477
0.868	0.969	0.101	x 56	5.639
0.969	0.995	0.027	x 56	1.499

Expected Number of Observations	Actual No.	Exp - Obs.	(Exp - Obs)^2 / (Exp)
Exp.	Obs.		
5.639	7	-1.361	0.329
12.477	11	1.477	0.175
16.257	17	-0.743	0.034
12.477	9	3.477	0.969
5.639	8	-2.361	0.989
1.499	4	-2.501	4.173
TOTAL (X^2) =			<b>6.668</b>

df = 6 - 1 - 2	3
Prob. of Normal (CHI-DIST)	<b>0.083</b>

> 0.05

Do not reject H0

Do not have sufficient evidence to prove that the data is not normally distributed  
(95% certainty)

### Chi-Squared Test for Uniform Distribution of Yes-Yes-Yes Responses

H0 = the data follows the uniform distribution

H1 = the data does not follow the uniform distribution

Level of Significance =  $1 - 0.95 = 0.05$

Exp. number of samples in each bin = (Percentage of Curve Area in that Bin) x  
Total number of samples

	Lower Bin Range	Upper Bin Range	Actual No.
Bin	BR	BR	Obs.
0	-0.1	0.1	7
0.2	0.1	0.3	11
0.4	0.3	0.5	17
0.6	0.5	0.7	9
0.8	0.7	0.9	8
1	0.9	1.1	4

Area in Bin		Expected Number of Observations
1 / 6		Exp.
0.167	x 56	9.333
0.167	x 56	9.333
0.167	x 56	9.333
0.167	x 56	9.333
0.167	x 56	9.333
0.167	x 56	9.333

Expected Number of Observations	Actual No.	Exp - Obs.	(Exp - Obs)^2 / (Exp)
Exp.	Obs.		
9.333	7	2.333	0.583
9.333	11	-1.667	0.298
9.333	17	-7.667	6.298
9.333	9	0.333	0.012
9.333	8	1.333	0.190
9.333	4	5.333	3.048
TOTAL (X^2) =			<b>10.429</b>

df = 6 - 1	5
Prob. of Uniform (CHI-DIST)	<b>0.064</b>

> 0.05

Do not reject H0

Do not have sufficient evidence to prove that the data is not uniformly distributed  
(95% certainty)

### Interpretation of the Chi-squared Test Results

Based on the results of the chi-squared test, I could neither reject the null hypothesis that the YYY survey responses have a normal distribution nor could I reject the null hypothesis that the responses have a uniform distribution. This appears to say that it could be both normally and uniformly distributed. To address the shortcoming of having one bin with a frequency of less than 5, I conducted the chi-squared test using 5 bins in place of the 6 bins that were initially used. For the 5 bins (values 0.0, 0.25, 0.5, 0.75, and 1.0), there was sufficient evidence to prove that the data is not normally distributed and also not uniformly distributed. I then decided to conduct the chi-squared test using 11 bins. For the 11 bins (values 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, and 1.0), there was sufficient evidence to prove that the data is not normally distributed and also not uniformly distributed. In conclusion: for 5 Bins; Not Normal and Not Uniform: for 6 Bins; Normal and Uniform: and for 11 Bins; Not Normal and Not Uniform. Hence, the shortcoming of insufficient sample size may have impacted the test and results. Nonetheless, since the distribution was not proven to be random, the potential reasons for the distribution needed to be identified.

### Potential Reasons for the Distribution of the Yes-Yes-Yes Responses for Questions on DFCS Measures per Survey

There were a number of potential reasons why the survey respondents tended to answer Yes-Yes-Yes to the questions for multiple DFCS measures. These are briefly discussed.

1. The DFCS measures included in the survey were mostly situated in the design phase and had the potential to improve construction safety.

This could be a sign that the first task, the indexing and categorization of DFCS measures, was effective in identifying the measures that were situated in the project design phase. Thus, the DFCS measures utilized in the survey were certainly not random in the first place.

2. Most of the survey respondents were safety conscious and thus had a favorable view of DFCS as a concept.

There were 644 email recipients and 90 email respondents. It is a possibility that the email respondents were those recipients that were safety conscious AEC design professionals with favorable views towards safety and hence, DFCS. This safety consciousness might have driven their participation and also driven them towards making multiple positive responses to the questions on the DFCS measures included in their respective surveys.

3. The placement of “Yes” as the first answer option may have motivated its selection.

Many respondents might have wanted to quickly complete the survey since they had “committed” to participating through their email responses. For this reason, they selected “Yes” throughout. Another possibility is that many may have selected “Yes” to avoid answering the question “Why?” But, as a matter of note, the survey did not require an answer for “Why?” to proceed. This was regardless of the answer (‘Yes’, ‘No’, or ‘Other’).

### Logical Sequencing of the Survey Responses and Implications on Future Research Tasks

There were 27 possible responses to the first segment of the three questions for each DFCS measure. These were indicated along with the number of DFCS measures that received the responses in *Table 39*.

	Is this measure applicable to the design phase of a project?	Do you feel this measure can improve construction worker safety?	Would you implement this measure in your design?	Number of DFCS Measures with the Responses
	Why?	Why? [Revisions]	Why? [Impediments]	
1	Yes	Yes	Yes	127
2	Yes	Yes	Other	18
3	Yes	Yes	No	6
4	Yes	Other	Other	15
5	Yes	Other	Yes	22
6	Yes	Other	No	3
7	Yes	No	No	10
8	Yes	No	Other	10
9	Yes	No	Yes	23
10	Other	Yes	Yes	3
11	Other	Yes	Other	11
12	Other	Yes	No	2
13	Other	Other	Other	9
14	Other	Other	Yes	1
15	Other	Other	No	2
16	Other	No	No	3
17	Other	No	Other	1
18	Other	No	Yes	1
19	No	Yes	Yes	7
20	No	Yes	Other	6
21	No	Yes	No	17
22	No	Other	Other	1
23	No	Other	Yes	1
24	No	Other	No	5
25	No	No	No	17
26	No	No	Other	4
27	No	No	Yes	0
				<b>325</b>

**Table 39:** Possible Responses to the First Segment of the 3 Questions for each DFCS Measure

As stated earlier, some measures had multiple responses that differed and these were double counted in the appropriate categories. Thus, the total of 325 DFCS measures with 317 measures utilized in the survey. Out of these possible responses, some were considered illogical. This was because the questions in the survey were related in a manner. Firstly, where the AEC design professional indicated that a measure was not applicable to the design phase of a project, it is illogical for the same respondent to indicate that he/she would implement the measure in his/her design. Secondly, where the respondent indicated that he/she does not feel that the DFCS measure can improve construction worker safety, it is illogical for the same respondent to indicate that he/she would implement the measure in his/her design. Responses considered illogical along with the number of DFCS measures that received the responses are seen in *Table 40*.

	Is this measure applicable to the design phase of a project?  Why?	Do you feel this measure can improve construction worker safety?  Why? [Revisions]	Would you implement this measure in your design?  Why? [Impediments]	Number of DFCS Measures with the Responses	Reason Why the Responses where Illogical
1.	Yes	No	Other	10	It was considered illogical for the respondent to indicate 'Other' with regards to if he/she would implement the DFCS measure when the respondent had already indicated that he/she does not feel the measure can improve construction worker safety.
2.	Yes	No	Yes	23	It was considered illogical for the respondent to indicate that he/she would implement the DFCS measure when the respondent had already indicated that he/she does not feel the measure can improve construction worker safety.
3.	Other	No	Other	1	It was considered illogical for the respondent to indicate 'Other' with regards to if he/she would implement the DFCS measure when the respondent had already indicated that he/she does not feel the measure can improve construction worker safety.
4.	Other	No	Yes	1	It was considered illogical for the respondent to indicate that he/she would implement the DFCS measure when the respondent had already indicated that he/she does not feel the measure can improve construction worker safety.
5.	No	Yes	Yes	7	It was considered illogical for the respondent to indicate that he/she would implement the DFCS measure in his/her design when the respondent had already indicated that the DFCS measure was not situated in the project design phase.

	Is this measure applicable to the design phase of a project?  Why?	Do you feel this measure can improve construction worker safety?  Why? [Revisions]	Would you implement this measure in your design?  Why? [Impediments]	Number of DFCS Measures with the Responses	Reason Why the Responses where Illogical
6.	No	Yes	Other	6	It was considered illogical for the respondent to indicate 'Other' with regards to if he/she would implement the DFCS measure when the respondent had already indicated that the DFCS measure was not situated in the project design phase.
7.	No	Other	Other	1	It was considered illogical for the respondent to indicate 'Other' with regards to if he/she would implement the DFCS measure when the respondent had already indicated that the DFCS measure was not situated in the project design phase.
8.	No	Other	Yes	1	It was considered illogical for the respondent to indicate that he/she would implement the DFCS measure in his/her design when the respondent had already indicated that the DFCS measure was not situated in the project design phase.
9.	No	No	Other	4	It was considered illogical for the respondent to indicate 'Other' with regards to if he/she would implement the DFCS measure when the respondent had already indicated that the DFCS measure was not situated in the project design phase.
10.	No	No	Yes	0	It was considered illogical for the respondent to indicate that he/she would implement the DFCS measure in his/her design when the respondent had already indicated that the DFCS measure was not situated in the project design phase.

**Table 40:** Illogical Responses to the First Segment of the 3 Questions for each DFCS Measure

Among those responses considered logical, there was also an AEC design professional that indicated that a DFCS measure was applicable to the project design phase and then indicated that he/she would not implement the measure because it was part of the construction process or sequence. The same respondent had a similar set of responses for another DFCS measure though he/she indicated willingness to implement the measure. Both sets of responses to the questions for the two respective DFCS measures are provided in *Table 41*.

With regards to future research tasks, the illogical responses to the first segment of the 3 questions and their respective DFCS measures were not utilized. Among these, those DFCS measures with 'Yes' and 'Other' responses with regards to being applicable to the project design phase had respondents that indicated that they did not feel the measures could improve construction safety. Additionally,

those DFCS measures for which there was a ‘No’ response with regards to being applicable to the project design phase were not utilized in future research tasks as they were not validated as design-phase DFCS measures besides having illogical responses to their respective questions. Meanwhile, the DFCS measures and the responses in *Table 41* were utilized in future research tasks. This was because the first segment was the level primarily used for the logical reasoning. And, at just two, the DFCS measures could be included in future research tasks with minimal scope impact. The need for control of the research scope arose because of the large number of DFCS measures identified as being situated in the project design phase from the first research task. There was a need to decrease the number of DFCS measures that would be utilized in the next research tasks, particularly the interviews of AEC design professionals. This was in the interest of feasibility. Logical sequencing served to prune down the numbers as well as eliminate illogical responses.

	DFCS Measures	Is this measure applicable to the design phase of a project?  Why?	Do you feel this measure can improve construction worker safety?  Why? [Revisions]	Would you implement this measure in your design?  Why? [Impediments]
1.	Design special attachments or holes in structural members at elevated work areas to provide permanent, stable connections for supports, lifelines, guardrails, scaffolding or lanyards.	Yes (1)	Yes (1)	No (1)  Designer is specifying construction method and procedure
2.	Install belaying bolts on pitched roofs for workers to connect fall restraint systems.	Yes (1)  May influence design loads	Yes (1)	Yes (1)  Only if became part of standard code. Otherwise designer is specifying construction method and procedure

**Table 41:** Illogical Responses to the Second Segment of the 3 Questions  
For each DFCS Measure where the First Segment was considered Logical

Also, those DFCS measures with logical responses, for which there was a ‘No’ response with regards to being applicable to the project design phase, were not to be utilized in future research tasks as they were not validated as design-phase DFCS measures. For all the remaining DFCS measures with logical responses, applicable safety incidents were to be identified. However, only the DFCS measures with Yes-Yes-Yes responses to their 3 respective questions were to be used in the interviews. Those DFCS measures were validated to be applicable to the project design phase, indicated to improve construction safety, and indicated to not have impediments to prevent their implementation. Those DFCS measures in this category but with indicated impediments imply that the impediments are not significant enough to prevent their implementation. This kept in line with the direction of this research, to minimize impediments to DFCS implementation. 127 DFCS measures were situated in this category. This was now a feasible number of DFCS measures to utilize in the interviews. The next research tasks for the

DFCS measures based on their survey responses are provided along with their number in *Table 42*.

	Is this measure applicable to the design phase of a project?  Why?	Do you feel this measure can improve construction worker safety?  Why? [Revisions]	Would you implement this measure in your design?  Why? [Impediments]	Number of DFCS Measures with the Responses	Next Research Tasks
1	Yes	Yes	Yes	127	<ul style="list-style-type: none"> <li>- Identify Preventable Safety Incidents for the DFCS Measures</li> <li>- Utilize in the Interviews of AEC design professionals</li> <li>- Include in the Relational Database Application</li> </ul>
2	Yes	Yes	Other	18	<ul style="list-style-type: none"> <li>- Identify Preventable Safety Incidents for the DFCS Measures</li> <li>- Include in the Relational Database Application</li> </ul>
3	Yes	Yes	No	6	
4	Yes	Other	Other	15	
5	Yes	Other	Yes	22	
6	Yes	Other	No	3	
7	Yes	No	No	10	
8	Other	Yes	Yes	3	
9	Other	Yes	Other	11	
10	Other	Yes	No	2	
11	Other	Other	Other	9	
12	Other	Other	Yes	1	
13	Other	Other	No	2	
14	Other	No	No	3	
15	No	Yes	No	17	<ul style="list-style-type: none"> <li>- Not to Utilize these DFCS Measures in future Research Tasks</li> </ul>
16	No	Other	No	5	
17	No	No	No	17	

**Table 42:** Next Research Tasks for the DFCS Measures with Logical Responses to the First Segment of their 3 Respective Survey Questions

As a result of the scope control approach and determination for the following research tasks, the DFCS measures were to be categorized into different tiers. This was based on their feasibility for implementation and the level of confidence in their effectiveness. Those DFCS measures utilized in the interviews were thus to have a higher tier. And those DFCS measures with ‘Yes’ responses with regards to being applicable to the project design phase were to have a higher tier than those with ‘Other’ responses.

### Unexpected Findings and Implications

Spillover effects from the output of the first research task were not unexpected. Upon completion of the first task, I anticipated that the large number of identified design-phase DFCS measures at 317 would subsequently result in a number that could be infeasible to fully utilize in the interviews of AEC design

professionals. As a result, logical reasoning and categorization were used to control the research scope. I must however note that I had not anticipated receiving illogical sets of responses to the questions. Though I was aware that the questions were linked, I had been primarily concerned with collecting and validating data. Logical sequencing arose as necessary to address the illogical set of responses and at the same time, to control the research scope.

The implication of the logical reasoning process was that only a few impediments to implementation of DFCS measures were utilized for validation through the interviews. This is because the DFCS measures utilized in the interviews were those that were validated to be applicable to the project design phase, indicated to improve construction safety, and indicated to not have impediments to prevent their implementation. It is thus understandable that such a set of measures had few identified impediments compared to those measures that were not to be utilized in the interviews. Hence, the interviews of AEC design professionals were also to be used to yield impediments to the included DFCS measures.

Another unexpected finding was the low response rate to the survey. Surveys have the known characteristic of low response rates. I anticipated a 20% response rate but yielded a 10.4% response rate. As a result, a very large number of email recipients were required for the research task. Identifying and contacting the 644 email recipients along with the elicitation of data from the email respondents took about 3.5 months. This more than doubled the time period that had been intended for survey administration. This extended the research timeline.

The final unexpected finding from this research task was the yielding of only the basis for revising 2 DFCS measures. One of the functions of the survey was to yield revisions of DFCS measures in the interest of improving their use and enhancing their effectiveness. The interviews of AEC design professionals were to validate these revisions and yield more where applicable. Given the survey results, the interviews were now to be primarily used in obtaining revisions and not validating revisions. This is besides the other two functions of the interviews, the validation and yielding of impediments to implementing the DFCS measures, and the validation of their identified preventable safety incidents.

### **4.1.3 Identification of Applicable Safety Incidents from OSHA Database**

#### **4.1.3.1 Objective**

The objective of this research task was to identify the preventable construction site hazard incidents from implementation of the DFCS measures applicable to the project design phase. This was important as the potential benefits of implementing a majority of DFCS measures had neither been determined nor provided. These hazard incidents are to serve as illustrative cases to justify implementation of the measures.

For each hazard incident, OSHA records the details of the accident, the degree of injury, the worker's occupation, the worker's establishment name, and the date of the accident. Also, OSHA specifies keywords for each hazard. The agency stores all this data in its publicly accessible database. This database accounts for practically all fatalities and a significant percentage of recordable injuries that occurred in the past 2-3 decades throughout the U.S construction industry. Using the project features to which each of the DFCS measures pertain, the OSHA database was searched for hazard incidences that could justifiably have been avoided through the measures.

#### **4.1.3.2      Procedure and Results**

This research task was executed through a number of steps. These steps were primarily situated on the OSHA Statistics and Data website (<http://www.osha.gov/oshstats/index.html>). This was the website through which the OSHA database was accessed. There were several types of searches or queries that could be used on the inspection data. These several types are provided and defined.

- Accident Investigation Search: This tool enables the user to search the text of Accident Investigation Summaries (OSHA-170 form) which were developed from OSHA accident inspections.
- Establishment Search: This query tool locates OSHA inspections conducted within a particular establishment.
- Frequently Cited OSHA Standards: This query tool allows the user to determine the most frequently cited Federal and State OSHA standards for a given SIC code.
- General Duty Standard Search: This tool enables the user to search the text associated with standards cited during OSHA inspections.
- Industry Profile for an OSHA Standard: This tool displays the industry SICs in which a specified Federal OSHA standard is most often cited.
- Inspection Information: This tool enables access to inspection information using the inspections' activity number.
- Search Inspections By SIC: This query tool locates OSHA inspections conducted within a particular industry group.
- SIC Manual: This enables users to access detailed information for a specified SIC, Division, or Major Group and also, to browse through the manual structure.

Amongst the several tools, the most appropriate for identifying applicable safety incidents for each DFCS measure was the Accident Investigation Search (AIS). Accident Investigation Summaries (OSHA 170 form) also known as Fatality and Catastrophe Investigation Summaries, are developed after OSHA conducts an inspection in response to a fatality or catastrophe. The summaries provide a description of the incident including the events leading to the incident and also the causal factors. Using the AIS, these summaries can be searched by keyword,

by text or description, event date, industry (SIC) and also, inspection number. These summaries currently include completed investigations from 1984 to 2011. The sources of the summaries in the OSHA database or Integrated Management Information System (IMIS) are the local federal and state offices in the geographical area where the activity occurred.

- Accident Investigation Search (AIS)

- o Search Fields and Terms

The AIS has an interface with many search fields. Terms placed in these fields are searched for in different parts of the investigation summaries. The interface also provides options for specifying other search criteria. It is imperative that the search terms and selections are neither too broad nor too specific in order to yield summaries of accidents that meet the requirements of the user. These entry fields and criteria are presented and briefly discussed.

- Description: Within the Description field, keyword(s) can be entered to search against the description of the accident summaries.
- Abstract: Within the Abstract field, keyword(s) can be entered to search against the abstract of the accident summaries.
- Keyword: Within the keyword field, keyword(s) are entered to search against the keywords of the accident summaries. A list of the key words used for the summaries is also provided on the AIS webpage.
- Display: The display box can be checked to display accident summaries that have only fatalities.
- SIC: The Standard Industrial Classification (SIC) is a United States government system for classifying industries by digit codes. The appropriate industry codes can be identified from the SIC manual situated on the OSHA website. ([http://www.osha.gov/pls/imis/sic\\_manual.html](http://www.osha.gov/pls/imis/sic_manual.html)). In this field, the SIC may be specified at the 2, 3, or 4-digit level. When searching using a two digit SIC, the search results will return the SIC range ending in 00 – 99 and when searching using a three digit SIC, the search results will return the SIC range ending in 0 – 9.
- OSHA Office: This drop-down list allows users to select the OSHA office or directorate involved in the inspection. The Fed & State selection identifies the OSHA Area Office or State reporting entity responsible for conducting the inspection.
- Event Date: This option enables specification of a date range for when the accidents in the summaries were investigated. A starting date and an ending date can be selected from the drop-down lists.

- Insp Nbr: This field enables entry of specific inspection numbers. When entered, results will be returned for the accident investigation with that unique inspection number.
- Search Results
 

The search results display the accident inspection summaries that meet the criteria and terms specified in the accident investigation search form. These results are presented in a tabular format with the specifics of the search criteria as the column headings. The column headings are listed.

  - Summary Nr (Summary Number)
  - Event Date
  - Report ID
  - Fat (Fatality)
  - SIC
  - Event Description

To get details of the identified accidents, the items in the “Summary Number” column are to be clicked on. There are also other interactive features on the page for selecting and sorting the search results.
- Accident Details
 

The accident report details page displays the accident number, description, report identification and event date along with other details. The details are listed and briefly described.

  - Inspection: This provides a unique digit identifier for the accident. This identifier can be clicked on to display the inspection detail page.
  - Open Date: This is the date the accident occurred
  - SIC: This indicates the 4-digit SIC code which most closely applies to the accident.
  - Establishment Name: This is the name of the employer whose employee encountered the accident.
  - The detailed description of the accident event
  - Keywords: These are the keywords used in identifying the accident.
  - End Use: This identifies the final use of the project if applicable.
  - Proj Type: This identifies the type of project.
  - Proj Cost: This identifies the cost range of the project.
  - Stories: This identifies the number of stories the building contains if applicable.
  - NonBldgHt: This identifies the non-building height if applicable.
  - Fatality: This indicates whether there was a fatality involved in the accident. An X indicates that there was a fatality.

- Age: This is the age of the person(s) involved in the accident.
  - Sex: This is the gender of the person(s) involved in the accident.
  - Degree: This is the degree of injury to the person(s) involved in the accident.
  - Nature: This is a brief description of the injuries sustained by the person(s) involved in the accident.
  - Occupation: This is the occupation of the person(s) involved in the accident.
  - Construction: This is the detail of the accident including the fall distance, fall height, cause of the accident, and the cause of the fatality if applicable.
- Inspection Details
 

The inspection details page displays the inspection report. This report contains information that includes the Inspection Number, Establishment Name, Report ID, SIC and Open Date of the accident. The North American Industry Classification System (NAICS) code is also indicated. The OSHA violations from the accident are also identified. Other information provided in the report are listed and briefly described.

    - Address of the accident site.
    - Inspection Type: The type of inspection performed.
    - Scope: The scope of the investigation.
    - Ownership: The type of ownership of the establishment involved.
    - Safety/Health: This indicates whether the inspection was safety or health related.
    - Planning Guide: The emphasis of the investigation.
    - Advance notice: This indicates whether the inspection was planned in advance.
    - Close Conference: The date the inspection was closed.
    - Close Case: The date the investigation was closed

### **Determining Accident Summaries applicable to specific DFCS Measures**

The accident details page was most appropriate for determining the safety incidents that are preventable through certain DFCS measures. This is since it provides the details and circumstances of the accidents. The inspection detail page meanwhile, places emphasis on the investigation itself and not the accident.

To demonstrate how this research task was executed, I present 4 DFCS measures considered applicable to the project design phase. 2 of these are applicable to architects while 1 is applicable to civil engineers and 1 to plumbing engineers. For each of these measures, I indicated the search terms I used, the

details I sought and the applicable OSHA incident. In all cases, priority was given to incidences that resulted in fatal injuries over those that resulted in non-fatal injuries. As the most serious type of injury, fatalities draw more attention. Thus, they are more likely to draw the interest of design professionals towards the DFCS measures that could have prevented them. Additionally, priority was given to more recent accidents where possible. This was because they are more likely to be applicable to current construction industry practices. It must however be noted that the Accident Investigation Search only allowed for a search period of 10 years at a time.

- ARCHITECTS

o Design a permanent guardrail that surrounds each skylight.

A guardrail will prevent injuries that occurred from individuals that unknowingly stepped and fell through a skylight. A guardrail will arrest falls by preventing the worker from stepping on the skylight. A worker may also sight the guardrail and just avoid the skylight. To find an applicable safety incident to the DFCS measure, I searched for incidences where a worker unknowingly stepped onto a skylight which then gave way. If a guardrail was present around the skylight, the worker could conceivably have been saved from injuries. The search terms used and the resulting applicable accident summary are provided.

▪ Search Terms

- Description: -
- Abstract: -
- Keyword: -
- Display: Fatality Only
- SIC: Skylight, Fall, Guardrail
- OSHA Office: All Offices
- Event Date; Start Date: January 1, 1984
- Event Date; End Date: December 31, 1993
- Insp Nr: -

▪ Search Results

There were 5 search results matching the search criteria. I read through the details of the accident summaries till I found an applicable incident. This incident is seen in *Figure 23*.

Accident: 170127344 - Employee Killed In Fall Through Skylight					
Accident: 170127344 -- Report ID: 0751910 -- Event Date: 09/22/1993					
Inspection	Open Date	SIC	Establishment Name		
115063703	09/23/1993	3255	Sioux City Brick & Tile Company		
Employee #1 was walking across a roof when he stepped on a green fiberglass skylight and fell through the roof onto a pile of bricks. He was killed. There was no guardrail or skylight screen to protect employees from falling through the roof.					
Keywords: fall, skylight, work rules, screen, roof, unguarded, guardrail, barrier guard					
Inspection	Age	Sex	Degree	Nature	Occupation
1 115063703			Fatality	Other	Occupation not reported

**Figure 23:** Accident Incident applicable to DFCS Measure  
[Design permanent guardrail that surrounds each skylight]

- In multi-story buildings, design each floor plan to have a smaller area than the story below to prevent objects and workers from falling more than one story.

This DFCS measure is intended to decrease the severity of injuries from the falls of workers and also objects. This is through the design of offsets that are caused by differences in area between floors in multi-story buildings. The lower floor should therefore have a larger area than the immediate upper floor.

To find an applicable safety incident to the DFCS measure, I searched for incidences where a worker fell for more than one story to the floor or ground. I considered falls from balconies to be appropriate incidences as balconies offer more of a fall hazard risk. Furthermore, where balconies are present on all floors and the immediate lower floor balcony was at an appropriate offset, the worker could have been prevented from falling through more than one story. The search terms used and the resulting applicable accident summary are provided.

- Search Terms
  - Description: Balcony
  - Abstract: -
  - Keyword: -
  - Display: Fatality Only
  - SIC: 15
  - OSHA Office: All Offices
  - Event Date; Start Date: January 1, 1994
  - Event Date; End Date: December 31, 2003
  - Insp Nr: -

- Search Results

There were 3 search results matching the search criteria. I read through the details of the accident summaries till I found an applicable incident. This incident is seen in *Figure 24*.

Accident: 170075329 - Employee Killed After Fall From Balcony							
Accident: 170075329 -- Report ID: 0257250 -- Event Date: 12/16/2003							
Inspection	Open Date	SIC	Establishment Name				
306662263	12/17/2003	1521	Constructora I Melendez Inc				
On December 16, 2003, an employee fell from the fourth floor balcony of a residential building and was instantly killed.							
Keywords:			fall, fracture				
End Use	Proj Type		Proj Cost		Stories	NonBldgHt	Fatality
Multi-family dwelling	Alteration or rehabilitation		\$50,000 to \$250,000		4	26	X
Inspection	Age	Sex	Degree	Nature	Occupation	Construction	
1 306662263			Fatality	Fracture	Occupation not reported	<b>FallDist:</b> 26 <b>FallHt:</b> 26 <b>Cause:</b> Temporary work (buildings, facilities) <b>FatCause:</b> Fall from/with structure (other than roof)	

**Figure 24:** Accident Incident applicable to DFCS Measure

[Design each floor plan to have a smaller area than the story below to prevent falling more than one story]

- CIVIL/STRUCTURAL ENGINEERS

- In order to allow sufficient walking surface, use a minimum beam width of 6 inches.

This DFCS measure is intended to prevent the fall of workers using beams as a walking surface. Where there is a narrow beam and therefore narrow walking surface, it is more likely that a worker will lose balance and fall. While considering this, it is important to note that fall protection systems are required in such circumstances and they should support the worker even in the event of a fall. However, not all workers use their fall protection as prescribed. Regardless, even when a worker does not use fall protection, he/she is more likely to fall off a narrow beam than a wide beam.

To find an applicable safety incident to the DFCS measure, I searched for incidences where a worker fell off a beam with/without fall protection. If the beam was wider, the chances of the worker falling could have been decreased but not eliminated. The search terms used and the resulting applicable accident summary are provided.

- Search Terms
  - Description: Fall
  - Abstract: Steel Beam
  - Keyword: -
  - Display: Fatality Only
  - SIC: -
  - OSHA Office: All Offices
  - Event Date; Start Date: January 1, 1994
  - Event Date; End Date: December 31, 2003
  - Insp Nr: -

- Search Results

There were 54 search results matching the search criteria. I read through the details of the accident summaries until I found an applicable incident. This incident is seen in *Figure 25*.

Accident: 951434 - Employee Killed In Fall From Beam							
Accident: 951434 -- Report ID: 0355114 -- Event Date: 10/23/1997							
Inspection 125470542	Open Date 10/27/1997	SIC 1751	Establishment Name King Construction				
Employee #1, who was installing plywood decking on the second floor of a single-family home under construction, was headed to the ladder to go down and get more material. He was walking across a 3 in. wide by 9 ft long steel beam when he slipped and fell 11 ft onto a concrete floor. Employee #1 struck his head and was transported to the hospital, where he died at 2:30 p.m. on October 24, 1997. The ladder was positioned in the wrong place for access.							
Keywords: construction, fall, unstable position, ladder, slip, struck against, head, work rules, walking on beam							
End Use		Proj Type		Proj Cost	Stories	NonBldgHt	Fatality
Single family or duplex dwelling		New project or new addition		Under \$50,000	2	11	X
Inspection	Age	Sex	Degree	Nature	Occupation	Construction	
1	125470542		Fatality	Fracture	Construction laborers	<b>FallDist:</b> 11 <b>FallHt:</b> 1 <b>Cause:</b> Installation Of Decking-Initial Laying Deck (Incl <b>FatCause:</b> Fall from/with ladder	

**Figure 25:** Accident Incident applicable to DFCS Measure  
[In order to allow sufficient walking surface, use a minimum beam width of 6 inches]

- MEP ENGINEERS – PLUMBING ENGINEERS

- Minimize flanges in piping under high pressure, or which contains explosive or lethal gases.

This DFCS measure is intended to prevent piping flanges from breaking or bursting due to high pressure and causing an explosion

or fire. To find an applicable safety incident to the DFCS measure, I searched for incidences that involved a piping flange. The search terms used and the resulting applicable accident summary are provided.

▪ Search Terms

- Description: -
- Abstract: Flange Pressure
- Keyword: -
- Display: -
- SIC: -
- OSHA Office: All Offices
- Event Date; Start Date: January 1, 1984
- Event Date; End Date: December 31, 1993
- Insp Nr: -

▪ Search Results

There were 20 search results matching the search criteria. I read through the details of the accident summaries until I found an applicable incident. This incident is seen in *Figure 26*.

Accident: 784256 - Employees Suffer Smoke Inhalation					
Accident: 784256 -- Report ID: 0452110 -- Event Date: 01/02/1989					
Inspection	Open Date	SIC	Establishment Name		
102016748	01/06/1989	2491	Louisville Division Of Fire		
Inspection	Open Date	SIC	Establishment Name		
104327184	01/02/1989	1711	Total Boiler Inc		
Inspection	Open Date	SIC	Establishment Name		
102016748	01/06/1989	2491	Louisville Division Of Fire		
Pressure built up in a rouper, causing a flange to break and releasing a pipe. The pipe went through the roof, causing sparks, which started a fire. Employees #1, #2, and #3 suffered smoke inhalation.					
Keywords: fire, spark, pipe, inhalation, smoke, smoke inhalation, high pressure, equipment failure, spark, respiratory					
Inspection	Age	Sex	Degree	Nature	Occupation
1 102016748			Non Hospitalized injury	Asphyxia	Firefighting occupations
2 102016748			Non Hospitalized injury	Asphyxia	Firefighting occupations
3 104327184					
4 102016748			Non Hospitalized injury	Asphyxia	Firefighting occupations

**Figure 26:** Accident Incident applicable to DFCS Measure

[Minimize flanges in piping under high pressure, or which contains explosive or lethal gases]

## DFCS Measures and Preventable Safety Incidents

This section provides a sample of DFCS measures and their preventable safety incidents as identified through this research task. These are provided for the different AEC design professions as seen in *Table 43*.

	DFCS Measures	Preventable Safety Incidents
	<b>ARCHITECTS</b>	
Ex. 1	Maintain a uniform stair slope throughout the project.	[Accident: 14222640] At approximately 11:45 a.m. on September 12, 2000, Employee #1 was on the third floor of a town home under construction showing a coworker how to install handrails on the stairs. He had been measuring the area where the handrails were to be installed and showing the coworker the area. As he was walking down, he stepped at the edge of a stair, lost his footing, and fell approximately 32 ft onto a concrete floor. The medical examiner's office gave the preliminary cause of death as multiple blunt trauma to the head.
Ex. 2.	Provide inserts in window jambs for guardrail attachment.	[Accident: 170245328] Employee #1, age 20, was one of a crew of four working on the framing of a condominium building. They were lifting an overhead structural beam into place when it became wedged between an outer guardrail support and a plumb support. Employee #1 stepped onto the sill of a third-floor window and reached up and out, trying to free the beam. The guardrail that was nailed to the outside of the building came free as Employee #1 leaned against it. He fell 25 ft and was killed.
	<b>CIVIL / STRUCTURAL ENGINEERS</b>	
Ex. 3	Design structural member depths to allow adequate head room clearance around stairs, platforms, valves, and all areas of egress.	[Accident: 170361919] Employee #1 was climbing onto a catwalk when he stood up under a large steel beam that was 60 1/2 in. above the catwalk and struck his head with enough force to break the suspension in his hard hat. He did not seek medical treatment at the time, but over a year later he began experiencing numbness in his extremities. He was diagnosed with severe stenosis of his neck vertebra and underwent surgery. The steel beam was neither marked nor padded.
Ex. 4	Design special attachments or holes in structural members at elevated work areas to provide permanent, stable connections for supports, lifelines, guardrails, scaffolding or lanyards.	[Accident: 200200475] Employee #1 was working on the seventh floor of an office building under construction. Preparations were underway for the floors to be formed and poured. Employee #1 was on the perimeter edge on the east side of the structure, patching and filling post tensioning holes. He was on the exterior side of an outer column, between floors, when he fell approximately 80 ft to the ground. Employee #1 was killed. At the time of the accident, he was wearing a safety harness and lifeline. There were no witnesses on the seventh floor and the superintendent on the second floor, who saw something drop, initially thought that some trash had been thrown over the side of the building. He went to investigate and saw Employee #1 lying on the ground. Another coworker, who was on the ground about 100 ft away, was facing the building and saw Employee #1 fall.

	DFCS Measures	Preventable Safety Incidents
	<u>M/E/P ENGINEERS</u> – MECHANICAL ENGINEERS	
Ex. 5	To reduce fall hazards, locate rooftop mechanical/HVAC equipment away from the edge of the structure.	[Accident: 170700595] At about 10:00 a.m. on April 22, 1994, Employee #1, an iron worker, was on the roof of a building to install a metal foundation for an HVAC unit. The work was conducted near the roof edge, which had a 16-inch high parapet. He fell backward over the parapet and then fell about 37 ft to a concrete sidewalk. Employee #1 was hospitalized with multiple fractures.
	<u>M/E/P ENGINEERS</u> – ELECTRICAL ENGINEERS	
Ex. 6	Ensure that the withstand rating is adequate for the available fault current.	[Accident: 202363776] On January 20, 2004, Employees #1 and #2, of Global Electric Communications, were installing a new three-phase run of wire in an energized 480-volt panel at a cabinet shop in Kent, WA. Employee #1 was trying to bolt a bracket to the panel's busbar when an electric arc occurred. He sustained thermal burns and was taken to Harborview Burn Center in Seattle, WA. Employee #2 was trying to show the owner of the cabinet shop what had happened to Employee #1 when another electric arc occurred. He also suffered thermal burns and was transported to the same hospital as Employee #1. The arc that burned Employee #1 was caused by a high fault current created by the bracket, of which Employee #1 had lost control. The bracket became energized and contacted another phase in the circuit breaker. Employee #2 thought the panel had been de-energized by the circuit protection at the source.
	<u>M/E/P ENGINEERS</u> – PLUMBING ENGINEERS	
Ex. 7	Design steam lines with drips or freeblows to prevent steam hammer or slugging.	[Accident: 200271096] On May 25, 2002, Employee #1 and his supervisor were slowly opening a 30-psi manual steam valve on a 30-in. steam line during plant start up procedures. When they heard what they believed to be a water hammer occurring in the line, they attempted to close the valve. The valve blew apart, the line separated, and Employee #1 was burned over 80 to 90 percent of his body. He died from his injuries on July 30, 2002.

**Table 43:** Sample DFCS Measures and their Preventable Safety Incidents

#### 4.1.3.3 Unexpected Findings and Implications for Next Research Tasks

Preventable safety incidents were identified for the DFCS measures considered to be applicable to the project design phase. There was however an unexpected finding. Not all the identified incidents were fully and directly preventable through their respective DFCS measures. This was because, after an extensive database search, no safety incident was found to be directly preventable through certain DFCS measures. As a result, those found to be most applicable were identified for those DFCS measures. It must be noted that in all instances, the DFCS measures were to have at least the potential of decreasing the risk of the identified safety incidents from the OSHA database.

This finding was unexpected because, given the large number of accidents in the OSHA database, I anticipated that an extensive search would identify directly preventable safety incidents for most of the DFCS measures and indirectly preventable safety incidents for the remaining measures. It is also important to note that a significant number of safety incidents in the OSHA database were not detailed in-depth or adequately for the purpose of this research. Such incidents could only apply more broadly and less specifically to the DFCS measures.

The implication for the next research task, the interviews of AEC design professionals, was that a certain outcome could be expected. One of the objectives of the interviews was the validation of safety incidents as preventable through implementation of the design-phase DFCS measures. Several of the safety incidents were likely to be identified as not being preventable through their respective DFCS measures. Additionally, unsafe acts of the injured worker or workers could be identified as the primary and/or only cause of a safety incident. On the basis of these expected outcomes, the DFCS measures and their details were to be further categorized to differentiate between those with preventable safety incidents that were validated and those with incidents that were not validated. Those in the former category would have a higher tier while those in the latter category would have a lower tier. It must also be noted that the safety incidents for the DFCS measures that were not to be used in the interviews were not subjected to validation and as such, retained a lower tier. The categorization of DFCS measures was to be primarily utilized in the development of the relational database application, which followed the interviews of AEC design professionals.

#### **4.1.4 Interviews of AEC Professionals**

##### **4.1.4.1 Objective**

The interviews of AEC design professionals were to be primarily used in validating three products from the earlier research tasks. As earlier stated, interviewing is considered appropriate for validating information obtained using other data collection methods (Maxwell, 2005). Firstly, the interviews were used in validating and yielding impediments to successful implementation of certain DFCS measures. These were measures that were earlier validated to be applicable to the project design phase, indicated to improve construction safety, and indicated to not have impediments significant enough to prevent their implementation. Secondly, the interviews were used to validate the applicable safety incidents identified from the OSHA database. Lastly, they were used in obtaining revisions to the DFCS measures where applicable, as revisions were not successfully yielded in the earlier research tasks.

#### 4.1.4.2 Procedure and Design

The interview process was thoroughly discussed in *Section 3.2.2.3*. In developing the research interview, I took all the discussed issues and guidelines into consideration. This section presents and discusses the features of the interviews that were conducted with AEC design professionals based on the steps described by King and Horrocks (2010) and McNamara (2007).

1. The type of interview was selected.

The type of interview was selected based on structure, format, mode of administration, number of participants and specialization.

- Highly Structured / Standardized Interviews

This type of interview was necessary to obtain the specific information sought through the interviews. This information was intended to validate earlier collected data. For this reason, the interview was structured. However, an informal approach was utilized for each of the questions as they were open-ended and flexible/exploratory (Merriam, 2009).

- Qualitative Interviews and Questions

This research was primarily qualitative. As such, the interviews and their questions were also qualitative. Also, as the interview was intended for validation of certain research products, the type of qualitative interview used was the standardized open-ended interview. In this type of interview, the exact wording and sequence of questions are determined in advance, and all interviewees are to be asked the same basic questions in the same order (Johnson and Christensen, 2007). In this research, interviewees were asked the same questions in the same order for the DFCS measures.

- Face-to-face and Remote Interviewing

The conventional interview approach, face-to-face interviewing, was to be primarily utilized. For this, the potential interview sample was to be situated at a proximal physical distance to ensure the face-to-face interviews were feasible and in most cases, the preferred option.

However, majority of the AEC design professionals only offered remote interviews. The only form of remote interviews utilized was telephone interviews. The interviewees were provided with the interview guide via email prior to the interviews.

- One-to-one Interviews

The conventional interview with one interviewer and one interviewee was utilized. This type of interview is most appropriate for obtaining in-depth information from individual participants and also for exploring sensitive areas (King and Horrocks, 2010). Many might consider construction worker safety a sensitive area.

- Interviewing of Elites Specialization  
In interviewing of elites, the interviewees are selected on the basis of their expertise in areas relevant to the research (Marshall and Rossman, 2006). In this DFCS research, the interviewees were AEC design professionals.
2. The sample was defined and the participants and key informants were recruited.
- Sample Selection  
To be appropriate to the DFCS research topic, purposive sampling was utilized. Data must be collected from the AEC professional the DFCS measures are most applicable to. The design disciplines and sub-disciplines addressed by the 430 design suggestions determined by the CII are indicated in *Table 24*. Based on the main disciplines addressed by the suggestions, certain AEC professionals from both industry and academia were included in the sample. These include architects, civil/structural engineers and MEP engineers. They were to preferably have experience of five years minimum so as to ensure they had the exposure to provide useful information on the DFCS measures.
  - Sample Sizing  
Blaxter et al (2006) considers half a dozen interviews as relatively modest for a research study. Meanwhile, McCracken (1988) states that research interviews should follow a few rules of thumb including that respondents should be no more than 8 in number. However, considering the interviews were to be used in validating certain data for design-phase DFCS measures, the number of interviews depended on the number of the measures. 127 DFCS measures were to be utilized in the interviews. These DFCS measures were split into different interview guide versions. Each of these versions was then required to have at least one respondent. As such, the size of the sample remained variable until the completion of the research task. This was a form of quota sampling that was also applied to the number of professionals from each design discipline. So where additional civil/structural engineers were required to provide data for civil engineering related DFCS measures, the sample size was expanded appropriately.
  - Gaining Access to the Selected Sample  
To gain access to the selected sample, the internet, search engines and professional networking sites were used. The same approach used in selecting the research survey sample was used but with one main specification. The interview sample was to be preferably

proximally situated. Therefore, the AEC design professionals were to be mostly selected from design firms and universities situated in the Pittsburgh, PA metropolitan area. Those that met my sample criteria were selected and their name, affiliation, email address and location recorded.

- Sample Recruitment

The interview sample was contacted via email. In the email, I introduced myself and stated my status. I also provided the name of my advisor. I stated the basis for the sample selection as being an AEC professional with experience in design and possibly, construction. I then requested input in my research pertaining to DFCS via an interview. I also indicated the expected timeframe for the interview. I then requested to know the potential interviewee's preferred mode of interview and location for the interview. I also noted my capability in being available at that location. Lastly, I requested a response or notification if the email recipient was willing to participate. I also included greetings and thanks while expressing the high value of the professionals' inputs to my research. I tailored all my emails to the particular professionals I contacted.

- Email Responses

Where the email recipients responded and agreed to participate, I expressed my appreciation and clarified the mode, timing, and location of the interview. With this correspondence complete, I sent a reminder email one day prior to the interview date. Depending on the email responses received, other AEC professionals were contacted to fulfill the required number of interviews. The sample size was thus appropriately expanded where no potential interviewee from a design discipline responded to an interview request. Purposive sampling was used towards this.

3. The interview guide was developed.

- Interview Guide based on Literature and Preliminary Work on the Research Area and Topic

The interviews were intended to validate two research products and obtain one research product. These products were determined based on literature and preliminary work on the research topic. The interview guide included questions that pertained to certain DFCS measures.

- Comprehensive Interview Guide

As there were specific questions that needed to be answered, I was to lead the interview direction to a large extent while providing opportunity for participants' perspectives.

- Types of Questions on the Interview Guide  
The interview guide included all types of interview questions such as background, experience, opinion, feeling, knowledge and sensory questions.
- Limited Flexibility of Interview Guide to Change  
During the course of the study, flexibility for changing the interview guide was limited. As the same questions were intended to be asked for each DFCS measure, it was imperative the interview guide was controlled and remained consistent to achieve the intended functions of the interview.
- Full-Question Interview Guide Format  
This format was necessary to ensure answers to the specific questions were obtained. As I was to take a directive role with interview flexibility controlled, this was the appropriate format.
- Probes or Prompts in the Interview Guide  
Probes were anticipated to provide more depth to the interviewees' or participants' responses. As such, the probes were included on the interview guide. They were however to be controlled to ensure they adhered to time constraints.  
Prompts were used as necessary when the interviewee expressed uncertainty of an interview question. Over the course of an interview, both probes and prompts were formulated to obtain comprehensible and useful information from the interviewee.
- Interview Guide Versions  
Different guides may be necessary for interviewing different groups of participants or interviewees (McNamara, 2007). I created separate versions of interview guides for each of the interviews. DFCS measures were included in each of the interview guide versions by AEC design profession. The measures were to be dissimilar in terms of the project feature they addressed as this would more likely retain the interest of the interviewees and also prevent multiple similar responses. Each of the interviews was executed with a sample from the design disciplines for which the DFCS measures were applicable to. These included architects, civil/structural engineers, and MEP engineers.
- Format and Structure of the Interview Guide
  - The interview guide had a cover page that provided the following information.
    - The research topic
    - The research purpose

- The intended use of the collected information
  - The basis for selecting the interviewees
  - The anonymity of responses
  - The expected length of the interview
  - Researcher's name and contact details
  - Research advisor's name and contact details
- The interview guide had 4 sections
    - Discussion Section: Liability for Worker Safety  
In this section, the issue of liability for worker safety and how DFCS can improve safety without violating model contract language was briefly discussed.
    - Section 1: General Information  
This section included questions intended for confirmation of the participant's background and also to serve as an icebreaker. The following information was collected about the interviewee.
      - Profession
      - Job Title/Position
      - Years of Experience
    - Section 2: Design Measures  
This section included questions on the DFCS measures. For each DFCS measure, three questions in line with the interview objectives were to be asked. These questions are seen in *Table 44*. An important advantage of interviews is they allow for interviewees to clarify the meanings of questions (Marshall and Rossman, 2006). Nonetheless, questions should be asked in a comprehensible manner. Interview questions are thus to be sequenced to address progressing issues pertaining to the DFCS measures (King and Horrocks, 2010).
    - Section 3: Other Questions  
This section included one question on the DFCS study and one on the participation of the interviewee. These are the two questions.
      - Would you like your participation in the study to be confidential?
      - Do you have any general comments or suggestions on DFCS or on the study?

	Question Function	Interview Questions
1.	To validate the impediments to successful implementation of the DFCS measures determined to be applicable to the project design phase.	<p>Possible impediments to successful implementation of this measure in the project design phase were identified. Do you find these or other impediments to be applicable?</p> <p>[Impediments identified by the research survey respondents are presented after the question]</p>
2.	To validate the revisions of the DFCS measures so as to increase their implementation on projects and possibly enhance their effectiveness in improving safety.	<p>Revisions of this DFCS Measure were made towards improving its implementation on projects. Do you find these or other revisions achieve this purpose?</p> <p>[Revisions determined by the research survey respondents are presented after the question]</p>
3.	To validate the safety incidents preventable by implementation of the DFCS measures. These incidents were those identified from the OSHA database.	<p>The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure.</p> <p>[The OSHA accident summary is presented]</p> <p>Is this incident preventable with implementation of this DFCS measure?</p>

**Table 44:** Interview Data Collection Questions for DFCS Measures

#### 4. The pilot interview was conducted.

- Sample Recruitment for Pilot Interview(s)
  - Interview Guide Versions
 

I created 2 versions of the interview guide for two different design disciplines, architects and civil engineers. DFCS measures applicable to each of the disciplines were included in the appropriate interview guides. Also, the measures were those I considered applicable to the project design phase.

    - Architect: 1 interview guide with 4 DFCS measures. This pilot interview guide is provided in *Appendix E1*.
    - Civil Engineer: 1 interview guide with 4 DFCS measures.
  - Sample Selection and Contact
    - I used purposive and convenience sampling to select 2 AEC professionals in my university (Carnegie Mellon University). One was an architect and the other a civil engineer. I applied these two criteria.
      - A minimum of 5 years in working experience
      - Some background in not just design but construction projects

- I contacted the sample of 2 AEC professionals via email. In the email, I introduced myself and stated my PhD student status. I also stated the name of my advisor. I then requested input in my research pertaining to DFCS. I then stated that the interview was to be a pilot interview that is expected to take no more than 30 minutes. I also indicated the basis for the sample selection, AEC professional with experience in design and construction. Lastly, I requested that I be notified if the email recipient was willing to participate. Greetings and thanks were also included.
- Sample Response and Recruitment
  - One email recipient responded and agreed to participate. I expressed my appreciation and requested for the respondent to provide me with a range of preferred times and a preferred location for the interview. I selected one of these times and confirmed that I would be present at the respondent's preferred location. The recruited pilot interviewee was the architect.
- The Interview Setting
 

The interview setting was the office of the interviewee. The location met the three important aspects of the physical interview environment which include comfort, privacy and quiet (King and Horrocks, 2010).
- Recording
 

The style of recording was note-taking on the interview guide itself. I designed the interview guide with spaces in-between and after the questions to enable note-taking. I found this necessary to ensure the comfort of the interviewee since some may consider safety and liability as sensitive issues. I did not ask for permission to take notes.
- Building Rapport
 

To build rapport, there are certain strategies I took to make the interviewee feel comfortable revealing his honest and complete answers.

  - Provision of duplicate interview guide: I provided the interviewee with a duplicate of the interview guide for 3 main reasons. Firstly, as specific issues were to be addressed, the interviewee would need a document to refer to for the DFCS information. This would minimize the need for lengthy dictations which could result in lost time. Secondly, this was to make the interviewee more comfortable as he knows the

exact information being sought and is assured there were no hidden motives to the interview. Thirdly, it provided a medium on which the interviewee could indicate his responses and also illustrate his explanation. Upon completion of the interview, this duplicate interview guide was collected from the interviewee.

- Introducing the project: I explained the first two pages of the interview guide which stated the interview purpose, the intended uses of the responses, assurances of confidentiality and also, identified my research advisor.
- Self-presentation: I dressed semi-formally to emphasize my student status.

- Probing

All types of probes were utilized in the pilot interview including elaboration, clarification and completion (King and Horrocks, 2010). All were however limited to avoid lost time. Some of the probes were already included in the interview guide while others were devised during the course of the interview.

- Improvements to Research Interviews based on Pilot Interview

The pilot interview was conducted in an identical manner to that intended for the research interview. Gillham (2000) recommended one or two pilot interviews. Based on the pilots, certain adjustments and alterations could be required to improve the effectiveness of the proposed interviews (Gillham, 2000). Three improvements were identified.

- The expected length of the interview was increased to 45 minutes. The pilot interview was only 25 minutes long and was successful in addressing only 3 DFCS measures.
- The number of DFCS measures to be included in the interview guide was set at 5-7 measures as appropriate for an interview timeframe of 45 minutes. With an improved set of interview questions and format, this was considered achievable.
- The interview questions were modified to minimize lost time due to clarifications and to yield more useful responses. King and Horrocks (2010) indicate that over-complex and multiple questions should be avoided in interviews. One later modification was the non-inclusion of revisions as they were not successfully yielded from earlier research tasks. Thus, the same question utilized for obtaining revisions in the research survey was to be utilized in the research interview guide. Though impediments to certain DFCS measures were yielded from the research surveys, these were not to be exclusively provided in the revised interview questions for those particular measures. Instead, all the six main

impediments to DFCS were to be included with the interview question. This was to allow for the interviewee to evaluate whether each of the impediments applied to the included DFCS measures. It was also to facilitate the identification of other impediments or concerns that applied to the DFCS measures. As this specification could be restrictive, as part of the interview, I was to ask if there were any other impediments that could prevent implementation of the DFCS measures. The wording of the question was also simplified for better understanding. Any impediments identified were then to be validated against the impediments identified from the survey where applicable. The revised interview questions that were asked for each included DFCS measure are indicated in *Table 45*.

- The order of the interview questions was also modified for the DFCS measures. It seemed more effective to ask the question with regards to improving construction safety, then ask the question with regards to being applicable to the provided safety incident, and then ask whether the design professional would implement the measure. This sequence seemed to better address progressing issues pertaining to the DFCS measures. It also allowed for the AEC design professional to ponder longer before indicating whether he/she would be willing to implement the DFCS measures. The revised order of interview questions for each DFCS measure is indicated in *Table 45*.

	Question Function	Revised Interview Questions
1.	To obtain the revisions of the DFCS measures so as to increase their implementation on projects and possibly enhance their effectiveness in improving safety.	Do you feel this measure can improve construction worker safety?  Why?
2.	To validate the safety incidents preventable by implementation of the DFCS measures. These incidents were those identified from the OSHA database.	The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure:  [The OSHA accident summary is presented]  Is this incident preventable with implementation of this DFCS measure?
3.	To validate the impediments to successful implementation of the DFCS measures determined to be applicable to the project design phase.	Would you implement this measure in your design?  Would any of the following factors prevent you from implementing this measure in your design? <ul style="list-style-type: none"> <li>- Exposure to liability</li> <li>- Increased cost</li> <li>- Schedule problems and time constraints</li> <li>- Decreased project quality and diminished design creativity</li> <li>- Designers' lack of safety expertise</li> <li>- Absence of designer interest and motivation</li> </ul>

**Table 45:** Revised Interview Data Collection Questions for DFCS Measures

5. The research interview was conducted.

○ Sample Recruitment for Interviews

I used purposive sampling to select the AEC design professionals for my interviews. This sample was primarily situated in the Pittsburgh metropolitan area. As earlier stated, the sample size remained variable until all the interview guides were utilized. The sample comprised of professionals in the different design disciplines as appropriate for the DFCS measures. The sample was contacted via email. I used the email to introduce myself, my research and to request for participation. I indicated that the expected timeframe for the interview was 45 minutes. I also indicated the basis for the sample selection and requested that I be notified if the email recipient was willing to participate. Once an email recipient responded and agreed to participate, I expressed my appreciation and continued correspondence to set the mode, time and location for the interview where applicable. The location was that preferred by the participant or interviewee. A sample of the sent email is provided in *Appendix G2*.

○ The Interview Guide: 22 Versions with 4 Sections

There were distinct versions of the interview guide for the research interviews. The number of versions was determined based on the number of DFCS measures to be utilized in the interviews and the number of DFCS measures applicable to the different design disciplines. As determined from earlier research tasks, 127 DFCS measures were to be utilized. Additionally, questions were to be included for 5-7 DFCS measures on each interview guide version. This determined the need for 22 distinct interview guides. As seen in *Table 46*, these versions were categorized for architects, civil engineers, and MEP engineers.

AEC Design Professionals		Number of DFCS Measures and Interview Guide Versions	
		<u>Design-phase DFCS Measures</u>	<u>Interview Guide Versions</u>
Architects		43	8
Civil/Structural Engineers		33	6
M/E/P Engineers		51	8
	<i>Mechanical</i>	14	2
	<i>Electrical</i>	19	3
	<i>Plumbing</i>	18	3
TOTAL		127	22

**Table 46:** Design-phase DFCS Measures and Interview Guide Versions by AEC Design Professional

The interview questions asked for each DFCS measure are indicated in *Table 45*. Versions of the research interview guide applicable to architects and civil/structural engineers are respectively provided in *Appendix E2* and *Appendix E3*. As seen, each interview guide had 4 sections. These are indicated.

- Discussion Section: Liability for Worker Safety
  - Section 1: General Background Information
  - Section 2: Design Measures and Questions
  - Section 3: Questions on the Study and Participation
- The Interview Setting  
The interview setting for the face-to-face interviews was the preferred location of the interviewee which was to be comfortable, private and quiet. This included the interviewees' offices or alternate locations such as rooms on the campus of Carnegie Mellon University. This issue was not applicable in the case of the telephone interviews.
  - Recording  
Note-taking was used for recording the interview. These notes were written on the interview guide, which was designed with spaces to allow for data entry.
  - Strategies used for Building Rapport
    - Provision of duplicate interview guide to the interviewee for reference and explanatory purposes.
    - Introduction of the interviewee to the project, the interview purpose and also, self-presentation.
  - Probing  
All types of probes were utilized in the interviews including elaboration, clarification and completion to yield more useful information on the DFCS measures. The use of probes was not over-excessive to avoid lost time.
  - Interview Administration Process  
The research interviews were administered similarly to the process and steps prescribed by McNamara (2007).
    - i. Greet and express appreciation for interviewee's participation.
    - ii. Introduce self.
    - iii. Briefly explain the research topic.
    - iv. Explain the purpose of the interview and the confidentiality of responses.
    - v. State the expected duration of the interview.
    - vi. Provide duplicate interview guide to the interviewee.  
For the telephone interviews, the interview guide was sent electronically prior to the interview.

- vii. Explain the format of the interview as indicated on the interview guide.
- viii. Ask if there are any questions or concerns that pertain to the interview prior to starting.
- ix. Ask and explain questions indicated on the interview guide.
- x. Record the interviewee's responses and probe for additional details.
- xi. Ask the interviewee if he/she would like to retain the duplicate interview guide. If not, collect the interview guide.  
This did not apply in the case of the telephone interviews.
- xii. Thank the interviewee.

## 6. The interview data was transcribed and analyzed.

- Partial Transcription and Thematic Analysis Approach  
Partial transcription was effective for collecting the information sought through the research interviews. Answers to all the specific questions were appropriately recorded either in entirety or using short phrases. Where any interviewee's response was unclear, I requested clarification. The thematic analysis of the interview was aimed at balancing clarity and inclusivity to ensure the responses and details were appropriately collected.
- Interview Data Analysis  
Matrix analysis was utilized for the data. This approach involves the use of visual displays of data, which typically tabulate units of analysis against key concepts or issues relevant to the research questions of a study (King and Horrocks, 2010). The basis for this analysis was to determine the validated products from the earlier research tasks. Earlier research data validated through the interview were validated by methodological triangulation. Only in the cases where there were multiple interviews that utilized the same interview guide did validation occur by data triangulation. Information collected from the pilot interview was used to demonstrate the data analysis process that was to be utilized for the research interviews. In this research, collected interview data was tabulated with the DFCS measures as the rows and the data collection questions as the columns. Data validated through the interview were indicated. This pilot analysis is seen in *Table 47*. As stated earlier, information for only 3 DFCS measures was evaluated in the 25 minute pilot interview. Using the revised data collection questions from *Table 45*, a similar analysis to that seen in *Table 47*, was conducted using data collected on DFCS measures through the research interviews. The tabulation of the validated data was then to be utilized in further research tasks.

	DFCS Measures	Possible impediments to successful implementation of this measure in the project design phase were identified.  Do you find these or other impediments to be applicable?	Revisions of this DFCS Measure were made towards improving its implementation on projects.  Do you find these or other revisions achieve this purpose?	The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure.  Is this incident preventable with implementation of this DFCS measure?
1.	In multi-story buildings, design each floor plan to have a smaller area than the story below to prevent objects and workers from falling more than one story.	Yes (V-SI)  - Decreased project quality (S) - Schedule problems and time constraints (I) - Increased cost (I)	No (V-SI)	Other-Maybe (I)  <u>OSHA Accident Case: 170075329</u> On December 16, 2003, an employee fell from the fourth floor balcony of a residential building and was instantly killed.
2.	Design a permanent guardrail that surrounds each skylight.	No (S)  Yes (I) - Decreased project quality (I) - Increased cost (I)	No (S)  Yes (I) Design permanent guardrails of 1 meter (3 feet) height minimum to surround skylights at 1 meter (3 feet) minimum distance from the edges.	Yes (V-I)  <u>OSHA Accident Case: 200674133</u> On January 14, 2003, a construction employee was working on the sixth story of a building. He was securing a lifeline on a concrete beam when he stepped back and fell through a skylight, approximately 60 feet to the ground. The employee was hospitalized with a concussion and died three days later from his injuries.
3.	Design window sills to be 42 inches minimum above the floor level. Window sills at this height will act as guardrails during construction.	Yes (V-SI)  - Decreased project quality (V-SI)	No (V-SI)	Other-Maybe (I)  <u>OSHA Accident Case: 200202745</u> On May 24, 2006, Employee #1, a superintendent, was walking in a room, when he tripped and fell through an unguarded window. The window was located on the second floor of a building. He fell approximately 18 ft upon an adjacent concrete patio and died from traumatic brain injuries that included a fractured skull.
Note: I = Sourced from Interview; S = Sourced from Survey; V = Validated				

**Table 47:** Validation Analysis of Pilot Interview Data

- Circumstances where New Data was collected on DFCS Measures  
Though the research interviews were primarily intended for validation, new data was collected for the DFCS measures. As in the case of all collected data that was not validated, this was duly noted in the research results.

- Steps utilized in Analyzing Research Interview Data  
The steps utilized in analyzing the collected interview data were to be similar to that indicated by McNamara (2007) but more applicable to this research approach. The steps are indicated.
  - i. Enter the collected interview data into a matrix table for analysis of the information on the DFCS measures.
  - ii. In the DFCS matrix table, indicate the information collected from the research surveys that have been validated through the interview data.
  - iii. Condense the information and present it in a clear format that indicates the findings using such visual displays as tables and figures.

#### **4.1.4.3      Results and Data**

##### **Response Rates and Characteristics of Interviewees**

To have each interview guide version utilized in at least one interview, a sample size of 223 was ultimately required. Out of the 223 total email recipients, 41 responded that they were willing to be interviewed. And out of these, 24 were interviewed. The primary reason given by the 17 that indicated willingness to participate but ultimately did not was unavailability till 1-2 months later. Only 1 set a date and then cancelled on the scheduled interview date, postponed and then ignored further contact. Ultimately, the overall interview participation rate was 10.8%. Given the low response rate of the surveys, I already anticipated a low response rate for the interviews as well. *Table 48* provides the number of email recipients by AEC design profession, the number of email respondents and the response/participation rates.

As there were 22 interview guide versions and 24 interviews, 2 interview guide versions had 2 interviewees each. This was because some email recipients did not respond until the required interviews were scheduled. I also scheduled these email respondents for interviews as a risk management strategy to have a fall-back in case of any cancellations. This also served to enable further validation of the responses to the questions on the DFCS measures in the interview guide versions with two interviewees. In selecting which interview guides to utilize for the interviews, I identified those with circumstances that did not permit the interview to be conducted fully or adequately. The civil engineering interview guide that was utilized for a second interview was initially utilized in a telephone interview that was cut short by the interviewee. The interviewee indicated that he would complete the interview guide in a detailed survey manner and submit it to me, which he did. The electrical engineering interview guide that was utilized for a second interview was initially utilized in a face-to-face interview in which the interviewee seemed a bit distracted.

Interviews	Number of Email Recipients						Number of Email Respondents
	Architects	Civil Engineers	MEP Engineers			TOTAL	
			Mechanical	Electrical	Plumbing		
	45	73	12	53	40	223	41
Number of Completed Interviews	8	7	2	4	3	24	
Number of Interview Guide Versions	8	6	2	3	3	22	
Number of Design-phase DFCS Measures	43	33	14	19	18	127	
				Email Response Rate			18.4%
				Interview Rate of Email Respondents			58.5%
				Interview Participation Rate			10.8%

**Table 48:** Interview Participation Rate and Email Recipients

A criterion in the selection of the interview sample was at least 5 years of working experience. The interviewees averaged 24.6 years of experience. The least was 8 years while the most was 42 years of experience. No interviewee indicated less than 5 years of work experience. *Table 49* provides the number of interviewees and the average years of experience of the interviewees by their AEC design profession and in total.

AEC Design Professionals [Interviewees]	Number of Interviewees	Average Years of Experience
Architects	8	30.4
Civil / Structural Engineers	7	22.1
MEP Engineers	9	21.4
<i>Mechanical Engineers</i>	2	29.5
<i>Electrical Engineers</i>	4	23.5
<i>Plumbing Engineers</i>	3	13.3
Total Number of Interviewees	24	
	Average Years of Experience of All Interviewees	24.6

**Table 49:** Years of Experience of the Interviewees

It must be noted that the interviewees mostly had senior job titles with 1 being a proprietor, 3 being presidents, 8 being principals, 5 being vice-presidents, and 1 being a full professor. The senior officers likely had more flexibility with regards to use of their time and were thus better able to accommodate the interviews. Information on the interviewees including profession, job title, and years of experience is provided in *Appendix F* along with the mode and location of their respective interviews.

## Interview Responses on DFCS Measures

This section presents responses to a sample of the 127 DFCS measures included in the 22 interview guide versions. As seen in *Table 50*, there were a variety of responses given by the interviewees to each of the three questions.

	DFCS Measures	Do you feel this measure can improve construction worker safety?  Why? [Revisions]	The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure  Is this incident preventable with implementation of this DFCS measure?	Would you implement this measure in your design?  Would any of the following factors prevent you from implementing this measure on your design? [Impediments]
	<b>Architects</b>			
Ex. 1	Orient the project to allow for the construction of temporary roads, fire lanes, and approach roads during construction.	Yes Under the blanket of constructability which is our responsibility as architects. We work in teams to address constructability. We point out difficulties. We have constructors and cost estimators on team. Means and methods do influence the design.	Other It is hard to say whether it could. I don't fully know the constraints of the site. The primary responsibility is with the contractor.  [Accident: 202446530] At approximately 2:30 p.m. on July 13, 2007, Employee #1, a construction foreman, was driving a 2003 Chevy, single cab, long bed, four-wheel drive pickup truck along an uphill roadway leading to a construction site. A scraper operator, unaware of Employee #1's pickup, backed his scraper down the roadway away from the entrance to the site to permit a water truck operator enough clearance to pass the scraper and apply water on the lot. Employee #1, who was in the scraper's blind spot, could not maneuver his vehicle out of the way of the backing scraper in time. The scraper backed up and over the front driver's side of the pickup truck. Employee #1's left hand and wrist sustained serious injuries, and he was air-lifted to Loma Linda University Medical Center.	Yes - Increased cost - Decreased project quality and diminished design creativity - Designers' lack of safety expertise
Ex. 2	Design in a means of attaching a railing of safety lines for roofing operations to ensure fall protection for workers.	Yes Falling off a roof is bad and must be prevented	Yes [Accident: 200841591] On June 21, 2007, Employee #1, an iron worker, was walking backward on a roof while positioning an angle iron in preparation for making connections. He accidentally walked off the flat, leading edge of the roof and fell approximately 20 ft, striking a heavy angle iron. Employee #1 suffered severe head trauma and multiple fractures. He was wearing a full body harness with lanyard, but there were no attachment points to which he could tie off or anchor himself.	Yes - Designers' lack of safety expertise

	DFCS Measures	Do you feel this measure can improve construction worker safety?  Why? [Revisions]	The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure  Is this incident preventable with implementation of this DFCS measure?	Would you implement this measure in your design?  Would any of the following factors prevent you from implementing this measure on your design? [Impediments]
Ex. 3	Provide inserts in window jambs for guardrail attachment.	No Because there are existing OSHA requirements	No Worker's fault. Because, if a guy wants to be risky, he will be risky even if guardrails are there.  [Accident: 170245328] Employee #1, age 20, was one of a crew of four working on the framing of a condominium building. They were lifting an overhead structural beam into place when it became wedged between an outer guardrail support and a plumb support. Employee #1 stepped onto the sill of a third-floor window and reached up and out, trying to free the beam. The guardrail that was nailed to the outside of the building came free as Employee #1 leaned against it. He fell 25 ft and was killed.	No <ul style="list-style-type: none"> <li>- Exposure to liability</li> <li>- Increased cost</li> <li>- Schedule problems and time constraints</li> </ul>
	<b>Civil Engineers</b>			
Ex. 4	Design structural member depths to allow adequate head room clearance around stairs, platforms, valves, and all areas of egress.	Yes There are code requirements. Particularly at stairways. This measure is not covered by IBC. One should avoid the confined space categorization. In a nuclear facility, the head room clearance requirement is 6' 6".	Yes The member should have been marked. Padding would have been desirable too.  [Accident: 170361919] Employee #1 was climbing onto a catwalk when he stood up under a large steel beam that was 60 1/2 in. above the catwalk and struck his head with enough force to break the suspension in his hard hat. He did not seek medical treatment at the time, but over a year later he began experiencing numbness in his extremities. He was diagnosed with severe stenosis of his neck vertebra and underwent surgery. The steel beam was neither marked nor padded.	Yes <ul style="list-style-type: none"> <li>- Increased cost</li> </ul>
Ex. 5	Design the top layer of floor slab reinforcing to be spaced at no more than 6 inches on center each way to provide a stable, continuous walking surface before placement of the concrete.	No It is impractical and doesn't eliminate the risk. It is still a tripping hazard and this does not eliminate the tripping hazard.	No It will still be a tripping hazard.  [Accident: 125890947] At approximately 7:15 a.m. on June 20, 1997, Employee #1, a construction supervisor, lost his balance and fell onto some uncapped rebar. His upper right leg became impaled, resulting in lacerations and a puncture wound. Coworkers lifted him off the rebar, rendered first aid, and called paramedics. Employee #1 was transported to the hospital, where he was treated for three days. On June 30, 1997, he returned to work on restricted duty.	No There were three times as many pieces due to this. <ul style="list-style-type: none"> <li>- Increased cost</li> <li>- Schedule problems and time constraints</li> </ul>

	DFCS Measures	Do you feel this measure can improve construction worker safety?  Why? [Revisions]	The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure  Is this incident preventable with implementation of this DFCS measure?	Would you implement this measure in your design?  Would any of the following factors prevent you from implementing this measure on your design? [Impediments]
Ex. 6	Use a single size, or a minimum number of sizes possible, of bolts, nails, and screws. If more than one size is required, specify sizes which vary greatly and are easily distinguishable.	Yes It simplifies things and makes it easier for the contractor. 3/4" A-25 bolts are standard.	Yes Better to simplify the connections.  [Accident: 977314] A 50 foot long steel girder, weighing 3500 pounds, was hoisted into place by a hydraulic boom crane. One end was bolted through the web to a flange that had been welded to a vertical beam. Two of the three 3/4 inch bolts and nuts were installed. The girder was supported approximately 12 feet from the other end by a vertical column which was shimmed one inch off the concrete floor by two 7/8 inch high nuts and 1/8 inch thick washers opposite each other, and 90 degrees from the two half inch bolts which protruded from the concrete floor. The bolts were set through 3/4 inch holes in the bottom plate. The nuts were wrench-tightened with one washer on each bolt. One ironworker, who was straddling the girder, had loosely fitted one of two 3/4 inch bolts and nuts to secure the girder to the column. The crane support was slacked off. The girder was "shaken" by the ironworker to see if it would support itself. The load was then unhooked by a second ironworker standing mid-way on the girder. After the load was disconnected, Employee #1 sustained severe head injuries when the column/girder fell approximately 20 feet to the floor. Employee #1 was leaning over trying to connect a second bolt when the beam fell.	Yes Typically, no one asks for additional money to ensure a minimum number or for type of bolts. I haven't had any requests.
	<b>MEP Engineers</b>			
	<u>Mechanical Engineers</u>			
Ex. 7	Provide guards around equipment (fan inlets/outlets and exhaust ports) to protect workers from moving parts.	Yes It can lessen the likelihood of accident.	Yes It might have been prevented.  [Accident: 200820363] Employee #1, an oiler, was checking the fluid levels in a high head pump when his loose-fitting rain jacket became caught by the blades of a large fan. He was pulled into the unguarded fan blades and sustained multiple lacerations. Employee #1 was killed.	Yes I have seen several cases where there are workers working around belts where not all the shafts are protected. It could be dangerous. - Exposure to liability - Increased cost

	DFCS Measures	Do you feel this measure can improve construction worker safety?  Why? [Revisions]	The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure  Is this incident preventable with implementation of this DFCS measure?	Would you implement this measure in your design?  Would any of the following factors prevent you from implementing this measure on your design? [Impediments]
Ex. 8	Locate valves such that they can be operated easily, or so that a standard type of operating device can be installed. Consider using remote valve operators.	Depends Yes in some circumstances. One might need to have others involved and thus, increased cost. It makes sense for valves to be operated easily. The rest, No. The terms are also relative.	Yes It might have reduced the severity but it would have happened anyway. It is the worker's fault.  [Accident: 200370872] At approximately 2:45 p.m. on January 11, 2000, Employees #1 through #3 were working on a steam line that was connected to a phosphorus storage tank. All insulation had been removed from the steam line and it was very similar in appearance to a phossey water line located nearby. After Employee #1 had cut loose a control valve, he attempted to make another cut in the regular water line, but cut the phossey water line instead. Employee #1 turned the valve with a pipe wrench to what he thought was the 'off' position, but instead turned it to full flow. The phossey water sprayed onto his hands, abdomen and legs. He was tied off to the tank and could not break free until Employee #3 finally unhooked his lanyard and got him to the water jump tank. Employee #1 suffered serious chemical burns. Employees #2 and #3 were also exposed to the phosphorus solution, and all three employees were hospitalized. Citations were issued for inadequate personal protective equipment, inadequate training, and inadequate means to notify employees of an imminent hazard.	No I am not so inclined. I also feel it will give a false impression of security. - Increased cost - Schedule problems and time constraints
	<u>Electrical Engineers</u>			
Ex. 9	Provide adequate passageways and safe access areas around all equipment in control, electrical, and electronic rooms to reduce electrical shock hazards.	Yes There was a case where there were exposed batteries in a UPS room. 2V x 200 batteries equaled 400V. We need to do something about DC voltages. Furthermore, there was no signage and no guarding in bus work.	No The worker did utilize PPE. These include insulated gloves, insulated mats, and hardhat. It was the worker's fault. There is need for training and enforcement to prevent such an accident.  [Accident: 645440] An elevator mechanic was troubleshooting a problem in an elevator control panel located in an elevator control room. The panel contained circuit parts energized at voltages up to 111 volts dc and 240 volts ac. The employee contacted an energized part with his head while his hands were grounded. The employee was electrocuted. (The current entry and exit points were found during an autopsy).	Yes This is part of code and we must meet code requirements.

	DFCS Measures	Do you feel this measure can improve construction worker safety?  Why? [Revisions]	The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure  Is this incident preventable with implementation of this DFCS measure?	Would you implement this measure in your design?  Would any of the following factors prevent you from implementing this measure on your design? [Impediments]
Ex. 10	Avoid placing overhead wiring close to windows or equipment. Locate overhead lines to minimize contact.	Yes I know the code has changed. Horizontal clearances are 6.5 feet while vertical clearances are 10 feet for un-insulated conductors. However, I am neither the utility nor the architect.	Yes It should be. The utilities and designer should do more.  [Accident: 14516363] Two employees were working on a 27-foot-by-15-foot-by-9-foot metal building, putting sealant between grooves. They were applying swepco heavy duty roof coating with a brush and a straw-type broom. Both employees were experienced in this type of work, having performed this task before. During the course of their work, one of the employees contacted an overhead power line. He was electrocuted. This employee's contact with the power line resulted in an explosion, engulfing him in flames and knocking the other employee from the roof of the building. The employee who fell from the building received a crushed heel, for which he was hospitalized.	Yes There is associated cost to protecting conductors and relocating power lines. - Increased cost
	<b>Plumbing Engineers</b>			
Ex. 11	Minimize flanges in piping under high pressure, or which contains explosive or lethal gases.	Yes This is within general guidelines. It would need more time. We don't do much of this but we don't define every flange location. We don't get into detail. The layout will dictate this. I wouldn't really want to specify.	Probably not There is always going to be an accident.  [Accident: 784256] Pressure built up in a rouper, causing a flange to break and releasing a pipe. The pipe went through the roof, causing sparks, which started a fire. Employees #1, #2, and #3 suffered smoke inhalation.	Probably Not This is so long as it is not life endangering. The contractors just have to build it. I hand an internship with an MEP company at a stadium project and no one wanted any fault in anything. For us, occupant and maintenance safety is most important. - Exposure to liability - Designers' lack of safety expertise
Ex. 12	Ensure that the shut-off head on all pumps is consistent with the associated piping.	Yes It is good design practice. You have to design for this.	No It is user error since the shut-off valve was not seated properly. It did not indicate the rating. They didn't set it right.  [Accident: 170190995] At approximately 8:45 a.m. on September 29, 1991, Employee #1 was installing a 4 ft long extension gas line at the upper side of a road. He had been beveling the edge of a 27 in. PCV gas header pipe with power beveling equipment for about 30 minutes when a spark from the beveling tools caused a sudden explosion. Employee #1's face and front forearms were burned. The shut-off valve was not set properly and a small amount of gas leaked out, causing the explosion and flash fire. A serious citation was issued to the employer for violating T8CCR 5416(c).	Yes Quality assurance even checks drawings for conformance to this measure.

**Table 50:** Interview Responses on a Sample of the 127 DFCS Measures

## **Observations on the Characteristics of the Interview Responses**

A number of observations were made as to the characteristics of responses given by the interviewees to the questions on the DFCS measures. The characteristics of the responses were summarized. They were also tallied by the number of interviewees that provided them and by the number of DFCS measures for which they were provided. Following each observation, there is a brief discussion on the matter.

1. 4 out of 24 interviewees (For 4 out of 127 DFCS measures) believed the implementation of DFCS measures would not prevent workers from taking unnecessary risks or from making mistakes. As one AEC design professional stated, "There is no way to stupid-proof the project setting".

Certain workers take unnecessary risks that result in accidents. Others make mistakes that lead to accidents. DFCS measures are intended to minimize the risk of accidents in the event of such mistakes. And where the accident does occur, certain DFCS measures are intended to decrease the severity of the resulting injuries. Additionally, some measures are intended to prevent certain accidents entirely even in the case of a risk-taking worker.

2. 3 out of 24 interviewees (For 3 out of 127 DFCS measures) indicated that educating the workers on safe practices and on certain project features are most essential to preventing certain safety incidents. They stated that incidents are primarily due to unsafe construction practice by workers. Thus, safety training should be a prerequisite to engaging any construction worker on projects. Safety precautions must be adhered to and personal protective equipment (PPE) must be appropriately utilized by the workers.

DFCS is a passive approach towards preventing construction safety incidents. The active approach must still be implemented by the contractor and construction workers. This involves training the workers on safe practices. It also involves educating the workers on the use of PPE and requiring them to use appropriate PPE to certain situations. Tackling safety from both the angles of design and construction has more potential of decreasing safety incidents than from the construction angle alone.

3. 1 out of 24 interviewees (For 1 out of 127 DFCS measures) indicated that projects are driven by value and not construction safety. As such, construction safety should be of minimal concern to the AEC design professional.

Projects are indeed driven by value. However, projects are still required to be safe to occupants and maintenance workers. The design professional

has to meet these requirements or he/she becomes directly liable. Thus, it is not a choice between driven by value or by safety. A project should be driven by value but should also accommodate a myriad of other factors. Construction safety incidents affect the project value as they result in work stoppage and litigation that could impact every project stakeholder financially. Thus, it should be a concern of the AEC design professional.

4. 2 out of 24 interviewees (For 3 out of 127 DFCS measures) indicated that they would be willing to implement certain DFCS measures if there are other benefits besides construction safety such as cost advantages. Basically, any benefit to the contractor in terms of construction safety must not be the primary benefit guiding the decision to implement the measure.

This is a reasonable standpoint. Multiple justifications for implementing a DFCS measure increase the chances of the DFCS measure being implemented. However, this viewpoint illustrates designers' reluctance to be involved in construction safety even through DFCS. For these design professionals, there also needs to be an incentive on the design side or other benefits. Some interviewees actually indicated that certain DFCS measures were cheaper as well as safer and they were thus willing to implement the measures in their designs. Two examples of such measures are provided:

- For elevated floors, use permanent metal formed decking with concrete fill rather than a concrete slab which requires temporary formwork.
- Consider the use of welded wire mesh for slab reinforcing to allow placement of the steel in large sections rather than the placement of many small pieces of reinforcing bars.

5. 3 out of 24 interviewees (For 5 out of 127 DFCS measures) indicated that the construction sequence is the main determinant of the effectiveness of the DFCS measures. Thus, where a safety design feature is not installed till the end of the construction phase, there is little or no impact on construction worker safety.

The construction sequence can indeed impact the effectiveness of DFCS measures. Some DFCS measures prescribe safer design features for permanent ladders. However, if the contractor utilizes a temporary ladder without such features till the very end of the construction phase and then installs the 'safer' permanent ladder, the effect on construction safety becomes negligible. However, in many cases, it is not effective for the contractor to delay constructing/installing certain features till the very end of the construction phase. Hence, a significant number of DFCS measures should have a more notable impact on construction worker safety.

6. 1 out of 24 interviewees (For 1 out of 127 DFCS measures) made it clear that he would abstain from designing any temporary feature such as construction ramps to avoid exposure to liability.

DFCS entails addressing the safety of construction workers in the design of the permanent features of a project (Gambatese et al, 2005). Thus, DFCS does not pertain to the design of temporary features used in construction. This is the contractor's responsibility. Designer involvement would result in liability in the event of a related safety incident. And this should be avoided.

7. 3 out of 24 interviewees (For 3 out of 127 DFCS measures) indicated that meeting code was already an undesired requirement. They indicated that they only intend to meet minimal code requirements and have no intention of exceeding code as this may not be of much benefit. They also indicated that most AEC design professionals would like the knowledge to achieve code at the lowest cost. For this reason, they find DFCS to be an unwanted addition to their concerns.

This viewpoint seems to be more directed at cost and time needs. A solution is the implementation of DFCS measures with minimal cost and time implications. Also, for DFCS measures to be considered by AEC design professionals with such viewpoints, there might need to be other benefits such as the measures being a cheaper option to the conventional approach.

8. 1 out of 24 interviewees (For 1 out of 127 DFCS measures) indicated that means and methods do influence design. This is because constructability is the responsibility of the AEC design professional. As such, DFCS could be incorporated under the blanket of constructability. However, he noted that construction safety is only an added benefit as constructability is mainly concerned with the ability to complete the project.

Constructability is the ability of a project to be constructed. Constructability analysis emphasizes the fact that means and methods do influence design. Toole (2007) defined DFCS as safety constructability. Thus, DFCS falls under the blanket of constructability. With regards to construction safety being only an added benefit, this seems to have been validated as Gambatese et al (2007) identified improved construction safety as only a benefit of enhanced constructability and not an objective or goal.

9. 2 out of 24 interviewees (For 2 out of 127 DFCS measures) indicated that owners have the most ability to influence safety on the capital project as if they required or allowed for the accommodation of cost and time requirements to enable the implementation of DFCS measures, then they can be implemented. On the other hand, owners generally exhibit reluctance to any additional requirement or recommendation as they seek the most project value at the lowest cost.

Owners may have the most ability to influence safety as they are the employers of both the project designers and the contractor and thus, can set safety requirements for them and make accommodations for meeting the requirements. However, owners typically do not get involved in construction safety to avoid economic losses and legal entanglements resulting from worker injuries (Huang, 2003). For such reluctant owners, the concept of DFCS should be explained to make them understand that it is a passive approach to improving construction worker safety that does not require any interference with contractor means, methods and sequences. Additionally, DFCS measures with minimal cost and time implications could be presented for implementation on such owners' projects along with those DFCS measures that have other benefits that add value to the projects. Owners may also be receptive to the implementation of such DFCS measures as many have come to realize that the costs of injuries are ultimately reflected in the cost of construction through delay, investigation, litigation and corrections (Huang, 2003).

10. 1 out of 24 interviewees (For 1 out of 127 DFCS measures) indicated that he would be willing to implement certain DFCS measures and he would also be willing to find economical ways to implement the DFCS measures.

DFCS is still an emerging area and as such, performance-based approaches to minimizing safety risks through the design of permanent project features are welcome and desired. DFCS implementation can be executed creatively to minimize cost and schedule implications. This makes their implementation more feasible for the AEC design professional.

11. 10 out of 24 interviewees (For 15 out of 127 DFCS measures) indicated that accidents are inevitable and as such, cannot be prevented whether through DFCS or OSHA regulations."DFCS is not a cure" one said. "At some point, you can only do so much" another AEC design professional said. Most however believe that the risks can be decreased. As another stated, "It would help but it can't prevent the accident 100 percent". Some also indicated that certain DFCS measures can reduce the severity of accidents or incidents but not prevent their occurrence.

The fact of the matter is that accidents will occur. Several of the interviewees indicated that though DFCS measures may not prevent the occurrence of certain accidents, they can minimize the risk of those accidents. After all, DFCS is aimed at minimizing the occurrence of accidents, and decreasing the potential and severity of injury when they occur. Along with other safety strategies and protective measures, DFCS is intended to assist towards this end. Accidents and injury can have adverse impacts on the project and all project stakeholders, and thus, the need to decrease their occurrence.

- 12.1 out of 24 interviewees (For 2 out of 127 DFCS measures) indicated that DFCS measures could prove useful particularly in cases where there are no code requirements to prevent certain safety hazards.

DFCS measures could certainly prove useful in cases where there are no code requirements to prevent certain safety hazards. As indicated by some interviewees, meeting code is an undesired requirement. This is likely because code requirements are mostly prescriptive. DFCS utilizes a performance-based approach but it is currently not mandatory. DFCS measures serve to provide guidance towards preventing certain safety hazards. And perhaps if the occurrence of such hazards becomes or remains rare, there will be little likelihood of new code requirements with regards to the hazards.

- 13.1 out of 24 interviewees (For 1 out of 127 DFCS measures) indicated willingness to implement DFCS if the contractor remained unaware that certain features were included in the design to enhance construction worker safety. The interviewee felt this would protect the designer from being exposed to liability should there be a safety incident that is in any way related to the feature.

DFCS does not require for the contractor to be aware of the features designed to enhance construction worker safety. Upon completing DFCS implementation, the design documents will not look any different from typical drawings and specifications. They will however reflect an inherently safer design that minimizes or eliminates risks of certain construction hazards (Toole et al, 2006). The contractor is then to execute the project as drawn or specified. Even in cases where the design professional specifies safety enhancing details and notes in the drawings and specifications, it is important that the details specify the function of the safety features without requiring a procedure for their use lest they expose the designer to liability in event of safety incidents linked to the features.

- 14.1 out of 24 interviewees (For 1 out of 127 DFCS measures) indicated willingness to go to a high level of design detail if it could impact construction safety.

Certain DFCS measures specify features to be designed to a relatively high degree of detail. This design professional indicated willingness to implement such measures if they could enhance the safety of construction workers. Such a response is indicative of a safety conscious AEC design professional.

- 15.2 out of 24 interviewees (For 2 out of 127 DFCS measures) indicated that the contractors' adherence to OSHA regulations should prevent most safety incidents.

This viewpoint seems to illustrate designers' reluctance to implementing DFCS since it highlights that construction worker safety should be addressed using OSHA regulations, which in turn only apply in the project construction phase. Agreeably, the contractor's adherence to OSHA regulations should prevent a large number of safety incidents. However, they do not account for many as well. This was emphasized by another interviewee who indicated that DFCS measures could prove useful particularly in cases where there are no code requirements to prevent certain safety hazards. DFCS addresses construction safety from the design side thus complementing the safety strategies situated in the construction phase. Additionally, one cannot ignore the fact that contractors might fail to adhere to OSHA regulations either due to negligence or oversight. DFCS implementation may serve to prevent certain safety incidents despite this sort of failure. This could be through the designers' implementation of DFCS measures that eliminate the need for adherence to specific OSHA regulations. For example, OSHA standards (1926.502(b)) specify the use of temporary guardrail systems for window openings with a sill height of less than 1.0m (39 in.). However, if the window sill is designed to exceed this height above the floor level, the guardrail system will not be required as the modification will inadvertently reduce the risk of falls through the window opening (Gambatese et al, 2003).

- 16.1 out of 24 interviewees (For 1 out of 127 DFCS measures) indicated that certain design-phase DFCS measures were more in the interest of occupant safety.

This viewpoint is valid. Certain DFCS measures have a more prolonged impact on safety in the operations/occupancy phase than in the construction phase. Examples of such DFCS measures are those that specify safer design of stair railings. These could positively impact construction worker safety particularly if installed before the end of the construction phase. However, given the construction phase is far shorter than the operations/occupancy phase in most circumstances, such DFCS measures will likely have more of an impact on occupant safety.

- 17.2 out of 24 interviewees (For 2 out of 127 DFCS measures) indicated that certain design-phase DFCS measures were more in the interest of maintenance safety.

This viewpoint is also valid as certain DFCS measures have a more prolonged impact on safety in the operations phase than in the construction phase. Examples of such DFCS measures are those that

pertain to the design of permanent ladders intended for maintenance access to certain building areas. These could positively impact construction worker safety if installed before the end of the construction phase. Otherwise, the impact will primarily be in enhancing maintenance worker safety. Regardless, given the construction phase is far shorter than the operations phase in most circumstances, such DFCS measures will likely have more of an impact on maintenance safety.

## **Interviewee Commentary on DFCS and Discussion**

At the last page of the interview guide is the question; “Do you have any general comments or suggestions on DFCS or on the study?” This section presents the interviewees’ responses as categorized based on the topics addressed. There is also a brief discussion with regards to the matters raised.

1. As a design professional, one can expect to be sued. DFCS might offer another avenue for the designer to be exposed to liability and be subjected to lawsuits.
  - “As an architect, whether you like it or not, you will be sued.”
  - “Generally, you get sued.”
  - “As a design professional, one can expect to get sued.”
  - “These are interesting times we are living in because of the litigious nature of the industry. It is a long and slippery slope to take in encouraging and adopting DFCS. It is a difficult position to take and defend. Lawyers can come at you with anything. The reality of the profession is such that for everything we do, there are so many opportunities for someone to take exception.”
  - “I am generally concerned about increased liability.”
  - “If in the presence of the owner and contractor, leave the room. This is the advice of our lawyers and insurance carriers. We as architects are to avoid being privy to any information exchanged between them to avoid liability.”
  - “You are relating design to construction safety. Our focus is on the end user. That’s means and methods. And that is what we are trying to avoid.”

The fear of liability constitutes a uniquely strong barrier to DFCS in the litigious United States (Toole, 2005). A study by Gambatese et al (2005) also found most designers believed DFCS will increase their liability exposure. It is for this reason that DFCS measures should be only those situated in the project design phase. It is required that the measures not prescribe means, methods, or sequences for the contractor. However, where the contractor is aware that certain features were designed for construction worker safety and an incident occurs in connection to the features, the

contractor may attempt to find the designer liable. This would likely prove unsuccessful if the feature is part of the design documents and no written or oral direction was given to the contractor. This is actually how DFCS should be implemented based on its definitions.

2. DFCS implementation might increase designers' insurance premiums and this would be an undesirable outcome.

- "DFCS is fine as well as it goes. But what does it do for your insurance premiums? When you already pay up to \$10,000 for your engineers, any addition would not be welcome."
- "Certain project owners require specific levels of liability coverage for hazards across construction, maintenance and occupant safety. For example, some institutions require \$5 million in liability but most design firms have only \$1 million in liability coverage."

Designers may indeed experience increased costs in the form of insurance premiums due to DFCS implementation (Toole, 2005). If designers begin explicitly attempting to contribute to worker safety, plaintiff lawyers may claim designers are at least partially responsible for preventing worker injuries (Toole, 2005). Insurance carriers providing designers with liability insurance could legitimately increase their premiums to cover increased costs associated with defending lawsuits against the designers. Cost increases associated with DFCS implementation may ultimately require design firms and designers to increase their professional fees. This would in turn make them less competitive with those still utilizing the traditional design process without DFCS implementation (Toole, 2005).

On the other hand, the costs of litigation and lawsuits are another motivating factor for improving construction safety that applies to all project participants. In event of an injury incident, there is typically buck-passing among all project participants where each attempts to avoid liability. Expectedly, all parties incur some legal costs. Furthermore, these court cases may prove time-intensive. The only sure way of reducing potential liability of all parties for worker injuries is by reducing the frequency and severity of construction injuries (Levitt and Samelson, 1993). And, where accident rates are lower, insurance programs will be less costly for all project participants (Toole et al, 2006).

Additionally, a proposed solution to addressing the matter of increased insurance premiums is to engage insurance experts to assist in developing insurance policies that protect designers from excessive legal liability for incorporating safety features in their designs (Gambatese et al, 2005).

3. Designers should involve themselves in site safety when the safety of pedestrians, occupants and even construction workers is continually compromised.

- “We have to stop what is going on when safety is continually compromised. We have been transferred the blame on a jobsite for taking charge though mostly with regards to the safety of pedestrians and occupants.”

Model contracts explicitly identify the design professional as not being responsible for construction site safety methods or programs. This is indicated in both the AIA A201 contract document which is used by architects and the EJCDC E-500 contract document which is used by engineers. Furthermore, in United States construction contract law, most project designers sign an indemnification clause with contractors to hold them harmless in case of safety incidents and injuries (Bockrath, 2002). By directly impacting activities during construction, the designers nullify the indemnity. Some designers even stated that they deliberately avoid addressing construction safety to minimize their liability exposure (Gambatese and Hinze, 1999). It will thus prove difficult to encourage designers to involve themselves in construction site safety even when the safety of pedestrians, occupants and even construction workers is continually compromised. Nonetheless, it would be inappropriate for the design professional to not take action. Professional, ethical and moral obligations require the safety of others be protected. It is therefore every AEC design professional's responsibility to preserve and protect human life including that of construction workers (Toole et al, 2006). Thus, the designer is encouraged to inform the owner so he/she can address the matter with the contractor. After all, the contract agreements are typically between the owner and the design firm and separately, between the owner and the contractor.

4. It is the design professional's responsibility to consider maintenance worker safety. While construction safety is not the responsibility of the designer, it would be irresponsible for the designer to not consider it at all.

- “We design for maintenance worker safety. We cannot mount items within 10 feet of roof edge and so on. We conduct a code analysis of the structure.”
- “It is company policy to design for maintenance safety.”
- “We work hand in hand with maintenance personnel.”
- “We always address how maintenance workers can function effectively.”

- “It would be irresponsible for an architect to totally not consider construction safety. When it comes to maintenance safety, it is the architect’s responsibility.”
- “As mechanical engineers, we are fairly knowledgeable when it comes to safety related issues.”
- “If the roof edge is within 10 feet and there is no parapet roof, one has to design for service safety. This cost should be buried in the price.”

By contractual agreement and industry practice, designers are clearly liable for occupant safety. It is also the designer’s responsibility to consider maintenance worker safety. This is particularly since the occupants and maintenance workers are one and the same in many instances. In other cases, there are areas of access that only maintenance workers utilize. Even for such areas, it is considered good practice for the designer to design for safety. As noted by an interviewee, cost implications should not prohibit designing for maintenance safety. Several interviewees also noted that they were knowledgeable when it came to maintenance worker safety.

Not considering construction worker safety at all, especially where certain hazards are apparent, is against the design professionals’ moral, ethical, and professional codes. It is therefore every AEC design professional’s responsibility to preserve and protect human life including that of construction workers (Toole et al, 2006).

Additionally, in event of a safety incident, the maintenance workers may seek to make claim against the owner and the designers. Thus, it is in the best interest of the designer to avoid the associated litigation and legal costs by designing for maintenance worker safety. The avoidance of these costs is also in the best interest of the owner.

5. Larger contractors tend to be more safety conscious than smaller contractors. They tend to have a more systematic approach to construction worker safety.

- “Large contractors tend to focus more on safety but not the small contractors.”
- “The bigger contractors are already very safety conscious. Safety is much more systematic with larger contractors. One should be more concerned with smaller companies where such issues as lead paint and poor ladder use tend to contribute to poor safety particularly on residential projects.”

This prevailing commentary by several research participants has been validated through earlier research. Larger construction firms were found to exhibit better safety results (Hinze, 1997; and CII,

2003). And, this is largely due to the fact that they have more financial means to not only train their workers on safety but to utilize other safety strategies (CII, 2003).

6. There will be lots of industry opposition to DFCS. The industry is notoriously slow to change. And design professionals already have a host of other issues such as constructability to consider without DFCS coming into the picture.

- “There will be lots of opposition to DFCS. Despite the changes in Europe, the industry is slow to change in the United States. I don’t see any move on the part of the AIA. Integrated Project Delivery (IPD) might bring it about. However, the focus is mostly on dollars. It is more of a teamwork approach. An outgrowth could be that all 3 parties (owner, designers and contractor) become responsible for construction worker safety.”
- “There are issues which I can see with DFCS. These include reluctance and absence of interest. We already have so much to think about. We already worry about constructability. We have to coordinate the different trades. DFCS is a whole different matter. I also don’t know if it’s in the area of expertise of architects to be involved in DFCS. DFCS may prove very hard to implement.”
- “You are relating design to construction safety. I don’t believe we think like that. Our focus is on the end user.”
- “Designers typically don’t take construction safety into account.”

Collaborative project procurement approaches such as Concurrent Engineering (CE) and Integrated Project Delivery (IPD) address the fragmented project delivery process by encouraging the collaboration of all project participants in matters that could include safety, early on in a project (Anumba, 1999; and AIA, 2010). Such approaches integrate people, systems, and practices into a process that collaboratively harness the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases from design to construction (AIA, 2010). Emphasis was initially on dollars alone but may be gradually expanded to include safety just as indicated through earlier research by Anumba (1999) and as indicated by an interviewee.

An interviewee also indicated that design professionals already have to worry about constructability and DFCS is an entirely different matter. This is not the case as DFCS is defined as safety constructability (Toole, 2007), the ability of a project to be constructed safely. DFCS implementation at least in part, depends on the interest and motivation of the individual designer since it is not a standard practice and also since it is not typically mandated in

U.S. design contracts (Gambatese et al, 2005). Expanding designer concern to go beyond the end users and include construction workers is a broader focus for the designers. As such, reluctance and disinterest could be expected. Additionally, it is important to note that absence of interest and motivation may be due to the other impediments to DFCS implementation. To address this issue, designers have to be better educated on DFCS. Also, solutions to the other DFCS impediments have to be yielded and/or utilized. And, the benefits of implementing design-phase DFCS measures have to be indicated or provided. This research is geared towards this direction.

7. Code requirements are already very restrictive. Many project owners do not allow for additional features that are not code requirements. Thus, they are not likely to accommodate DFCS unless it is enforced as code and this is undesirable.
  - “I feel the IBC code is too restrictive.”
  - “If DFCS is enforced as code, you hamper the designer ability and give more liability.”
  - “In a developer driven project, if a measure or feature is not legally required, they are not willing to do it. There is generally owner reluctance. So, DFCS measures must be required for the owner.”
  - “Safety measures detailed on drawings are usually the result of a code requirement.”

Code requirements are considered restrictive and undesired by several interviewees. This is likely because code requirements are mostly prescriptive. Prescriptive-based code requirements will hamper the designer ability. However, both prescriptive-based and performance-based regulations will give the designer more liability as not meeting either of them would result in liability exposure. DFCS utilizes a performance-based approach and it is currently not mandatory.

As DFCS is still an emerging area, making it a prescriptive-based requirement would be detrimental. There is need for identification of new DFCS strategies and collection of actual DFCS implementation information. As for making it performance-based code, this would not be detrimental as it would allow for the design professional to reach creative solutions to address the identified hazards. As in the case of the CDM regulations of the United Kingdom that require the involvement of all major project participants including designers in addressing construction worker safety, the performance-based regulations would specify the hazards to be addressed but not the measures to utilize. Thus, establishing DFCS as a performance-based code requirement should be welcome as an approach for

improving the poor safety record of the construction industry. After all, as some interviewees noted, many owners may not implement DFCS unless required. For such reluctant owners, the concept of DFCS should be explained to make them understand that it is a passive approach to improving construction worker safety that does not require any interference with contractor means, methods and sequences. Additionally, DFCS measures with minimal cost and time implications could be presented for implementation on such owners' projects along with those DFCS measures that have other benefits that add value to the projects. Owners may also be receptive to the implementation of such DFCS measures as many have come to realize that the costs of injuries are ultimately reflected in the cost of construction through delay, investigation, litigation and corrections (Huang, 2003).

8. When implementing DFCS, the designer should make certain considerations such as the creation of new hazards and the expertise of the construction workers.
  - "One needs to watch out for other potential hazards while trying to prevent hazards. For example, stair rails could create a ladder."
  - "But one has to consider safety training and expertise for construction workers before deciding to implement certain measures."

One could prevent creating new hazards while implementing DFCS. This includes preventing safety incidents that could not only occur from mistakes but from unsafe or risky practices by construction workers. It must however be noted that not all the hazard risks can be mitigated. In the words of a number of research participants, one cannot 'stupid-proof' the project setting, especially the inherently hazardous construction site.

As for considering the safety training and expertise of the construction workers, this is beyond the scope of DFCS. Construction workers are employees of the contractor and making design considerations based on their safety expertise with the knowledge of the contractor will significantly expose the designer to liability. In DFCS implementation, the designer is only to design features that can enhance construction safety. It is then up to the contractor to construct the features with or without the knowledge that they are meant to enhance construction worker safety. After all, in most instances, the contractor is employed after completion of project design.

9. The responsibility for construction safety lies with the contractor.

- “The responsibility falls to the general contractor. Also, the construction worker should know better to be safer.”
- “If you have no control, you should have no responsibility.”
- “OSHA puts the burden on the contractor.”

Construction worker safety has often been regarded the sole responsibility of the contractor (Hinze and Wiegand, 1992). As the primary party that executes construction, the contractor is also responsible for ensuring the safety of its workers. Root causes for construction accidents such as unsafe methods or sequencing, deficient enforcement of safety, lack of proper worker training and absence/non-use of safety equipment are all issues that fall under the contractor's responsibility to address (Toole, 2002). Though contractors may attempt to shift liability in the event of construction accidents, the traditional general contracting method of project delivery recognizes them as the party responsible for construction site safety (Gambatese, 1998; and Mroszczyk, 2006). Model contracts explicitly state the contractor as being responsible for construction site safety methods or programs. This is indicated in both the AIA A201 contract document which is used by architects and the EJCDC E-500 contract document which is used by engineers. Thus, contractors have the exclusive responsibility of implementing safety strategies applicable to the construction phase. Additionally, OSHA regulations specify that the prime contractor assumes all obligations prescribed in its standards for construction, whether or not any part of the work is subcontracted by the contractor (OSHA Standards; 1926.16). Where the contractor subcontracts the construction work, both the prime contractor and subcontractor may have responsibility for adherence to the standard either jointly or for their portions of the work.

However, also based on model contract language, one can infer that so long as the designer does not prescribe means, methods, techniques, sequences or procedures, the designer can be involved in construction worker safety although the designer is not responsible for site safety. Hence, to avoid liability exposure, designers' role in construction safety must not infringe on contractor responsibilities. Designers must therefore not attempt to manage worker and site safety during construction. They should only focus on minimizing or eliminating safety hazards through their designs. Also, their expertise should address the safety aspects of permanent structures and not the temporary structures used during construction. These guidelines collectively underlie the DFCS concept.

10. Many DFCS measures also impact maintenance worker safety.

- “Also, when it comes to DFCS, a lot of the measures bridge the gap between maintenance worker safety and construction worker safety. It bridges building codes and OSHA.”

Many measures impact maintenance worker safety. A large number of DFCS measures have a more prolonged impact on maintenance worker safety than on construction worker safety. Examples of such DFCS measures are those that pertain to the design of permanent ladders. These could positively impact construction worker safety if installed before the end of the construction phase. Otherwise, the impact will primarily be in enhancing maintenance worker safety. Regardless, given the construction phase is far shorter than the operations phase in most circumstances, such DFCS measures will likely have more of an impact on maintenance safety. Some also bridge building codes particularly in the case of the measures applicable to mechanical, electrical, and plumbing engineers. Others also bridge OSHA requirements by attempting to design to avoid the need for meeting certain requirements.

11. Accidents are inevitable and there are limits to what architects/engineers can do to minimize their occurrence.

- “You can do things to make workers safe but there are limits to the work of the architect/engineer. You have cases which the architect has no control over. Some workers are unlucky while others are stupid. You can’t protect everybody. Some workers are risk takers. There was the case of a residential construction worker who was not wearing PPE at around 3 stories height.”
- “No one wants to be involved in injury or death. Plenty of people have interest in this. People’s lives and health are protected. However, not everything is preventable. People make mistakes.”

There are certainly limits to what the architect/engineer can do with regards to construction safety. The design professional can only design features to enhance construction worker safety. As for ensuring that the contractor utilizes only adequately trained workers or ensuring that the contractor utilizes safety strategies situated in the construction phase, this is beyond the control of the design professionals and beyond the scope of DFCS. DFCS measures are targeted at preventing hazards that primarily occur due to mistakes. Where an individual takes unnecessary risks, there is a limit to the effectiveness of the DFCS measures. It must however be noted that certain measures eliminate certain hazard risks even in the case of risk-taking workers and may also serve to decrease the

severity of their injuries in the event of safety incidents. As indicated by an interviewee, accidents and injury can have adverse impacts on the project and all project stakeholders, and thus, the need to minimize their occurrence.

12.DFCS is an interesting and important subject that should be encouraged for adoption.

- “DFCS is an important subject. There is an application to it. I encourage that designers maintain creativity while adhering to it. I encourage this to be universal. We encourage practitioners to appreciate the reality.”
- “I think DFCS is a great thing. As electrical engineers, we are always focused on worker safety. We ensure that an electrician can evacuate a space to avoid getting hurt. A safer outcome is always desired.”
- “It is interesting to see where DFCS goes.”
- “DFCS is an interesting topic.”
- “This is an interesting topic. It’s good.”
- “I think DFCS is an interesting concept.”
- “DFCS is an interesting thing to look at.”

These commentaries are indicative of support for the DFCS concept and/or support for enhancing the safety of construction workers. An interviewee advocated for the wide adoption of DFCS as good industry practice. And, with DFCS remaining performance-based, designers should be able to creatively design to prevent certain identified hazards. Some interviewees indicated that they already took construction worker safety into account when they design. And, others are interested in seeing how DFCS develops to impact design firms and construction companies.

13.A smaller design firm is more likely to enable the dissemination of information and expertise with regards to implementing DFCS.

- “We trade a lot of information across the horizontal. It is necessary to have a small firm. We saw the value of such a size. There is also the compartmentalization of design and use of consultants at the firm to address broader issues.”

This commentary was with regards to the diffusion of DFCS information. This is necessary to address one of the impediments to DFCS information, designers’ lack of safety expertise. An alternate solution is the provision of information to guide DFCS implementation. This research strives towards this direction. This way, the size of the design firm will not be a determining factor as to whether or not DFCS can be effectively implemented.

14. Institutions are generally more willing to accommodate project features in the interest of safety. Some owners are also hands-on when it comes to safety issues.

- “Institutions are more willing to implement design measures for project safety.”
- “Big owners do not consider small details like handrails and their costs. Such costs should be buried in the price. Institutions look at the bigger picture. In my experience with institutions, rejection of safety features has not occurred.”
- “Institutions are generally understanding towards safety improvement.”
- “In my time as a mechanical engineer, I have encountered both hands-on and hands-off owners when it comes to safety.”

Institutions are ‘big’ project owners. They usually have access to large amounts of financial resources and they tend to develop projects to last for undefined or extended time periods. As a result, safety details to effectively enhance occupant, maintenance worker, and even construction worker safety are generally accommodated. Additionally, institutions are a ‘good’ target for an injured party to make claims against. This is since they usually have substantial resources and go through great lengths to protect their reputations. They might thus choose to settle a claim if they consider the claim to be minute. Hence, institutions have a need to address as many issues as feasibly possible to protect themselves from both reasonable and frivolous claims. If this still proves unsuccessful, institutions usually have the resources to withstand significant legal and litigation costs to protect themselves against the claims.

As indicated by an interviewee, he has encountered both hands-off and hands-on project owners when it comes to construction safety. The hands-off project owners may recognize construction safety as not being their core competency and do not get involved to avoid economic losses and legal entanglements resulting from worker injuries (Huang, 2003). Meanwhile, the hands-on project owners may have become cognizant of the importance of safety on the construction site due to increases in accident costs and legal cases involving owners as the third-party defendants (Huang, 2003). They may have come to realize that the costs of injuries are ultimately reflected in the cost of construction through delay, investigation, litigation and corrections (Huang, 2003).

15.DFCS can be implemented with minimal cost implications.

- “Many of the DFCS measures are not budget busters.”

For numerous DFCS measures, cost was not identified as an impediment to their implementation. Thus, for such measures, their cost implications were indicated as neither being prohibitive nor significant. This is alluded to by the commentary.

16.DFCS can be implemented with minimal time implications.

- “Considering safety does not require much work or much additional time.”

Schedule problems and time constraints were not identified as an impediment to the implementation of numerous DFCS measures. Thus, for such measures, their time implications were indicated as neither being prohibitive nor significant. This is alluded to by the commentary.

17.The design industry is experiencing an increased consideration for construction safety.

- “We seem to be moving away from not being involved in construction safety. In the steel industry, connection design places an emphasis on construction safety. The concrete industry is already involved. So many things are safety related such as base plate design and splice design. Fall protection is also incorporated in several instances. One can design to minimize forces during construction. We look up appropriate products for steel deck and I-girder that are designed for large loadings. Various industries react differently to the need for safety. For example, the construction industry has been developing helmets with numerous other features to enhance safety. Another measure aimed at safety is that one can’t have studs shot onto beams in the field.”
- “Steel columns now have to have 4 anchors unlike before when they used to have 2 anchors.”

Concern for safety has intensified due to the increasing costs of workers’ compensation insurance, the intensification of safety regulations, and the increasing number of liability lawsuits (Gambatese et al, 1997). These lawsuits usually enjoin all key project participants including the design firms. As a result, the design industry has increased consideration for safety. And as noted by some interviewees, it is gradually becoming part of good practice to consider construction safety when designing project features. This seems to be the case particularly when it comes to civil and structural engineers.

18. Constructability should place an emphasis on construction safety. However, this is not the case in engineering curricula. Additionally, the safety education of construction workers is sometimes inadequate.

- “I have checked through the ABET (Accreditation Board for Engineering and Technology) requirements for curricula and have not seen anything with regards to safety. Even when they focused on constructability, there was no mention of construction safety. I usually end up explaining to some contractors what they have to look for in order to ensure safety. This is different from when one is in the chemical industry where safety is a key concern for all. Also, the construction industry can learn a lot from the mining industry. Where mining is taught, safety is taught. There are always courses in mining safety.”
- “In the erection of steel, one has to assess the practicality and safety associated with welding and bolting for specific applications.”

As noted by an interviewee, constructability does not place much of an emphasis on construction safety even when it comes to educational curricula. Gambatese et al (2007) only identify improved construction safety as an added benefit of enhanced constructability and not an objective or goal. As safety constructability, DFCS could be incorporated under the blanket of constructability and be appropriately taught. One of the solutions identified to address designers' lack of safety expertise as a DFCS impediment is the inclusion of construction safety in undergraduate engineering curricula through courses, internships and projects (Gambatese, 2003). As for ensuring that construction workers are educated on safe practices, this is the responsibility of the contractor. The contractor is to ensure their construction workers are safety trained and educated prior to engaging them on the construction site. This education could be provided through courses or through other means by the contractor's company.

19. OSHA requirements are considered tedious and undesired by many contractors. Contractors cannot be expected to follow all OSHA guidelines.

- “Generally, contractors hate OSHA requirements. But one good fine changes them. Additionally, OSHA is vague on certain safety requirements such as defining the wind velocity for which to design wall bracing.”
- “You can't totally rely on contractor to follow OSHA guidelines with all the regular changes.”

Most prescriptive based requirements tend to be undesired by the project participants they pertain to. Thus, in the case of OSHA requirements, they too are considered tedious and undesired by many contractors. And failure to adhere to these regulatory requirements will directly result in liability and fines either in the event of a hazard incident or if observed by an OSHA inspector. It must also be noted that those safety requirements considered to be vague tend to be those with performance-based components. As for changes in OSHA regulations, these typically occur on a bi-annual basis and for only a few guidelines. The contractor should thus be able to keep up with the changes.

As stated by an interviewee, contractors might fail to adhere to OSHA regulations either due to negligence or oversight. DFCS implementation may serve to prevent certain safety incidents despite this sort of failure. This could be through the designers' implementation of DFCS measures that eliminate the need for adherence to specific OSHA regulations.

20. DFCS implementation involves making design trade-offs.

- "There are tradeoffs when it comes to DFCS. You can't abolish certain features to remove their associated risks."

DFCS involves making considerations and determining which design measures can be feasibly implemented to enhance construction worker safety. This feasibility refers to the fact that the DFCS measures must not compromise project function and quality, and they must not be cost or schedule prohibitive. As an example, an architect might design a skylight over a building atrium for daylight and aesthetics. DFCS does not require the skylight to be eliminated to prevent the hazard of someone falling through the skylight while working on the roof. DFCS would suggest that guardrails be placed around the skylight to prevent the worker from stepping on the skylight. This would come at a cost. If this cost is infeasible, then an alternate DFCS measure can be utilized. Such is the nature of trade-offs when it comes to DFCS.

21. There are concerns about increased cost when it comes to implementing DFCS. There are also cost trade-offs with regards to implementing DFCS.

- "I am not sure to what extent the building should be designed to enhance construction safety. As long as it is safe when it is fully built, it mostly comes down to cost."
- "There are several issues to get through with regards to this topic. I am generally concerned about increased cost."

One of the main impediments to DFCS is concern about increased cost. Performing DFCS may increase direct and indirect costs for projects, design firms and designers. This includes design and/or construction cost. Project costs may increase due to additional protective features incorporated into the design. It is however important to note that, in cases where DFCS eliminates a feature, decreased project costs may result. Additionally, eliminating the need to install temporary protection systems during construction may result in overall construction cost savings (Gambatese and Hinze, 1999). The solution to the impediment of increased cost is the identification, selection and implementation of DFCS measures that can improve construction safety with minimal or no cost implications.

22. Some design professionals already implement DFCS and accommodate its associated concerns.

- “We already take measures to prevent accidents. When we place mechanical equipment on the roof, if within 5 feet of the roof edge, we make sure a railing is installed. This is company policy. When we are involved with firms that don’t get into these issues, we talk to them. When there are big units that are built up above the roof, we design for handrails and steps. If it is sophisticated, we have a structural engineer design it. When we had a project at a university, we had to ensure that platforms were designed for the mechanical systems. We designed for safe access and included railings. This was above and beyond code requirements. Even when it comes to our electrical work, we adhere to all NEC requirements. We insist on building safety into design. We are very specific about boiler switches. I just wrote a report of code deficiencies and safety. We note when we notice hazardous situations. We always coordinate with the architect. For example, air handlers need filters and HEPA filtration takes room to do. We always make sure of using plywood decking for safety where applicable.”

This commentary from one of the interviewees indicates the feasibility of implementing DFCS in the current construction and contractual environment. This was despite the impediments including increased cost due to additional project features and designers’ lack of safety expertise which was addressed by engaging other design professionals. This AEC design professional and his firm were identified as being particularly safety conscious given his commentary.

23. Commissioning is essential to ensure construction worker safety, maintenance worker safety and occupant safety.

- “A lot of the elements lead to construction safety. This includes elements such as testing and test methods. The National Electrical Testing Association (NETA) also specifies testing requirements. There are a lot of measures that are built into the commissioning of mechanical, electrical and plumbing systems. For example, we do a lot of testing to prevent inadvertent system activation. Additionally, with regards to commissioning, owners welcome it particularly for the safety of occupants and maintenance workers. We don’t specifically want to expose ourselves to liability so it is very important that we commission our designed systems.”

LBL (2012) defines building commissioning as an intensive quality assurance process that begins during design and continues through construction, occupancy, and operations, to ensure that a new building operates initially as the owner intended and that building staff are prepared to operate and maintain its systems and equipment. Commissioning is particularly important for the mechanical, electrical and plumbing systems of a project. In most instances, it is a contractual or code requirement. It prevents such occurrences as inadvertent system activation and catastrophic failures that may result in injury to occupants, maintenance workers, and also, construction workers. However, the least emphasis is placed on construction workers. This is understandable as the operations and utilization project phase is typically much longer than the construction phase.

#### **4.1.4.4      Interpretation of Results**

##### **Outcome of Objectives**

The outcomes with regards to each of the interview objectives were distinct. With regards to the first objective, the validation and yielding of the impediments to successful implementation of the DFCS measures, this was accomplished. Examples of DFCS measures for which certain impediments were methodologically validated are provided in *Table 51*. The interviewee responses are also provided. As for the DFCS measures for which impediments were yielded, several are provided in *Table 50*.

With regards to the second objective, the validation of applicable safety incidents identified from the OSHA database, this was achieved. Those safety incidents that received “Yes” responses with regards to being preventable by their respective DFCS measures were considered data validated. As can be seen from *Table 50*, several also received “Other” or “No” responses. Where such

responses were provided, most interviewees indicated that the DFCS measures would not have prevented their identified safety incidents as the workers were the cause due to unsafe practices. These safety incidents were not considered validated although a significant majority was identified as being related. This was ultimately used as a basis for categorizing the DFCS measures and their data.

	<b>DFCS Measures</b>	<b>Do you feel this measure can improve construction worker safety?</b>  <b>Why?</b> <b>[Revisions]</b>	<b>The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure</b>  <b>Is this incident preventable with implementation of this DFCS measure?</b>	<b>Would you implement this measure in your design?</b>  <b>Would any of the following factors prevent you from implementing this measure on your design?</b> <b>[Impediments]</b>
Ex. 1	To reduce the chance of falls, consider stairs in lieu of a permanent ladder when the ladder will be used frequently to move material and equipment.	Yes (V-SI) It would be more for the owner. The contractor may have a ladder to use during the construction.	Yes (V-I)  [Accident: 14480511] Employee #1 was last seen climbing a fixed ladder secured to a column in a warehouse, heading toward a Milwaukee 20-ton overhead crane. He fell from either the ladder or the rest platform (landing) and suffered a crushed chest, a fractured pelvis, and numerous internal injuries. Employee #1 was killed. The cage of the fixed ladder started at 32 feet above the floor. The rest platform, which was not equipped with guardrails, was also located 32 feet above the floor.	Yes (V-SI) It comes down to money. Perhaps if owner directed. One may have to make space for stair. <ul style="list-style-type: none"><li>- Increased cost (V-SI)</li><li>- Decreased project quality and diminished design creativity (S)</li></ul>
Ex. 2	In order to allow sufficient walking surface, use a minimum beam width of 6 inches.	Yes (V-SI) Particularly for high steel workers. They are surprisingly safety conscious as they are much more of a family. There was said to be high safety standards in the Worldwide Plaza project in New York City.	Yes (V-I) The only problem is that one may not be able to find a 9 foot beam with 6 inch flanges. There may however be another way around.  [Accident: 951434] Employee #1, who was installing plywood decking on the second floor of a single-family home under construction, was headed to the ladder to go down and get more material. He was walking across a 3 in. wide by 9 ft long steel beam when he slipped and fell 11 ft onto a concrete floor. Employee #1 struck his head and was transported to the hospital, where he died at 2:30 p.m. on October 24, 1997.	Yes (V-SI) <ul style="list-style-type: none"><li>- Increased cost (V-SI)</li></ul>

Note: I = Sourced from Interview; S = Sourced from Survey; V = Validated

**Table 51:** Interviewee Responses on 2 DFCS Measures with Methodologically Validated Impediments

Lastly, with regards to the third objective, obtaining revisions to the DFCS measures where applicable, this was also achieved. The basis for revising 13 DFCS measures was yielded. The interview responses to the pertaining questions and the revisions are provided in *Table 52*.

	DFCS Measures	Do you feel this measure can improve construction worker safety?  Why? [Revisions]	Revised DFCS Measures
	<u>ARCHITECTS</u>		
1.	Locate exterior stairways and ramps on the sheltered side of the structure to protect them from rain, snow, and ice to minimize fall hazards.	Other Inherent problem in the question. Don't believe this will be adequate to decrease risk. It must be enclosed. Extreme environments such as Albany, Chicago and Buffalo could have up to 8 feet of drifting snow.	Locate exterior stairways and ramps on the sheltered side of the structure or fully enclose them to protect them from rain, snow, and ice to minimize fall hazards.
2.	Provide access by means of a ladder or stairway between horizontal surfaces when there is a change in elevation exceeding 19 inches.	Yes One could still fall when the elevation is at 18 inches. The contractor should be dictating the fall protection issues.	Provide access by means of a ladder or stairway between horizontal surfaces when there is a change in elevation exceeding 15 inches.
3.	Design intermediate vertical members on stairrails and guardrails to be at most 19 inches apart.	No Should be closer to prevent kids from falling through	Design intermediate vertical members on stairrails and guardrails to be at most 19 inches apart while the space between pickets should be such that a 6" sphere cannot pass through.
4.	In the design of permanent ladders and ladder wells, design the inside width of ladder wells to be at least 30 inches for ease of ascent/descent.	Yes I don't know how I feel about this. However, I feel 30 inches is not very big but it would be good for safety.	In the design of permanent ladders and ladder wells, design the inside width of ladder wells to be at least 36 inches for ease of ascent/descent.
5.	In areas which receive snow, provide a covering, overhang, or extend the roof line over exterior ramps.	Yes But so could installing a snow melt system.	In areas which receive snow, provide a covering, overhang, or extend the roof line over exterior ramps and where not feasible, specify a snow melt system.
6.	Build stair landings up above an uneven grade.	No Makes matters worse. Better to slope it.	Build stair landings up above an uneven grade or slope the stair landing.
7.	In the design of permanent ladders, design vertical bars to be on the inside of the horizontal bands and fastened to them.	No You want to ensure that the vertical bars project from the wall. This is worse than if the other way round. It is better if clear. There might be a code requirement that is safer.	In the design of permanent ladders, design vertical bars to be on the outside of the horizontal bands, clear and projecting from the wall.
	<u>CIVIL / STRUCTURAL ENGINEERS</u>		
8.	In the design of stairs/railings, design handrails and the top rails of stairrail systems to withstand at least 200 lbs. applied within 2 in. of the top edge in any downward or outward direction, at any point along the top edge.	Yes (2)  This gives the designer some guidance on what loads to design the rail to.  Handrail safety has improved. It is now code to also include 50lb/linear foot. They are required to have increased strength.	In the design of stairs/railings, design handrails and the top rails of stairrail systems to withstand at least 200 lbs. applied within 2 in. of the top edge in any downward or outward direction and/or 50 lbs/linear foot applied at any point along the top edge.
9.	Design each rung on fixed permanent ladders to be capable of supporting a load of at least 250 lbs. applied in the middle of the rung.	Yes But for 300lbs which is the industry standard that is used by convention. Stair threads and ladder rungs have to be designed for 300lb loads minimum.	Design each rung on fixed permanent ladders to be capable of supporting a load of at least 300 lbs. applied in the middle of the rung.
10.	Provide column splices at two-floor intervals and locate them at approximately 4 feet above the finished floor level to facilitate safe and accessible splice work.	Yes It eliminates the tripping hazard. However, I don't see why the 2-floor interval would improve safety. Typically, one can place railings of 3' 6" height around tripping hazards.	Locate column splices at approximately 4 feet above the finished floor level to facilitate safe and accessible splice work.

	DFCS Measures	Do you feel this measure can improve construction worker safety?  Why? [Revisions]	Revised DFCS Measures
	<u>MEP ENGINEERS – MECHANICAL ENGINEERS</u>		
11.	Locate valves such that they can be operated easily, or so that a standard type of operating device can be installed. Consider using remote valve operators.	Depends Yes in some circumstances. One might need to have others involved and thus, increased cost. It makes sense for valves to be operated easily. The rest, No. The terms are also relative.	Locate valves such that they can be operated easily, or so that a standard type of operating device can be installed. Consider using easily-accessible remote valve operators.
12.	To reduce fall hazards, locate rooftop mechanical/HVAC equipment away from the edge of the structure.	Yes I believe strongly in this. We don't locate air handling units in the air. If it has to be up high, we place it on a platform. Sometimes, you have a choice in placement. We use railings where it is not possible to avoid. We can design the railings in.	To reduce fall hazards, locate rooftop mechanical/HVAC equipment away from the edge of the structure and where not possible, use railings.
	<u>MEP ENGINEERS – ELECTRICAL ENGINEERS</u>		
13.	Provide permanent electrical outlets on the roof to allow for easy tie-in during construction and future roof maintenance.	Yes If it was a flat roof, then it could. And it's position relative to the safety hatch.	Provide permanent electrical outlets on flat roofs to allow for easy tie-in during construction and for future roof maintenance.

**Table 52:** Revisions of DFCS Measures and Pertaining Interviewee Responses

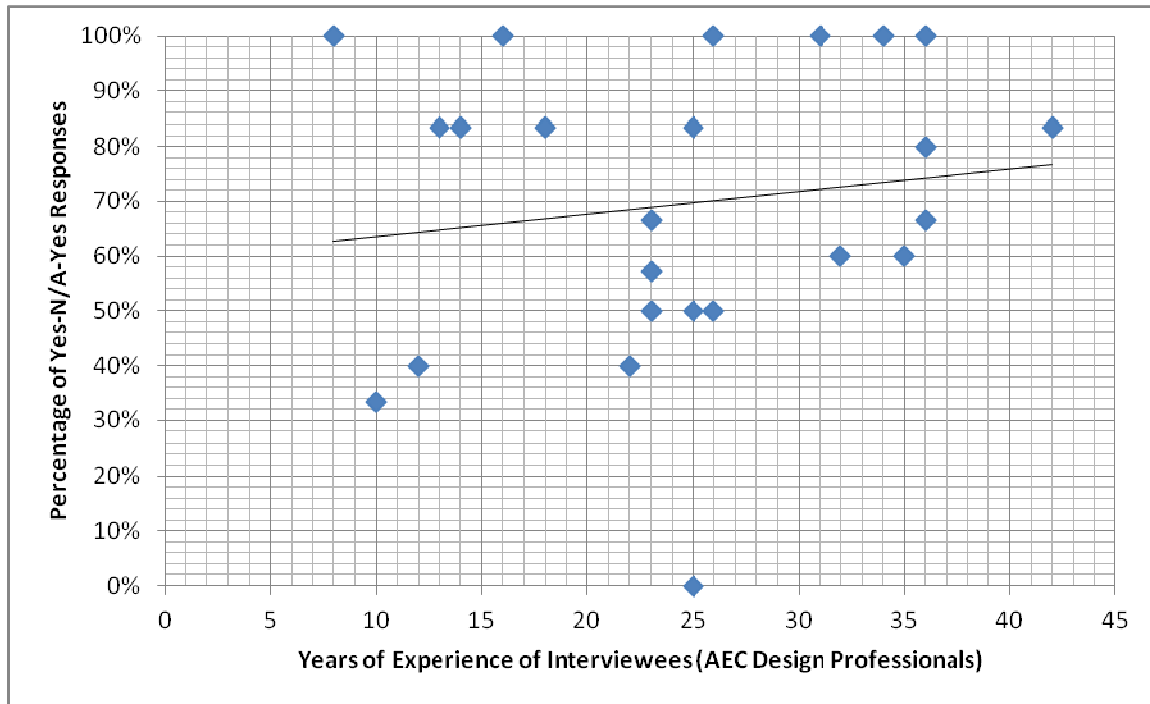
Conclusively, the objectives of the interviews were achieved as impediments to implementing the design-phase DFCS measures were validated and yielded, safety incidents were validated as being preventable by implementation of the DFCS measures, and revisions to the DFCS measures were yielded where applicable.

### Assessment of Interviewee Perceptions on Construction Safety

An observation was made from the interviewee responses. It seemed as though the AEC design professionals with more years of experience were more safety conscious. To evaluate this, the percentage of DFCS measures for which there were Yes-N/A-Yes responses in each interview was derived and plotted against the years of experience of the respective interviewees. As earlier stated, the interviews collected information on between 5 and 7 DFCS measures. Percentages were used to make all the collective interviewee responses on DFCS measures comparable. Thus, where an interviewee provided Yes-N/A-Yes responses for 3 out of the 5 DFCS measures in his interview, 60% was the percentage of Yes-N/A-Yes responses for the interviewee, and this was graphed against his indicated years of experience.

Meanwhile, the Yes-N/A-Yes responses corresponded to DFCS measures that the interviewee indicated willingness to implement and also indicated that they could improve construction worker safety. The N/A stands for 'Not Applicable' and this was with regards to the question on the applicability of the provided

safety incidents to the DFCS measures. The responses to this question were not necessarily indicative of the perceptions of the interviewees on construction safety. The responses only pointed out whether the interviewees felt the incidents were preventable by their respective DFCS measures. For this reason, the response to the second interview question on each DFCS measure was not factored. The graph of the percentage of Yes-N/A-Yes responses on DFCS measures per interview versus the years of experience of the interviewees is provided in *Figure 27*.



**Figure 27:** Percentage of Positive Responses towards Construction Safety Versus the Years of Experience of the Interviewees

From *Figure 27*, it can be inferred that there is a positive relationship between the years of experience of the interviewees and their perceptions on construction safety. This could be due to a number of reasons. Firstly, the more experienced design professionals may have higher exposure to the project site and its dangers. They are thus likely to have been involved in more projects that witnessed serious safety incidents. This may have ignited increased humanitarianism on their part. Secondly, they are more likely to have been enjoined in lawsuits that arose from construction safety incidents. And, they know the impact of the associated legal and litigation costs even when they or their firms were not found liable. Also, as mostly senior officers in their respective places of work, the more experienced AEC design professionals may also be more familiar with the rising liability coverage requirements for involvement on projects. These reasons were derived from the commentaries of some of the interviewees with regards to DFCS as a concept.

## Categorization of DFCS measures based on Interview and Survey Responses

Due to the outcomes of earlier research tasks, the DFCS measures were to be categorized into different tiers. This was based on their feasibility for implementation and the level of confidence in their effectiveness. The categorization became necessary as a scope control approach. Not all the DFCS measures utilized in the surveys could be feasibly utilized in interviews. As a result, the survey responses were used to determine which to utilize. Only the DFCS measures with Yes-Yes-Yes survey responses to their 3 respective questions were used in the interviews. Those DFCS measures were validated to be applicable to the project design phase, indicated to improve construction safety, and indicated to not have impediments significant enough to prevent their implementation. Those DFCS measures that were not utilized in the interviews were categorized based on their survey responses. Those that were utilized in the interviews were categorized as such, and then even further categorized based on the interview responses.

The basis for categorizing the DFCS measures based on the survey and interview responses is provided in *Table 53* along with the number of DFCS measures that are situated in each of the categories or tiers. *Table 54* provides the textual description of the different tiers.

Tier of Feasibility of the DFCS Measures	Responses to Survey Questions			Responses to Interview Questions			Were impediments identified for the DFCS measure either through the survey or interviews?	Number of DFCS Measures in the Tiers
	Is this measure applicable to the design phase of a project?	Do you feel this measure can improve construction worker safety?	Would you implement this measure in your design?	Do you feel this measure can improve construction worker safety?	The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure. Is this incident preventable with implementation of this DFCS measure?	Would you implement this measure in your design?		
1A	Yes	Yes	Yes	Yes	Yes	Yes	No	39
1B	Yes	Yes	Yes	Yes	Yes	Yes	Yes	21
2A	Yes	Yes	Yes	At least 1 No/Other response			No	25
2B	Yes	Yes	Yes	At least 1 No/Other response			Yes	39
3A	Yes	Yes/No/Other	Yes/No/Other	N/A: Not utilized in the interviews			No	49
3B	Yes	Yes/No/Other	Yes/No/Other				Yes	14
4A	Other	Yes/No/Other	Yes/No/Other				No	17
4B	Other	Yes/No/Other	Yes/No/Other				Yes	8
							TOTAL	212

**Table 53:** Categorization of DFCS Measures based on Survey and Interview Responses and their Numbers

Given that some DFCS measures received two survey respondents and/or two interviewee respondents, it is essential to indicate how such measures were categorized. Generally, the response that indicated a higher tier was ultimately utilized. The identified impediments where applicable were used in the categorization with none discarded. The two DFCS measures, utilized in multiple interviews, for which the responses yielded placed them in different tiers are

provided in *Table 55*. As earlier stated, only two interview guides were utilized in two interviews each given that there were 22 interview guides and 24 interviewees in total.

Tier of Feasibility of the DFCS Measures	Description of the Tiers
1A	This tier includes DFCS measures that were validated to be applicable to the design phase, to have the capability of improving construction worker safety, and to be feasible for implementation. The preventable safety incidents identified for these DFCS measures were also validated as being applicable. AEC design professionals did not identify any impediments to implementing these measures. At least 2 AEC design professionals were involved in evaluating these measures.
1B	This tier includes DFCS measures that were validated to be applicable to the design phase, to have the capability of improving construction worker safety, and to be feasible for implementation. The preventable safety incidents identified for these DFCS measures were also validated as being applicable. AEC design professionals identified impediments to implementing these measures. At least 2 AEC design professionals were involved in evaluating these measures.
2A	This tier includes DFCS measures that were validated to be applicable to the design phase. However, the measures were noted but not necessarily validated to have the capability of improving construction worker safety and/or to be feasible for implementation. This also applies to the preventable safety incidents identified for the DFCS measures. AEC design professionals did not identify any impediments to implementing these measures. At least 2 AEC design professionals were involved in evaluating these measures.
2B	This tier includes DFCS measures that were validated to be applicable to the design phase. However, the measures were noted but not necessarily validated to have the capability of improving construction worker safety and/or to be feasible for implementation. This also applies to the preventable safety incidents identified for the DFCS measures. AEC design professionals identified impediments to implementing these measures. At least 2 AEC design professionals were involved in evaluating these measures.
3A	This tier includes DFCS measures that were validated to be applicable to the design phase. However, the measures were not necessarily validated to have the capability of improving construction worker safety and/or to be feasible for implementation. Also, the preventable safety incidents identified for the DFCS measures were not validated as being applicable. AEC design professionals did not identify any impediments to implementing these measures. At least 1 AEC design professional was involved in evaluating these measures.
3B	This tier includes DFCS measures that were validated to be applicable to the design phase. However, the measures were not necessarily validated to have the capability of improving construction worker safety and/or to be feasible for implementation. Also, the preventable safety incidents identified for the DFCS measures were not validated as being applicable. AEC design professionals identified impediments to implementing these measures. At least 1 AEC design professional was involved in evaluating these measures.
4A	This tier includes DFCS measures that were not necessarily validated to be applicable to the design phase. However, the measures were not noted to be inapplicable to the project design phase. Also, the measures were not necessarily validated to have the capability of improving construction worker safety and/or to be feasible for implementation. Additionally, the preventable safety incidents identified for the DFCS measures were not validated as being applicable. AEC design professionals did not identify any impediments to implementing these measures. At least 1 AEC design professional was involved in evaluating these measures.
4B	This tier includes DFCS measures that were not necessarily validated to be applicable to the design phase. However, the measures were not noted to be inapplicable to the project design phase. Also, the measures were not necessarily validated to have the capability of improving construction worker safety and/or to be feasible for implementation. Additionally, the preventable safety incidents identified for the DFCS measures were not validated as being applicable. AEC design professionals identified impediments to implementing these measures. At least 1 AEC design professional was involved in evaluating these measures.

**Table 54:** Description of the different Categories/Tiers utilized for the DFCS Measures

	DFCS Measures	Do you feel this measure can improve construction worker safety?  Why? [Revisions]	The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure  Is this incident preventable with implementation of this DFCS measure?	Would you implement this measure in your design?  Would any of the following factors prevent you from implementing this measure on your design?
	<u>CIVIL / STRUCTURAL ENGINEERS</u>			
1.	In the design of stairs/railings, design handrails and the top rails of stairrail systems to withstand at least 200 lbs. applied within 2 in. of the top edge in any downward or outward direction, at any point along the top edge.	Yes (2)  This gives the designer some guidance on what loads to design the rail to.  Handrail safety has improved. It is now code to also include 50lb/linear foot. They are required to have increased strength.	Depends (1) If the rail was new, yes it could have prevented the accident. If it was existing, it could have been deteriorated.  Yes (1) I picture an old and deteriorated building with failing handrails. This DFCS measure is a requirement in Chicago.  [Accident: 202341889] At approximately 4:30 p.m. on November 2, 2007, Employee #1 was cleaning up the fire escape on a five-story apartment building after he had finished using it as a work platform for a day of brick pointing. He was walking from the fifth level fire escape to the roof when the guardrail on the stairs broke and he fell approximately 35 ft to the second-floor fire escape. Employee #1 was transported to Beth Israel Hospital, where he was pronounced dead on arrival.	Yes (2)
	<u>MEP ENGINEERS – ELECTRICAL ENGINEERS</u>			
2.	Where high light fixtures are incorporated into a structure, design the possibility of the entire light fixture to be lowered for safe repair and installation of new bulbs.	Not so sure (1) I don't think it is that dangerous. It seems relatively simple.  Yes (1) It would. If the fixture is on the ground, it provides a better working environment.	No (1) It is the employee's fault. He was being lazy. He should be a qualified electrician. Lighting tends to have 277 volts. He should have de-energized it. It is not within a designer's capability to prevent this. Lowering the voltage could also be an approach to decreasing this risk.  Yes (1) It would be preventable. Although, I have not seen a wall mounted device that can be lowered. My answer could thus be no as well.  [Accident: 14516934] Two employees were troubleshooting lighting fixtures on the exterior of a building. One of the employees was on a ladder checking the wiring for a lighting fixture. The circuit for this fixture was energized. After determining that the problem was a defective ballast, this employee removed the ballast without deenergizing or otherwise protecting the circuit. He apparently leaned forward to reach the ballast and contacted the energized circuit conductors. He received an electric shock, which caused him to fall 15 feet to the pavement, on which he hit his head. He died later of the head injuries he received in the fall.	No (1) Unless on a large pole. The owner will likely not agree due to the cost implication. - Increased cost  Yes (1) Construction budget reasons have owners reject certain maintenance worker safety suggestions. - Increased cost

**Table 55:** DFCS measures with Multiple but Different Interview Responses placing them in Different Tiers

Meanwhile, there were a total of 10 DFCS measures utilized in multiple interviews, for which the responses yielded placed each of them in only one category or tier. A sample of these DFCS measures is provided along with the interviewee responses in *Table 56*. For such DFCS measures, their categorization was essentially validated.

	DFCS Measures	Do you feel this measure can improve construction worker safety?  Why? [Revisions]	The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure  Is this incident preventable with implementation of this DFCS measure?	Would you implement this measure in your design?  Would any of the following factors prevent you from implementing this measure on your design?
	<u>CIVIL / STRUCTURAL ENGINEERS</u>			
Ex. 1	Minimize the size and weight of masonry blocks.	<p>No (2)</p> <p>Making the material smaller will cause more pieces to be handled increasing the odds of dropped material</p> <p>We you look at the history of masonry, it used to be bricks. I don't hear of a lot of injuries of backs and others due to the large size of masonry blocks.</p>	<p>No (2)</p> <p>This accident would have been prevented with proper means and methods of shoring.</p> <p>A key issue in construction is bracing. It has more to do with worker safety training and procedure. The wind must be monitored so as not to exceed 20mph without evacuation or safety measures.</p> <p>[Accident: 901892] At approximately 3:30 p.m. on November 6, 2006, two employees of an excavation subcontractor left the worksite of a two-story warehouse under construction. At that time, the partially braced front masonry wall, (8-in.-wide by 160-ft long by 20-ft high was still standing. Concerned over personal equipment left at the site they returned 30 minutes later to find about 80 ft of the front wall had collapsed. The employees retrieved their gear and were about to leave when they heard the ringing of a cell phone coming from under the pile of concrete blocks. Pulling away several of the 8-in. by 8-in. by 16-in concrete blocks they found Employee #1's body. Employee #1 was pronounced dead at the hospital.</p>	<p>Yes (1)</p> <ul style="list-style-type: none"> <li>- Increased cost</li> </ul> <p>No (2)</p> <ul style="list-style-type: none"> <li>- Increased cost</li> <li>- Schedule problems and time constraints</li> </ul>

	DFCS Measures	Do you feel this measure can improve construction worker safety?  Why? [Revisions]	The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure  Is this incident preventable with implementation of this DFCS measure?	Would you implement this measure in your design?  Would any of the following factors prevent you from implementing this measure on your design?
Ex. 2	Keep detailed work above grade; simplify all below grade work to reduce worker exposure to cave-ins.	<p>No (1) Occasionally the sub grade work is more complex that the above grade work. It would be difficult to not have workers go below grade.</p> <p>Yes (1) The less time you have guys in the trenching, the safer. It depends on bracing.</p>	<p>Yes (1) If all detailed work was above grade. However, especially in the case mentioned, Underpinning could not be constructed without a worker going below grade.</p> <p>No (1) I don't so. I don't know how one would avoid it. Chicago City requires a 2:1 sloped trench. This is more about trenching.</p> <p>[Accident: 202353546] On March 26, 2004, Employee #1 was digging a footer for the under pinning operation within a trench. The trench dimensions were 5.33-ft in length by 2.25-ft in height by 1.67-ft in depth, and was located between two existing block columns. As he worked from a crouched position within the excavation, a side of trench collapsed covering him with dirt. The weight of the collapsed trench fractured his back. Employee #1 was transported to a medical center for treatment and hospitalized for postoperative care.</p>	<p>No (1)  <ul style="list-style-type: none"> <li>- Increased cost</li> <li>- Schedule problems and time constraints</li> <li>- Decreased project quality and diminished design creativity</li> </ul> </p> <p>No (1) I don't think there is much I can do  <ul style="list-style-type: none"> <li>- Exposure to liability</li> <li>- Increased cost</li> <li>- Schedule problems and time constraints</li> <li>- Decreased project quality and diminished design creativity</li> </ul> </p>
	<u>MEP ENGINEERS – ELECTRICAL ENGINEERS</u>			
Ex. 3	Avoid locating electrical rooms under pipes carrying liquids that could pose a shock hazard.	<p>Yes (2)  This is part of NEC code provisions. It facilitates rerouting. You don't want to expose liquids to wires.</p>	<p>Yes (2)  It should be in a box. This was an installation error. It could have been prevented.</p> <p>The fact that the employee had to work around pipes, Yes, it is preventable.</p> <p>[Accident: 655902] An employee standing on a 1.8-meter-tall stepladder was trying to locate a leak in a covered pipe above a suspended ceiling. The employee reached around the pipe to locate the source of water and accidentally touched an exposed 277-volt, 20-ampere relay switch. He received an electric shock, which caused him to fall from the stepladder to the floor. He was hospitalized for his injuries.</p>	<p>Yes (2)  We look to design it that way. We look to the architect to assist. When we are involved late, it is tough for us. We endeavor to not place switches near pipes. We will pan the pipes where such a circumstance occurs.</p>

	DFCS Measures	Do you feel this measure can improve construction worker safety?  Why? [Revisions]	The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure  Is this incident preventable with implementation of this DFCS measure?	Would you implement this measure in your design?  Would any of the following factors prevent you from implementing this measure on your design?
Ex. 4	Provide grounding circuits to all 480 volt lighting fixtures.	Yes (2)  It could potentially  This is an NEC code requirement. You want to provide lighting fixture grounding to prevent electrocution.	No (2)  People should know what voltage they are dealing with. This was an error, not from the electrical engineer. This is from workplace safety. I wouldn't know how to link the two issues in this instance.  There was likely a ground fault. He tapped into a feeder which should not have been energized.  [Accident: 14323547] An employee was installing an industrial lighting fixture. He was electrocuted when he inadvertently attempted to tap into an energized 480-volt feeder.	Yes (2)

**Table 56:** DFCS measures with Multiple Interview Responses placing them each in Single Tiers

## Unexpected Findings

There were limited unexpected findings in the interviews of AEC design professionals. The low response rate of 10.8% was not unexpected. However, it was unexpected that most of the interviewees were those with senior job titles at their places of work. My earlier perception was they would either be too busy to be involved or they might feel the interview was poor use of their time.

With regards to both the responses and commentaries made by the interviewees, I already anticipated responses across varying spectrums. Some were in favor of addressing construction safety through design while others were not as interested. My observations were reported and discussed.

However, an unexpected finding was 'reverse responses'. The third interview question on each DFCS measure provided the 6 main impediments to DFCS and asked if they would prevent the interviewee from implementing the measures. These included exposure to liability, increased cost, schedule problems and time constraints, decreased project quality and diminished design creativity, designers' lack of safety expertise, and absence of designer interest and motivation. Some interviewees responded that they would implement certain DFCS measures to avoid exposure to liability, to decrease cost, and/or to minimize the project schedule needs. Avoiding exposure to liability was a reason highlighted for implementing certain DFCS measures that were identified as code requirements by some interviewees. These were reasons for implementation and not impediments to implementation. I was sure to clarify before recording the information in such cases.

## **Implications of this Research Task on the Development of the Relational Database Application**

The implication of the findings of this research task was the data was to be incorporated in the development of the relational database application to aid DFCS implementation, the next research task. As intended and planned, the yielded and/or validated impediments to implementing the DFCS measures, their identified or validated preventable safety incidents, and the yielded revisions of certain DFCS measures were all to be included in the database. The categorization of the DFCS measures, based on the survey and interview responses, was also to be utilized in the application.

### **4.1.5 Development of Relational Database Application**

#### **4.1.5.1 Objective**

The function of the relational database application is to assist designers in making safety considerations in the project design phase. Based on the comparative analysis of existing DFCS tools in *Table 5*, there was an identified need for a more effective DFCS tool that could effectively function in the current contractual environment of the U.S AEC industry. The beneficiaries of the software application primarily include design professionals; architects, civil/structural engineers and mechanical/electrical/plumbing engineers. Other project participants could also utilize the software.

The application is a vehicle to encapsulate and utilize the research findings. The earlier research tasks yielded a structured collection of data on DFCS measures. The application is intended to enable users to retrieve this data. This essentially enables use of the research results. As such, the relational database application makes this research more likely to have an impact on improving construction safety.

The application is to provide design-phase DFCS measures by profession and based on project characteristics along with the potential benefits of implementing the measures. The product of using the tool is a printable set of guidelines for AEC design professionals considering DFCS implementation on their projects.

Relational database applications can be developed using such existing software as Microsoft Access, Visual FoxPro, Oracle, Siebel and MySQL among others. My familiarity with using Microsoft Access made it my preferred choice for developing the tool. The relational database application was named DFCS-TIPS. This is an abbreviation for Design for Construction Safety - Tool for Implementation on Projects and Systems.

#### **4.1.5.2      Design and Development**

Requirements engineering is the process of eliciting, documenting, analyzing, validating, and managing requirements (Laplante, 2007). Requirement engineering is concerned with determining the goals, functions, and constraints of software systems (Laplante, 2007). Software requirements specification (SRS) is an aspect of requirements engineering that is the set of activities designed to capture behavioral and non-behavioral aspects of the system (Laplante, 2007). Laplante (2007) identified the types of SRSs which include user requirements, system requirements and software design specifications. For the DFCS-TIPS application, these are discussed.

#### **DFCS-TIPS Application User Requirements**

User requirements specify functional and nonfunctional requirements as they pertain to externally visible behavior in a form understandable by clients and system users (Laplante, 2007). The user requirements for the DFCS-TIPS application are specified.

1. The software application must exclusively provide design-phase DFCS measures.

Considering regulations and current contractual structures in the U.S AEC industry do not require designer involvement in construction safety, software that provides a means or framework for implementing DFCS without providing actual DFCS measures is inadequate. Furthermore, the computer application must provide DFCS measures that do not provide a means for increased liability exposure. Thus, the DFCS-TIPS application must exclusively provide design-phase DFCS measures. This will also include the measures revised through the earlier research tasks.

2. The software application must provide the design-phase DFCS measures by project features or characteristics.

The CII's DFCS Toolbox provides design suggestions for construction safety by 20 categories which are not all situated in the project design phase. As the DFCS-TIPS application was to include only design-phase DFCS measures, it was more appropriate to categorize them by project features or characteristics. This also serves to address one of the NIOSH NORA research gaps. This is the creation of a repository of design suggestions for construction worker safety that can be adapted according to the characteristics of a project.

3. The software application must provide the design-phase DFCS measures by design profession.

The CII's DFCS Toolbox with its over 400 design suggestions utilizes checklists. These checklists are not arranged by profession and include suggestions applicable to architects, civil/structural engineers and MEP engineers. Thus, design professionals are required to read through in order to identify those applicable to them. This is ineffective. As such, the DFCS-TIPS application is to provide design-phase DFCS measures categorized by their appropriate design professions.

4. The software application must provide details with regards to implementing each of the design-phase DFCS measures.

As earlier stated, the CII's DFCS Toolbox utilizes checklists to present its design suggestions for construction safety. Checklists, while easy to use, have a number of disadvantages. Checklists typically lack detail and do not provide an indication of an item's effectiveness. Additionally, they do not provide a means for prioritizing the items. This highlighted the need for developing a tool that not only utilizes a more effective format but provides the safety benefits to motivate the implementation of each included design-phase DFCS measure. This is particularly important since regulations and contractual structures currently do not require designer involvement in construction safety. In the DFCS-TIPS application, these safety benefits are the preventable hazard incidents that could be realized from implementation of the DFCS measures. The other set of details include the potential impediments to implementing the DFCS measures.

5. The software application must be user-friendly.

One of the impediments to DFCS implementation and diffusion is absence of designer interest and motivation (Gambatese et al, 2005). For this reason, tools developed to aid DFCS must be user-friendly to make implementation easier. Furthermore, part of the reason for building databases is to simplify the interface that the user encounters (Whitehorn and Marklyn, 2007). Therefore, the DFCS-TIPS application is to be user-friendly and its interface easily understandable and navigable.

6. The software application must be dynamic.

The application must allow for updating and/or addition of new DFCS measures and their associated details such as their potential implementation impediments, and preventable safety incidents. This is to enable the adaptability of the software application to the user based on earlier knowledge and lessons learned. Enabling the incorporation of knowledge is essential particularly given that DFCS is still an emerging area and as such, is primarily performance-based.

## **DFCS-TIPS Prototype Development**

A prototype of the DFCS-TIPS application was developed. This was to enable the refinement of the software design specifications through the identification of desired features and capabilities.

### DFCS-TIPS Prototype Design

1. The design-phase DFCS measures and information to be used in the software application are stored in a database.
  - a. The database includes the following columns/fields:
    - DFCS Measures
    - Preventable Incidents
    - Project Features
    - Profession
  - b. Each DFCS measure and its data occupy a row in the database table.
  - c. The database only includes design-phase DFCS measures and other information derived and/or evaluated in the research and therefore does not allow for editing by the software users or beneficiaries.
  - d. DFCS measures and their preventable incidents are retrievable from the database based on profession and project features specified.
2. The software application allows for entry of project, organization and user-specific information.

This includes the following information:

  - Project Name
  - Name of Organization
  - Name of User
  - Date
3. The software application provides an opportunity for the user to select his/her profession or that of the intended users of the process output.
  - a. The major AEC design professions are presented for selection in the software application. The DFCS measures are classified by the professions in the DFCS database. They include the following:
    - Architect
    - Civil Engineer
    - MEP Engineer
      - Mechanical
      - Electrical
      - Plumbing
  - b. As the process output may be applicable to multiple professions, the software application allows for the selection of multiple professions.

4. The software application provides an opportunity for selection of project features or characteristics based on the AEC design profession(s) indicated.

DFCS measures to which the project features and design professions apply are generated based on this selection. Where no project characteristics are selected, all DFCS measures applicable to the indicated design professions are provided.
5. The software application generates a printable output page to serve as a recommendation or guideline for DFCS implementation on the particular project.
  - a. The output page includes the following data:
    - Project Name
    - Name of Organization
    - Name of User
    - Date
    - Profession
    - DFCS Measures
    - Incidents preventable by the DFCS Measures
  - b. The output page has capabilities that prompt a computer to print. The information and format should fit appropriately in the print preview and printed document.
6. The software application should incorporate user-friendly features.

For ease of use and also development, the prototype application has two pages or screens. The features of the two pages are briefly described.

  - i. This first page or form is where all the data entry and selection occurs. The page has a “Next” button to move on to the next page. It also has an “Exit” button to exit out of the software application.
  - ii. The second page or report is where the retrieved DFCS information and the entered project, organization and user data are presented in a printable format. This page has a “Print” button that prints a document with all the information on the page/report. The page also has a “Back” button to enable the software user to go back to the first page/form and make changes to his/her data entries and selections. Also, the page has an “Exit” button to exit out of the software application.

#### The DFCS-TIPS Prototype Data

The data in the application prototype includes DFCS measures that I earlier considered to be situated in the design phase and as applicable to the different AEC design disciplines. This was to better enable demonstration of the

application's capabilities and functionality. Seen in *Table 57*, the included DFCS measures are provided along with their applicable professions, project features and preventable safety incidents.

	<b>DFCS Measures</b>	<b>Professions</b>	<b>Project Features</b>	<b>Preventable Incident</b>
1	Design a permanent guardrail that surrounds each skylight.	Architect	Skylights	On January 14, 2003, a construction employee was working on the sixth story of a building. He was securing a lifeline on a concrete beam when he stepped back and fell through a skylight, approximately 60 feet to the ground. The employee died.
2	Design window sills to be 42 inches minimum above the floor level. Window sills at this height will act as guardrails during construction.	Architect	Windows	On May 24, 2006, a superintendent was walking in a room when he tripped and fell through an unguarded window on the second floor of a building. He fell 18 feet and died.
3	Design scaffolding tie-off points into exterior walls of buildings for construction purposes.	Architect	Walls	Case yet to be identified
4	On sloped sites, orient the project layout or grade the site accordingly to minimize the amount of work on steep slopes.	Architect	Sloped Site	Case yet to be identified
5	In multi-story buildings, design each floor plan to have a smaller area than the story below to prevent objects and workers from falling more than one story.	Architect	Multi-story Project	On December 16, 2003, an employee fell from the fourth floor balcony of a residential building and was instantly killed.
6	Locate exterior stairways and ramps on the sheltered side of the structure to protect them from rain, snow, and ice to minimize fall hazards.	Architect	Exterior Stairways	Case yet to be identified
7	Use a single size, or a minimum number of sizes possible, of bolts, nails, and screws. If more than one size is required, specify sizes which vary greatly and are easily distinguishable.	Civil Engineer	Structural Connections	Case yet to be identified
8	Consider alternative steel framing systems which reduce the number of elements and where beams are landed on supports rather than suspended between them.	Civil Engineer	Steel Framing	Case yet to be identified
9	In order to allow sufficient walking surface, use a minimum beam width of 6 inches.	Civil Engineer	Beams	On May 21, 2002, Employee #1, while laying decking and putting up safety lines, fell 37-feet to the ground. The employee was walking across a steel beam when he lost balance and fell to his death.
10	Design wood piles such that they are below the water table, and do not specify creosote for protection of the piles from environmental deterioration.	Civil Engineer	Pile Foundations	Case yet to be identified

	DFCS Measures	Professions	Project Features	Preventable Incident
11	On spread and continuous footings, and mat foundations, design the top layer of reinforcing steel to be spaced at no more than 6 inches on center, each way, to provide a continuous, stable walking surface before the concrete is poured.	Civil Engineer	Continuous Foundations	Case yet to be identified
12	Provide the constructor with floor and roof design loads for use in determining material stockpile locations and heavy equipment maneuverability.	Civil Engineer	Constructor Provisions	Case yet to be identified
13	Indicate on the contract drawings the locations of existing underground utilities and mark a clear zone around the utilities. This is essential when excavation operations take place.	MEP Engineer - Mechanical	Underground Utilities	Case yet to be identified
14	Provide adequate passageways and safe access areas around all equipment in control, electrical, and electronic rooms to reduce electrical shock hazards.	MEP Engineer - Electrical	Electrical Rooms	Case yet to be identified
15	Route pipes at least 30 inches above the finished floor level to keep them from becoming trip hazards.	MEP Engineer - Plumbing	Floor-level Piping	Case yet to be identified

**Table 57:** DFCS Measures and Data in the DFCS-TIPS Prototype Database

### Features of the Prototype Database

Using Microsoft Access 2007, the prototype database was developed to adhere to the capabilities earlier specified. A single base table was used in the prototype database and the screenshot is seen in *Figure 28*. With regards to maintaining the integrity of data stored in the database, I entered all the data and access to the database was not enabled for the software beneficiaries and users. Thus, I took precautions and also cross-checked to ensure the integrity of the data utilized in the database.

ProjectFeatures	DFCSMeasures	Profession	PreventableIncident
Beams	In order to allow sufficient walking surface, use a minimum beam width of 6 in	Civil Engineer	On May 21, 2002, Employee #1,
Constructor Provision	Provide the constructor with floor and roof design loads for use in determinin	Civil Engineer	Case yet to be identified
Continuous Foundations	On spread and continuous footings, and mat foundations, design the top layer	Civil Engineer	Case yet to be identified
Electrical Rooms	Provide adequate passageways and safe access areas around all equipment in	MEP Engineer	Case yet to be identified
Exterior Stairways	Locate exterior stairways and ramps on the sheltered side of the structure to	Architect	Case yet to be identified
Floor-level Piping	Route pipes at least 30 inches above the finished floor level to keep them fro	MEP Engineer	Case yet to be identified
Multi-story Project	In multi-story buildings, design each floor plan to have a smaller area than the	Architect	On December 16, 2003, an empl
Pile Foundations	Design wood piles such that they are below the water table, and do not specif	Civil Engineer	Case yet to be identified
Skylights	Design a permanent guardrail that surrounds each skylight.	Architect	On January 14, 2003, a construct
Sloped Site	On sloped sites, orient the project layout or grade the site accordingly to mini	Architect	Case yet to be identified
Steel Framing	Consider alternative steel framing systems which reduce the number of elem	Civil Engineer	Case yet to be identified
Structural Connector	Use a single size, or a minimum number of sizes possible, of bolts, nails, and s	Civil Engineer	Case yet to be identified
Underground Utilities	Indicate on the contract drawings the locations of existing underground utiliti	MEP Engineer	Case yet to be identified
Walls	Design scaffolding tie-off points into exterior walls of buildings for constructi	Architect	Case yet to be identified
Windows	Design window sills to be 42 inches minimum above the floor level. Window s	Architect	On May 24, 2006, a superintend

**Figure 28:** DFCS-TIPS Prototype Database Table

The selected type of database architecture was stand-alone (single-tier) architecture where the entire database is developed on a personal computer (PC) and is used there (Whitehorn and Marklyn, 2007). This architecture was selected to meet the desired capabilities of the prototype.

### Visual Basic and Features of the User Interface

Building a user interface and controlling data entry at the form level are typically accomplished using GUI (Graphical User Interface), macro language or programming language (Whitehorn and Marklyn, 2007). A very common programming environment used in building user interfaces for databases is Visual Basic.

Visual Basic is an ideal programming language that utilizes a GUI for creating sophisticated professional applications for Microsoft Windows (Levy, 2002). All the major Autodesk products including AutoCAD and REVIT were initially developed on the Microsoft Windows platform. The DFCS-TIPS application was to be developed for use on the Microsoft Windows platform. This was also the case for the prototype. Features of Visual Basic include easy comprehension, user-friendliness, fast application development and many other aspects such as use of ActiveX technology and Internet features (Levy, 2002). Visual Basic, also a Microsoft product, is compatible with databases developed on Microsoft Access. As a matter of fact, Visual Basic for Application (VBA) is a complimentary inclusion in the Microsoft Access software. An additional advantage is I am familiar with using Visual Basic to develop simple applications. For all the aforementioned reasons, Microsoft Visual Basic was selected for developing the user interface of the DFCS-TIPS application as well as for the prototype. As the more recent version of the programming environment, Visual Basic 6.0 was utilized.

Visual Basic has 20 classic components (Mansfield, 1999). Out of these, seven are data-aware and are thus capable of being linked to a data control or a data environment. These include TextBox, Label, CheckBox, PictureBox, Image, ComboBox and ListBox. Mansfield (1999) defines the function of each of these components or controls as follows:

- TextBox: To display text that may be edited directly by the user.
- Label: To display text that cannot be changed directly by the user.
- CheckBox: To give the user a choice of yes/no multiple choice options.
- ComboBox: A combination of a TextBox and a ListBox control.
- ListBox: Displays a list of items that may be selected by the user.
- PictureBox: To display images or act as a container to other controls.
- Image: To display a picture.

Another important control is the CommandButton control which is used by the user to invoke some action. The default event for a CommandButton is "Click". Other components or controls such as Frame, OptionButton, Timer, Shape, and

Line among many others, also serve distinct functions in defining what actions application users can perform. Three-letter mnemonic prefixes are mostly used for controls, commands and as naming conventions in Visual Basic (Mansfield, 1999).

Through over 200 command options, Visual Basic allows the application developer to create a desired outcome (Chruscinski, 2010). These can be used separately or in combination. Chruscinski (2010) categorized the command options which are briefly discussed below:

- Math Equations: These commands are used to perform mathematical operations such as addition "+", subtraction "-", multiplication "\*" and division "/" among many others.
- Data Relationships: These commands are used to define or utilize the relationship between data that is necessary for certain desired responses. Examples of such commands include greater than ">", less than "<", equal to "=" and not equal to "<>" among many others.
- Looping Commands: These commands are used to allow for a continual action to occur under a certain set of circumstances. This is performed by using a "While Wend" statement.
- If Then Else Commands: These commands are used to perform a specific action in response to a fulfilled condition. Accordingly, in completing the command, "If", "then" and/or "else" are used in a conditional statement.
- Time Commands: These commands center on time calculations and are used to get the current date, time, or both. The commands include "Date", "Time" and "Now". Additionally, they can be further specified to "Day", "Hour", "Minute" and "Second".
- File and Directories: These commands are used to access other files within a directory. Examples of such commands include "CurDir" which returns the current directory and "MkDir" which creates a new directory. Other examples are the "Open" and "Close" commands which are respectively used to open and close files.

In Visual Basic, the "Form" is the main stage of the application (Mansfield, 1999). More than one form may be used in an application and each will be a window in the application. By default, Visual Basic starts with a form called "Form1". There are two main ways to add a new Form to a Visual Basic project. One can either select "Add Form" from the "Project" menu or right-click the Forms folder in the Project Explorer and select, "Add", and then "Form" (Mansfield, 1999). And to load a new form, one can use the "Load" command.

Controls are added to the form in two ways. This is either by selecting the control and drawing a bounding rectangle on the form or simply by double-clicking the controls in the toolbox. The controls on the form were selected as appropriate to meet the prototype design requirements. As earlier stated, two pages, windows or forms were intended for the DFCS-TIPS application prototype. For the first form, textbox controls were selected for all the data entries. For the selections,

checkbox controls were used since multiple options were to be selectable. The controls selected for each of the data entries and selections on the first form are indicated in *Table 58*.

Data Input	Data Input Type	Selected Visual Basic Controls
Project Name	Entry	Textbox
Name of Organization	Entry	Textbox
Name of User	Entry	Textbox
Date	Entry	Textbox
Profession	Selection	Checkbox
Project Features	Selection	Checkbox

**Table 58:** Selected Visual Basic Controls for DFCS-TIPS Prototype Data Input Form

The second form of the DFCS-TIPS application prototype provided DFCS information in a printable manner. Thus, there was not to be any data input or editing on this form. Accordingly, label controls were used since they displayed text that could not be changed directly by the user. Label controls were used to provide the project name, name of organization, name of user, date, profession, applicable DFCS measures and incidents preventable by the DFCS measures. Labels were also extensively used on both forms to guide the application user. Another control used on both forms was the CommandButton. This enabled the application user to exit out of the application, to navigate between the forms, and to print the second form/report.

Mansfield (1999) provided the procedure for opening a project and form and then attaching a data-aware control when database programming in Visual Basic. This includes connecting the controls to the Microsoft Access database. These steps were very applicable for the placement of a Textbox. Other controls could be placed with minor differences to the steps provided by Mansfield (1999). The steps are listed below:

1. Choose File → New Project.
2. Double-click the Standard EXE icon in the dialog box.
3. Add a Data Environment Designer to the project, and attach it to the database.
4. Add a command object to the project, pointing to the table that contains the data to be displayed.
5. Put the Control on Form1.
6. Double-click the Control's DataSource property in the Properties window.
7. Double-click the Control's DataMember property in the Properties window.
8. Complete the connection between the database and the Control by clicking the Control's DataField property in the Properties window. Then click the down-arrow icon in the property box.

9. In the Properties window, click the name of the field to be displayed in or for the Control.

10. Press F5 to run the project.

The two forms for the DFCS-TIPS application prototype were developed following the listed steps. A screenshot of the first or data input form is seen in *Figure 29*. That of the second or report form is seen in *Figure 30*.

The screenshot shows the Visual Basic 6.0 IDE with the 'Form1 (Form)' window. The form is titled 'DFCS-TIPS' and contains the following fields and controls:

- Project Name:** Text box
- Name Of Organization:** Text box
- Name Of User:** Text box
- Date:** Text box
- Profession:** Group box containing several checkboxes:
  - ☐ Architect
  - ☐ Civil Engineer
  - ☐ MEP Engineer
  - ☐ Mechanical
  - ☐ Electrical
  - ☐ Plumbing
- Project Features (Select features applicable to the project):** Group box containing three columns of checkboxes:
  - Architecture:** ☐ ☐ ☐
  - Civil Engineering:** ☐ ☐ ☐
  - MEP Engineering:** ☐ ☐ ☐
- Next** and **Exit** buttons at the bottom.

The Properties window on the right shows the 'Form1 Form' properties, including Name, Appearance, AutoRedraw, BackColor, BorderStyle, ClipControls, ControlBox, DrawMode, DrawStyle, DrawWidth, Enabled, FillColor, and Caption.

**Figure 29:** DFCS-TIPS Application Prototype Data Input Form in Visual Basic 6.0

The screenshot shows the Visual Basic 6.0 IDE with the 'Form2 (Form)' window. The form is titled 'DFCS - TIPS' and contains the following fields and controls:

- Project Name:** Text box
- Organisation Name:** Text box
- Name Of User:** Text box
- Date:** Text box
- Profession:** Text box
- DFCS Measures:** Text box
- Preventable Incidents:** Text box
- Back**, **Print**, and **Exit** buttons at the bottom.

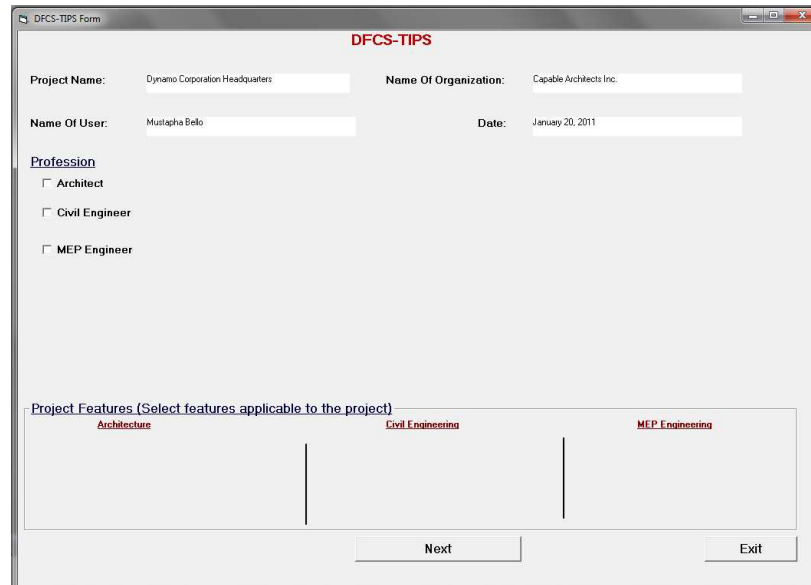
The Properties window on the right shows the 'Form2 Form' properties, including Name, Appearance, AutoRedraw, BackColor, BorderStyle, Caption, ClipControls, ControlBox, DrawMode, DrawStyle, DrawWidth, Enabled, FillColor, and Caption.

**Figure 30:** DFCS-TIPS Application Prototype Report Form in Visual Basic 6.0

## Operation of the DFCS-TIPS Application Prototype

The DFCS-TIPS application prototype operates through a number of steps. These are briefly discussed and illustrated by running the project on Visual Basic and making the appropriate data entries and selection. Screenshots of the application were used to illustrate the operation.

1. Enter the project, organization and user information in the textboxes on the application interface. This is seen in *Figure 31*.

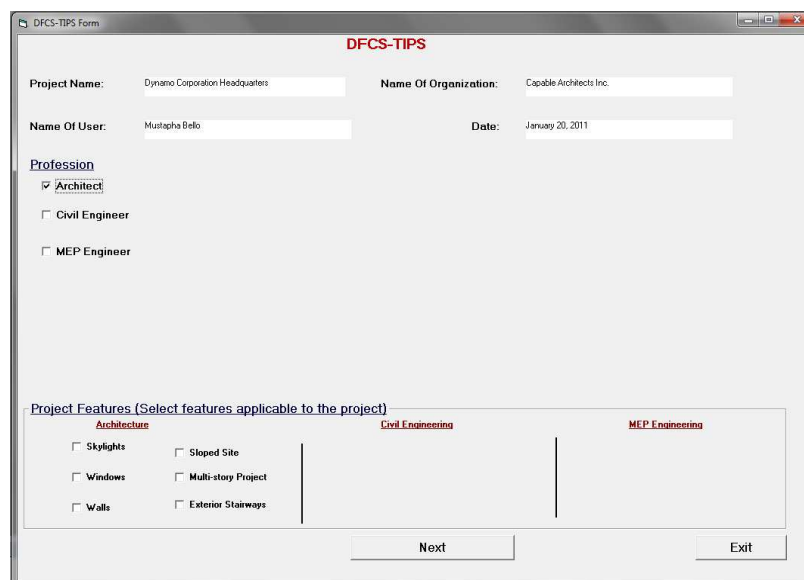


The screenshot shows a window titled "DFCS-TIPS Form" with a red header "DFCS-TIPS". The form contains the following fields and sections:

- Project Name:** Dynamo Corporation Headquarters
- Name Of Organization:** Capable Architects Inc.
- Name Of User:** Mustapha Bello
- Date:** January 20, 2011
- Profession:**
  - ☐ Architect
  - ☐ Civil Engineer
  - ☐ MEP Engineer
- Project Features (Select features applicable to the project):**
  - Architecture:** (empty)
  - Civil Engineering:** (empty)
  - MEP Engineering:** (empty)
- Buttons:** "Next" and "Exit" at the bottom right.

**Figure 31:** DFCS-TIPS Application Prototype Operation – Project and User Data Input

2. Select the profession. Once the profession or professions are selected, project features applicable to the profession appear with their checkboxes for selection. This is seen in *Figure 32*.



The screenshot shows the same "DFCS-TIPS Form" window, but with the "Architect" profession selected. The "Project Features" section now includes checkboxes for the Architecture category:

- Project Name:** Dynamo Corporation Headquarters
- Name Of Organization:** Capable Architects Inc.
- Name Of User:** Mustapha Bello
- Date:** January 20, 2011
- Profession:**
  - ☒ Architect
  - ☐ Civil Engineer
  - ☐ MEP Engineer
- Project Features (Select features applicable to the project):**
  - Architecture:**
    - ☐ Skylights
    - ☐ Windows
    - ☐ Walls
    - ☐ Sloped Site
    - ☐ Multi-story Project
    - ☐ Exterior Stairways
  - Civil Engineering:** (empty)
  - MEP Engineering:** (empty)
- Buttons:** "Next" and "Exit" at the bottom right.

**Figure 32:** DFCS-TIPS Application Prototype Operation – Profession Data Input

3. Select the project features. Multiple selections can be made in the checkboxes. This is as seen in *Figure 33*.

The screenshot shows the 'DFCS-TIPS Form' window. It contains the following fields and options:

- Project Name:** Dynamo Corporation Headquarters
- Name Of Organization:** Capable Architects Inc.
- Name Of User:** Mustapha Bello
- Date:** January 20, 2011
- Profession:**
  - ☒ Architect
  - ☐ Civil Engineer
  - ☐ MEP Engineer
- Project Features (Select features applicable to the project):**
  - Architecture:**
    - ☒ Skylights
    - ☒ Windows
    - ☐ Walls
  - Civil Engineering:**
    - ☐ Sloped Site
    - ☒ Multi-story Project
    - ☐ Exterior Stairways
  - MEP Engineering:** (No options visible)

At the bottom, there are 'Next' and 'Exit' buttons.

**Figure 33:** DFCS-TIPS Application Prototype Operation – Project Features Input

4. Press the “Next” button to advance to the printable DFCS-TIPS report form. The report is seen in *Figure 34*.

The screenshot shows the 'DFCS-TIPS Report' window. It contains the following information:

- Project Name:** Dynamo Corporation Headquarters
- Organisation Name:** Capable Architects Inc.
- Name Of User:** Mustapha Bello
- Date:** January 20, 2011
- Profession:** Architect
- DFCS Measures:**
  - Design a permanent guardrail that surrounds each skylight.
  - Design window sills to be 42 inches minimum above the floor level. Window sills at this height will act as guardrails during construction.
  - In multi-story buildings, design each floor plan to have a smaller area than the story below to prevent objects and workers from falling more than one story.
- Preventable Incidents:**
  - On January 14, 2003, a construction employee was working on the sixth story of a building. He was securing a lifeline on a concrete beam when he stepped back and fell through a skylight, approximately 60 feet to the ground. The employee died.
  - On May 24, 2006, a superintendent was walking in a room when he tipped and fell through an unguarded window on the second floor of a building. He fell 18 feet and died.
  - On December 16, 2003, an employee fell from the fourth floor balcony of a residential building and was instantly killed.

At the bottom, there are 'Back', 'Print', and 'Exit' buttons.

**Figure 34:** DFCS-TIPS Application Prototype Operation – Report

## Further Development of the DFCS-TIPS Application Prototype

To further develop the DFCS-TIPS application from the prototype to the research deliverable, certain tasks were to be completed. Firstly, the database was to be populated with all the DFCS measures determined to be situated in the project design phase through the research tasks. Collected data on the DFCS measures were also to be included in the database. Secondly, the project features were to be increased and/or updated on the application user interface to account for all the included design-phase DFCS measures. Thirdly, the DFCS-TIPS interface and forms were to be refined to have a more effective, presentable and aesthetic format. And lastly, the DFCS-TIPS application was to be developed and evaluated to ensure it meets user requirements, software design specifications and system requirements.

### **DFCS-TIPS Software Design Specifications and System Requirements**

Software design specifications are the most detailed level requirements specifications used as a basis for a system's architecture and design (Laplante, 2007). Meanwhile, system requirements are detailed descriptions of services and constraints (Laplante, 2007). Systems requirements are derived from analysis of the user requirements and should be structured and precise (Laplante, 2007). On this basis, the software and systems requirements are specified.

1. The DFCS-TIPS application is to be a stand-alone desktop-based application.  
Most AEC design software are executable desktop applications and not web-based. Autodesk currently holds 85% of the market share for AEC design software. The most popular Autodesk products such as AutoCAD and REVIT are desktop applications. In line with this, the DFCS-TIPS application is also to be an executable desktop application.
2. The DFCS-TIPS application is to be a relational database application to be developed utilizing Microsoft Access.  
My familiarity with using Microsoft Access RDBMS made it my preferred choice for developing the application. Additionally, Microsoft Access is one of the most broadly available and used database management systems.
3. The DFCS-TIPS application is to be a personal level tool.  
The DFCS-TIPS application is to be a personal level tool and not an organizational level tool or project organizational level tool. Hence, it was to utilize stand-alone (single-tier) architecture. The controls were to be appropriate for this specification. This was also in line with the most popular design software, AutoCAD and REVIT, which are both personal level tools. And as in the case of both the software, the DFCS-TIPS application files were to be transferable.

4. The DFCS-TIPS application is to utilize a database table that includes the following columns seen in *Table 59*.

AEC Design Profession	Project Feature	Stage of Design Phase	Tier of Feasibility of the DFCS Measures	DFCS Measures	Applicable Safety Incidents	Potential Impediments to Implementation	Potential Solutions to the Impediments
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**Table 59:** Columns for the DFCS-TIPS Application Database Table

The reasons or basis for each column or category of data is provided in *Table 60*.

	Columns	Basis / Reasons
1.	AEC Design Profession	Earlier tools do not provide DFCS measures by AEC design profession. This column data would enable adaptability of the software application to the user. This would make the application more user-friendly and thus, more effective.
2.	Project Feature	Earlier tools do not exclusively provide design-phase DFCS measures by project features. This data would enable adaptability of the software application to the project. This would make the application more user-friendly and thus, more effective. This would also serve to address one of the NIOSH NORA research gaps. This is the creation of a repository of design suggestions for construction worker safety that can be adapted according to the characteristics of a project.
3.	Stage of Design Phase	The DFCS measures are applicable to different stages of the design phase. These stages include preliminary design, design development, and construction documents. This column data would enable the software user to identify applicable DFCS measures to the stage(s) of the design phase in which DFCS implementation is being considered.
4.	Tier of Feasibility of the DFCS Measures	Earlier tools did not provide a means for determining the effectiveness or for prioritizing DFCS measures. This column data would allow a user to identify those design-phase DFCS measures validated to have no identified impediments and those with some identified impediments. It would also allow users to identify measures based on confidence in their level of effectiveness as determined through research. This data would essentially aid the user in determining the feasibility of implementing specific DFCS measures.
5.	DFCS Measures (Design-phase)	Considering regulations and current contractual structures in the U.S AEC industry do not require designer involvement in construction safety, software that provides a means or framework for implementing DFCS without providing actual DFCS measures is inadequate. Furthermore, the computer application must provide DFCS measures that do not provide a means for increased liability exposure. Thus, the DFCS-TIPS application must exclusively provide design-phase DFCS measures. This also includes the measures revised through the earlier research tasks. Design-phase DFCS measures constitute a research deliverable.
6.	Applicable Safety Incidents to the DFCS Measures	Earlier tools did not provide a means for determining the effectiveness or for prioritizing DFCS measures. This highlighted the need for developing a tool that provides the safety benefits to motivate the implementation of each included design-phase DFCS measure. This is particularly important since regulations and contractual structures currently do not require designer involvement in construction safety. In the DFCS-TIPS application, these safety benefits are the preventable hazard incidents that could be realized from implementation of the DFCS measures. The preventable safety incidents of the design-phase DFCS measures constitute another research deliverable.

	Columns	Basis / Reasons
7.	Potential Impediments to Implementing the DFCS Measures	Earlier tools did not provide a means for determining the effectiveness or for prioritizing DFCS measures. This highlighted the need for developing a tool that provides the potential impediments to implementing each included design-phase DFCS measure. This is particularly important since regulations and contractual structures do not currently require designer involvement in construction safety. Impediments to implementing the design-phase DFCS measures constitute another research deliverable.
8.	Potential Solutions to the Impediments of the DFCS Measures	Given that potential impediments to implementing the DFCS measures are to be provided, it could prove detrimental to not provide potential solutions to the impediments. It would create a 'dead-end' scenario. For this reason, this column of data was included. The solutions were those identified to broadly address the impediments to DFCS. Though not distinctly specified for each DFCS measure, they were generally applied for each impediment as identified through the research tasks.

**Table 60:** Reasons for the Columns in the DFCS-TIPS Application Database Table

As observed from *Table 59* and *Table 60*, there are a number of columns for which data was not identified or yielded in earlier research tasks. 'AEC Design Profession' was identified for all DFCS measures in the first research task, the categorization of and indexing of DFCS measures. 'DFCS Measures' were determined through the first research task and through the surveys of AEC design professionals. 'Tier of Feasibility of the DFCS Measures' and 'Potential Impediments to Implementation' were determined through the surveys and interviews of AEC design professionals. 'Applicable Safety Incidents' were derived through the third research task and validated or not-validated through the interviews of AEC design professionals.

'Project Feature' was determined based on the feature to which the DFCS measure(s) mostly pertains. *Table 61* provides all the entries in the 'Project Feature' column. Where the project feature entries were considered to be similar, they were merged into one project feature category. This was to avoid multiple similar categories which could make application use more tedious and the application less user-friendly. *Table 62* provides a sample of design-phase DFCS measures and their project feature entries.

<b>Entries in the Project Feature Column for the DFCS Measures</b>		
- Project / Site Orientation	- Multi-level Project	- Underground Equipment
- Stairways / Ramps	- Floor Design	- Protective / Safety Guards
- Permanent Ladders	- Member Design	- Equipment Location
- Roof	- Foundation / Earthwork Design	- Equipment Controls
- Building Materials	- Member Connections	- Relief Valves
- Finishing	- Wall / Masonry Design	- Fueled Equipment
- Walkways	- Stairs / Railings	- System Design
- Windows	- Tank Design	- Component Placement
- Egress	- Equipment Support	- Fixture Design
- Floor Openings	- Pressurized Equipment	- Piping System Placement

**Table 61:** Entries in the Project Feature Column of the DFCS-TIPS Database Table

‘Stage of Design Phase’ was determined based on the level of detail achieved at the time that a DFCS measure can be implemented. For example, DFCS measures that describe the placement of structures on the project site can only be implemented at the earliest stage. Thus, such a measure is placed in the “Preliminary Design” stage of the design phase. Meanwhile, a measure that specifies the types of finishing to use is most likely to be situated in the “Construction Documents” stage of the design phase. *Table 62* provides a sample of design-phase DFCS measures and their ‘Stage of Design Phase’ entries.

	<b>AEC Design Profession</b>	<b>Project Feature</b>	<b>Stage of Design Phase</b>	<b>DFCS Measure</b>
1.	Architect	Stairways / Ramps	Preliminary Design	Locate exterior stairways and ramps on the sheltered side of the structure or fully enclose them to protect them from rain, snow, and ice to minimize fall hazards.
2.	Architect	Project / Site Orientation	Preliminary Design	Orient the project to allow for the construction of temporary roads, fire lanes, and approach roads during construction.
3.	Architect	Stairways / Ramps	Design Development	Use steel or concrete instead of wood for stairways in areas where fire sources are present.
4.	Architect	Roof	Design Development	Place skylights on a raised curb (10-12 inches).
5.	Architect	Finishing	Construction Documents	Design signs to be integral parts of walls and floors using color, tiles, or floor coverings.
6.	Civil / Structural Engineer	Floor Design	Preliminary Design	For elevated floors, use permanent metal formed decking with concrete fill rather than a concrete slab which requires temporary formwork.
7.	Civil / Structural Engineer	Member Design	Design Development	In order to allow sufficient walking surface, use a minimum beam width of 6 inches.
8.	Civil / Structural Engineer	Foundation / Earthwork Design	Preliminary Design	Keep detailed work above grade; simplify all below grade work to reduce worker exposure to cave-ins.
9.	Mechanical Engineer	Relief Valves	Design Development	Ensure that safety relief valves exhaust and drain away from passageways and work areas.
10.	Mechanical Engineer	Equipment Location	Design Development	To reduce fall hazards, locate rooftop mechanical/HVAC equipment away from the edge of the structure and where not possible, use railings.
11.	Electrical Engineer	System Design	Design Development	Ensure that the withstand rating is adequate for the available fault current.
12.	Electrical Engineer	Component Placement	Construction Documents	Minimize the number of wires, cables, and hoses laid on walking surfaces by the use of elevated cable trays or hose supports.
13.	Plumbing Engineer	System Design	Design Development	Minimize flanges in piping under high pressure, or which contains explosive or lethal gases.
14.	Plumbing Engineer	Piping System Placement	Design Development	Pipe pump seal water in a manner to avoid slipping, e.g. case drains/base plates to hubs.

**Table 62:** Sample List of Design-phase DFCS Measures with Profession, Project Feature and Stage of Design Phase Data

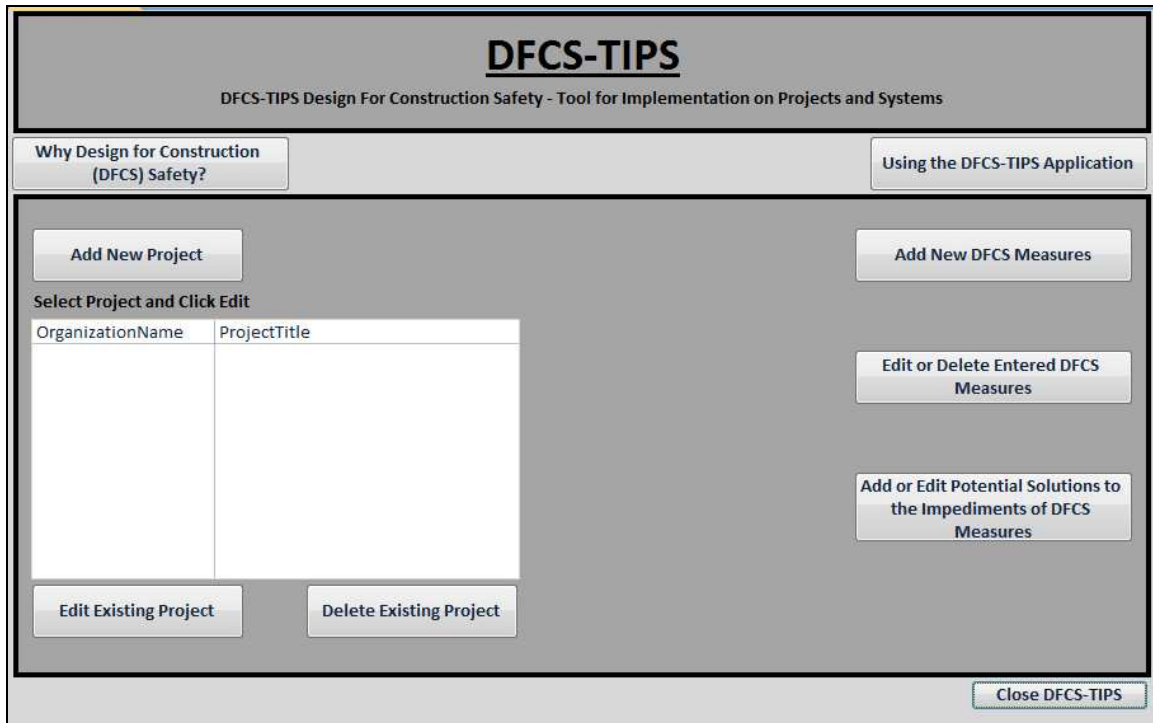
‘Potential Solutions to the Impediments’ were identified from earlier research by Gambatese et al (1997), Gambatese (2003), Gambatese et al (2005), and Toole (2005). These were the solutions to the impediments of DFCS implementation as provided in *Table 3*. Those solutions that could be applied to the impediments of implementing individual DFCS measures and/or those that could be applied to individual projects were derived. These were then indicated as the potential solutions in all the cases where their respective impediments were yielded. *Table 63* provides the impediments to DFCS implementation and their respective potential solutions as used in the DFCS-TIPS application’s database table.

	<b>Impediments to DFCS Implementation</b>	<b>Potential and Possible Solutions</b>
1.	Exposure to liability	<ul style="list-style-type: none"> <li>- Revised contract language</li> <li>- Revised insurance policy</li> </ul>
2.	Designers’ lack of safety expertise	<ul style="list-style-type: none"> <li>- Engage outside safety experts to review designs</li> <li>- Utilize designers with formal safety training</li> </ul>
3.	Increased cost	<ul style="list-style-type: none"> <li>- Investigate avenues of potential cost savings on other project features</li> </ul>
4.	Schedule problems and time constraints	<ul style="list-style-type: none"> <li>- Investigate avenues of decreasing the time needs of other project features</li> </ul>
5.	Decreased project quality and diminished design creativity	<ul style="list-style-type: none"> <li>- Identify alternative design features to address the associated safety hazards</li> </ul>
6.	Absence of designer interest and motivation	<ul style="list-style-type: none"> <li>- Identify alternative design measure to address the associated safety hazards</li> </ul>

**Table 63:** Potential Solutions to DFCS Impediments as used in the DFCS-TIPS Database Table

The information entered in the DFCS-TIPS database is provided in its entirety in *Appendix J*. All the design-phase DFCS measures that were identical but written differently were consolidated along with their collected information. This was to minimize or eliminate redundancies. Hence, a total of 212 DFCS measures are included in the database.

5. The original information in the DFCS-TIPS database is not to be editable. Only the newly entered data by the user is to be editable.  
The reason for this is the data was yielded and validated or not-validated through this research. This specification would serve to maintain the integrity of the research data and allow for its full utilization. Meanwhile, the user is to have the capability to edit data he/she adds to the database. The user has the capability to add rows of information to the database table and this added information can be edited. This is to ensure that the software is dynamic and adaptable to the user and his/her experiences. And, if there are entry errors or necessary additions to his/her added data, these can be applied by the user.
6. Once opened, the DFCS-TIPS application presents a simple interface for the application user. *Figure 35* shows the DFCS-TIPS Application Interface.



**Figure 35:** DFCS-TIPS Application: Interface

The interface allows for the following functionalities:

- a. Add new project
  - i. When this button is clicked on the DFCS-TIPS interface, the application presents the “Project Interface Page” that has textboxes to allow for the entry of the following information:
    1. User Name
    2. Organization Name
    3. Project Title
    4. Project Expected Completion Date
    5. Other Details

This is important to allow the user to return to saved information and also to edit the information and use for other similar projects. *Figure 36* shows the DFCS-TIPS Project Interface Page.

**DFCS-TIPS**

DFCS-TIPS Design For Construction Safety - Tool for Implementation on Projects and Systems

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User Name:

Organization Name:

Project Title:

Project Expected Completion Date:

Other Details:

**Figure 36:** DFCS-TIPS Application: Project Interface Page

- ii. At the right side of the “Project Interface Page” are buttons that allow the user to ‘Select DFCS Measures for Implementation’, ‘View the Selected DFCS Measures’, and ‘Print the Selected DFCS Measures’
1. Select DFCS measures for implementation.
    - a. When this button is clicked on the interface, the application presents an “Input” page that allows for the selection of the ‘AEC design Profession’, ‘Project Feature’, and/or ‘Stage of Design Phase’. One or all three inputs can be selected to yield the output DFCS measures and corresponding details. At the bottom of the page, there is a “Back” button to return to the “Project Interface Page”, and a “Provide DFCS Measures” button. On the page are also buttons that include “Select DFCS Measures by Search Term” and “Select DFCS Measures from Index”. *Figure 37* shows the DFCS-TIPS Input Page.

## DFCS-TIPS

DFCS-TIPS Design For Construction Safety - Tool for Implementation on Projects and Systems

Select DFCS Measures  
by Search Term

Select DFCS Measures  
from Index

**AEC Design Profession:**

Select	AEC Design Professional
<input checked="" type="checkbox"/>	Architect
<input checked="" type="checkbox"/>	Civil / Structural Engineer
<input type="checkbox"/>	Mechanical Engineer
<input type="checkbox"/>	Electrical Engineer
<input type="checkbox"/>	Plumbing Engineer

Record: 14 2 of 5 No Filter Search

**Stage of Design Phase:**

Select	Stage Of Design Phase
<input type="checkbox"/>	Preliminary Design
<input checked="" type="checkbox"/>	Design Development
<input type="checkbox"/>	Construction Documents

Record: 14 2 of 3 No Filter Search

**Project Features:**

Select	Project Feature
<input type="checkbox"/>	Equipment Support
<input type="checkbox"/>	Finishing
<input checked="" type="checkbox"/>	Floor Design
<input type="checkbox"/>	Floor Openings
<input type="checkbox"/>	Foundation / Earthwork Design
<input type="checkbox"/>	Member Connections
<input checked="" type="checkbox"/>	Member Design
<input type="checkbox"/>	Multi-level Project
<input type="checkbox"/>	Permanent Ladders
<input type="checkbox"/>	Project / Site Orientation
<input type="checkbox"/>	Roof
<input type="checkbox"/>	Stairways / Ramps
<input type="checkbox"/>	Tank Design
<input checked="" type="checkbox"/>	Walkways
<input type="checkbox"/>	Wall / Masonry Design
<input checked="" type="checkbox"/>	Windows

Record: 14 9 of 18 No Filter Search

Back

Provide Applicable DFCS  
Measures

**Figure 37:** DFCS-TIPS Application: Input Page

- b. From the “Input” page, once the input(s) are selected and the “Provide Applicable DFCS Measures” button is clicked, the “Output” page opens. Based on the selected inputs (‘AEC design Profession’, ‘Project Feature’, and/or ‘Stage of Design Phase’), the page provides the applicable outputs (‘Tier of Feasibility of the DFCS Measures’, ‘DFCS Measures’, ‘Applicable Safety Incidents’, ‘Potential Impediments to Implementation’, and ‘Potential Solutions to the Impediments’). The outputs appear in a tabular form with checkboxes by their (left) side. These checkboxes allow for the selection of those DFCS measures (with their corresponding details) that will be implemented on the project. At the bottom of the page, there is a “Back” button to return the user to the previous “Input” page. There is also a “Complete Selection” button which saves the selections and returns the user to the Project Interface Page. *Figure 38* shows the DFCS-TIPS Output Page.

<h2 style="text-align: center;">DFCS-TIPS</h2> <p style="text-align: center;">DFCS-TIPS Design For Construction Safety - Tool for Implementation on Projects and Systems</p>					
Select	Tier	DFCS Measures	Applicable Safety Incidents	Potential Impediments to Impl.	Potential Solutions to the Imp.
<input checked="" type="checkbox"/>	3B	Design window sills at a consistent level throughout the project.	[Accident: 200960136]: Employee #1, carpenter, was part of a four-man work crew installing pre-made roof trusses. He was standing on the second floor at the edge of an unprotected 7 ft tall by 6 ft wide picture window opening from which the bottom sill had been removed. Employee #1 was reaching out of the opening for a 2 by 8 that was leaning upright beside it when he fell approximately 14.5 ft through the opening to the sloping ground. He sustained minor lacerations, contusions, and sprains, and was transported to the hospital for treatment and observation. Employee #1 was wearing regular work clothes and shoes, but no other form of personal protective equipment.	Decreased project quality and diminished design creativity	Identify alternative design features to address the associated safety hazards
<input checked="" type="checkbox"/>	1B	Design structural member depths to allow adequate head room clearance around stairs, platforms, valves, and all areas of egress.	[Accident: 170361919]: Employee #1 was climbing onto a catwalk when he stood up under a large steel beam that was 60 1/2 in. above the catwalk and struck his head with enough force to break the suspension in his hard hat. He did not seek medical treatment at the time, but over a year later he began experiencing numbness in his extremities. He was diagnosed with severe stenosis of his neck vertebra and underwent surgery. The steel beam was neither marked nor padded.	Increased Cost	Investigate avenues of potential cost savings on other project features

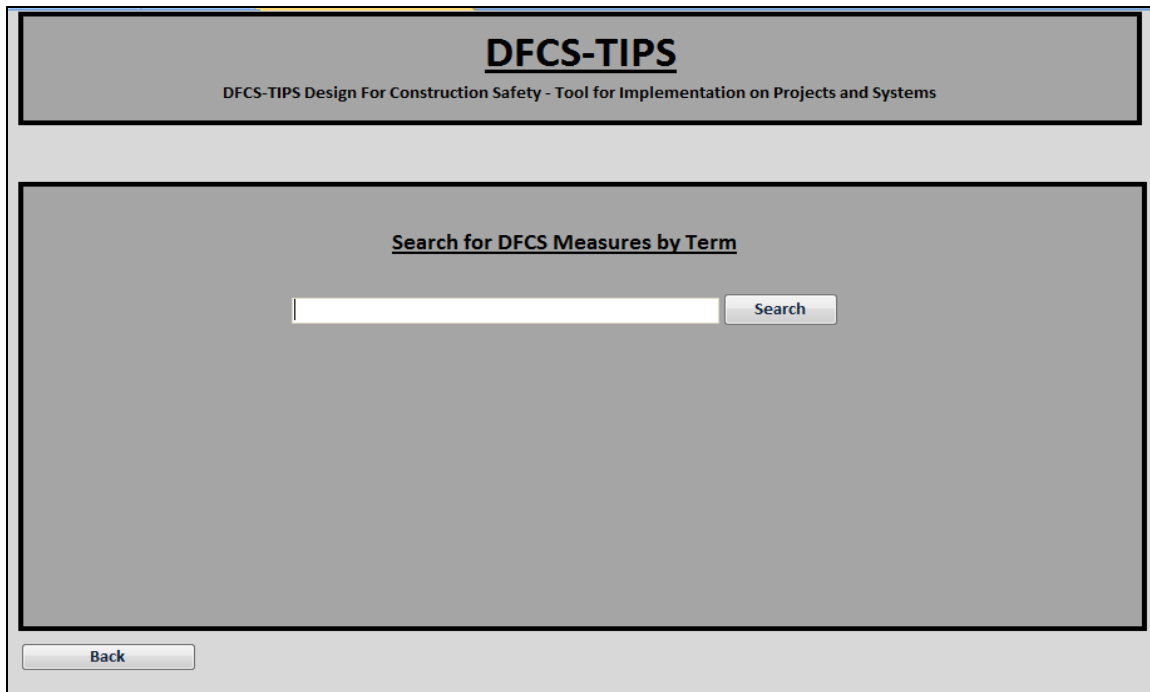
Record: 10 of 12    No Filter    Search

Back    Complete Selection

**Figure 38:** DFCS-TIPS Application: Output Page

- c. From the “Input” page, once the “Select DFCS Measures by Search Term” button is clicked, a page opens. The page has a ‘search textbox’ with capabilities of searching the ‘DFCS Measures’ column in the database for the entered term. There is a “Search” button by the textbox. At the bottom of the page, there is a “Back” button to return the user to the previous “Input” page. Based on the search term entered, the application opens the “Output” page with the applicable outputs (‘Tier of Feasibility of the DFCS Measures’, ‘DFCS Measures’, ‘Applicable Safety Incidents’, ‘Potential Impediments to Implementation’, and ‘Potential Solutions to the Impediments’). The outputs appear in a tabular form with checkboxes by their (left) side. These checkboxes allow for the selection of those DFCS measures (with their corresponding details) that will be implemented on the project. At the bottom of the page, there is a “Back” button to return the user to the previous

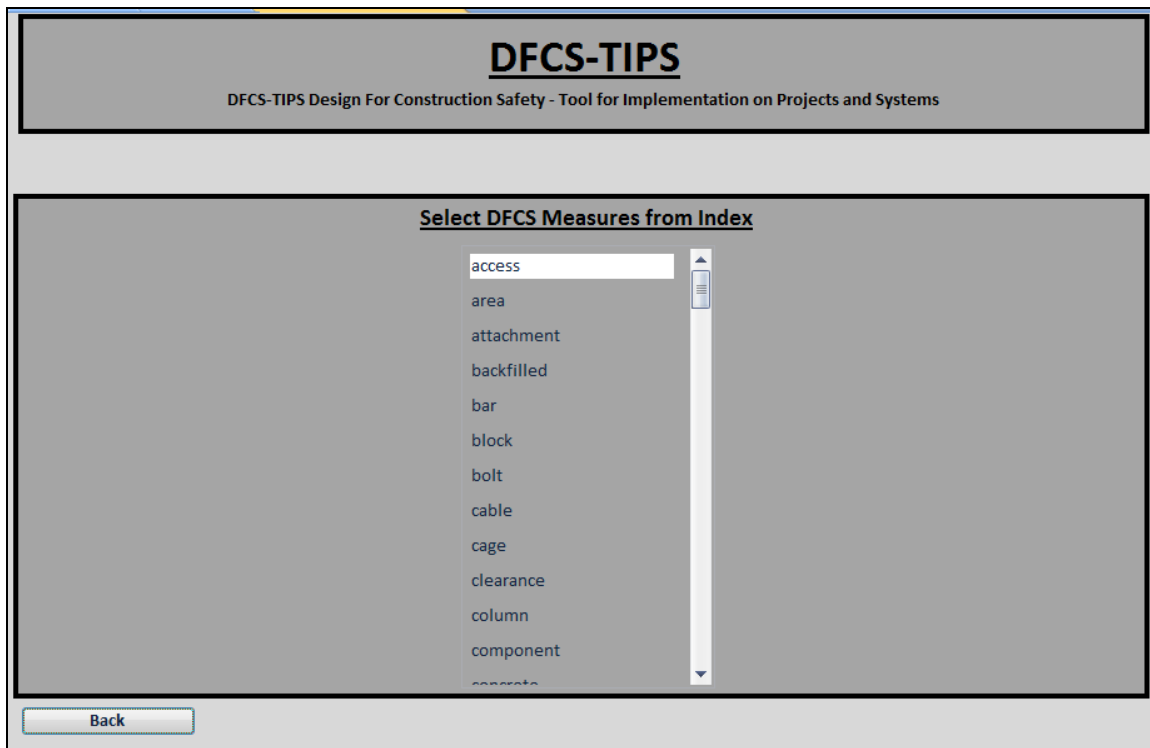
“Search” page. There is also a “Complete Selection” button which saves the selections and returns the user to the Project Interface Page. *Figure 39* shows the DFCS-TIPS Search Page.



The screenshot shows a web application interface for DFCS-TIPS. The top section is a dark gray header with the text "DFCS-TIPS" in large, bold, white letters, and below it, in smaller white text, "DFCS-TIPS Design For Construction Safety - Tool for Implementation on Projects and Systems". The main content area is a light gray rectangle. Inside this area, the text "Search for DFCS Measures by Term" is centered. Below this text is a white search input field with a small "Search" button to its right. At the bottom left of the main content area, there is a "Back" button.

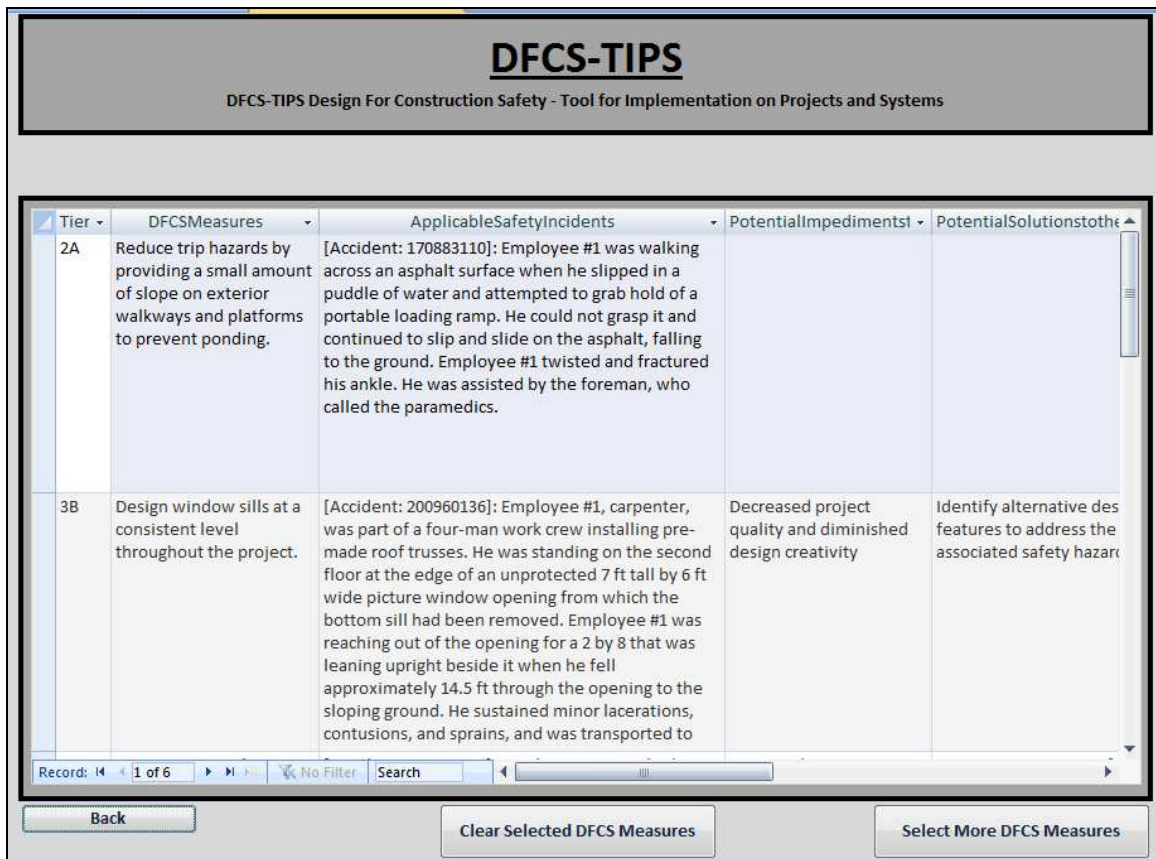
**Figure 39:** DFCS-TIPS Application: Search Page

- d. From the “Input” page, once the “Select DFCS Measures from Index” button is clicked, a page opens. The page has an index list of different major terms. When any of the index terms are clicked, the “Output” page opens with all the applicable outputs (‘Tier of Feasibility of the DFCS Measures’, ‘DFCS Measures’, ‘Applicable Safety Incidents’, ‘Potential Impediments to Implementation’, and ‘Potential Solutions to the Impediments’). The outputs appear in a tabular form with checkboxes by their (left) side. These checkboxes allow for the selection of those DFCS measures (with their corresponding details) that will be implemented on the project. At the bottom of the page, there is a “Back” button to return the user to the previous “Index” page. There is also a “Complete Selection” button which saves the selections and returns the user to the Project Interface Page. *Figure 40* shows the DFCS-TIPS Index Page.



**Figure 40:** DFCS-TIPS Application: Index Page

2. View the selected DFCS measures for implementation.
  - a. When this button is clicked on the interface, the application presents a page with the outputs derived from the selection exercise (from the 'Select DFCS Measures for Implementation' button). These outputs are presented in a tabular form and include the 'Tier of Feasibility of the DFCS Measures', 'DFCS Measures', 'Applicable Safety Incidents', 'Potential Impediments to Implementation', and 'Potential Solutions to the Impediments'. Accordingly, where none have been selected, no output is shown. *Figure 41* shows the DFCS-TIPS View Selected Measures Page.
  - b. At the bottom of the page, there is a "Back" button to return to the Project Interface Page. There is also a "Select more DFCS measures" button which takes the user to the "Input" page. There is also a "Clear selected DFCS Measures" button which clears the selected measures.



**Figure 41:** DFCS-TIPS Application: View Selected Measures Page

3. Print the selected DFCS measures for implementation.
  - a. When this button is clicked on the interface, the application presents a page with the following information:
    - i. User Name
    - ii. Organization Name
    - iii. Project Title
    - iv. Project Expected Completion Date
    - v. Other Details
    - vi. Selected DFCS Measures and Details in a tabular format
      1. Tier of Feasibility of the DFCS Measures
      2. DFCS Measures
      3. Applicable Safety Incidents
      4. Potential Impediments to Implementation
      5. Potential Solutions to the Impediments

- b. From this page, one can return to the Project Interface Page. There is also a “Print” button that activates printing capabilities. The information and format should fit appropriately in the print preview and in the printed document. *Figure 42* shows the DFCS-TIPS Print Page.

## DFCS-TIPS

User NameMustapha Bello
Organization NameCarnegie Mellon
Other DetailsThe project is of epic proportions.

Project TitleAECM Complex
Project Expected Completion Date5/20/12

Tier of Feasibility	DFCS Measures	Applicable Safety Incidents	Potential Impediments to Implementation	Potential Solutions to the Impediments	New Potential Solutions Impediments
2B	Design a small amount of slope into walkways to prevent ponding.	(Accident: 201183209): On November 14, 2006, employees were working at the Public Health Center. At approximately 3:10 p.m., Employee #1 was on the second floor walking down the central hall on the right side of the hallway towards the rest room when she stepped into a puddle of water. Employee #1's right foot slipped forward and she fell onto her left knee, which was bent. A coworker arrived and called an ambulance. Employee #1 was transported to the hospital. Employee #1 had shattered the lower one-half to one-third of her patella (left knee cap). Employee #1 was hospitalized and underwent surgery.	Designers' lack of safety expertise	Engage outside safety experts to review designs; Utilize designers with formal safety training	
3B	Design window sills at a consistent level throughout the project.	(Accident: 200960136): Employee #1, carpenter, was part of a four-man work crew installing pre-made roof trusses. He was standing on the second floor at the edge of an unprotected 7 ft tall by 8 ft wide picture window opening from which the bottom sill had been removed. Employee #1 was reaching out of the opening for a 2 by 8 that was leaning upright beside it when he fell approximately 14.3 ft through the opening to the sloping ground. He sustained minor lacerations, contusions, and sprains, and was transported to the hospital for treatment and observation. Employee #1 was wearing regular work clothes and shoes, but no other form of personal protective equipment.	Decreased project quality and diminished design creativity	Identify alternative design features to address the associated safety hazards	
1B	In order to allow sufficient walking surface, use a minimum beam width of 6 inches.	(Accident: 951434): Employee #1, who was installing plywood decking on the second floor of a single-family home under construction, was headed to the ladder to go down and get more material. He was walking across a 3 in. wide by 9 ft long steel beam when he slipped and fell 11 ft onto a concrete floor. Employee #1 struck his head and was transported to the hospital, where he died at 2:30 p.m. on October 24, 1997.	Increased Cost	Investigate avenues of potential cost savings on other project features	
3A	Design pre-fabricated members to be of one size and shape, or make them easily distinguishable to avoid incorrect placement.	(Accident: 170824026): Employee #1, a foreman, and Employee #2, a carpenter's helper, were constructing six townhouses. They were using a mobile hydraulic crane to set prefabricated walls, floors, and roofs. The third floor was set on to two exterior walls, then braced and secured, and an interior wall package was set onto the floor in the center. The employees went to the deck on the bracing below the third floor. While they were on the second floor, they heard a crack and the third floor broke and fell. Employee #1 sustained a minor scratch on his nose, and Employee #2 sustained a bruise on his left arm. The foreman stated that he must have overlooked the manufacturer's recommendation for two separate support posts constructed out of three 2 by 4s instead of the one double 2 by 4 post they had used.			

Page 1 of 1

**Figure 42:** DFCS-TIPS Application: Print Page

- iii. When the “Print” page is closed, the application returns the user to the DFCS-TIPS Project Interface page.

b. Edit existing project

- This button is clicked after an existing project is selected from a table that provides the ‘Organization Name’ and ‘Project Title’.
- When the button is clicked, the application opens the “Project Interface Page” with the earlier entered information on the project, organization, and user. As earlier stated, this page provides the functionality to select DFCS measures,

view the selected DFCS measures, and print the selected DFCS measures. It also has a “Save and Close” button. This button saves the information and returns the user to the DFCS-TIPS interface. The DFCS-TIPS Project Interface Page is seen in *Figure 36*.

c. Add new DFCS measures to the Database.

- i. When this button is clicked on the interface, the application presents a “New DFCS Measure” page that allows for the entry of new DFCS measures and their accompanying details. This is essentially the entry of a new line item in the DFCS-TIPS database. Thus, there are textboxes for the entry of ‘DFCS Measure’, ‘Applicable Safety Incident’, ‘Potential Impediments to Implementation’, and ‘Potential Solutions to the Impediments’. *Figure 43* shows the DFCS-TIPS New DFCS Measure Page.

**DFCS-TIPS**  
DFCS-TIPS Design For Construction Safety - Tool for Implementation on Projects and Systems

DFCS Measure:	Use seated connections for beam-to-column connections particularly where there are multiple beams
Applicable Safety Incidents:	During construction of the ABC building project, a beam collapsed though it had been visibly secured. This occurred in July 2011. Fortunately, only one construction worker was injured though there were five in close vicinity.
Potential Impediments to Implementation:	Increased Cost
Potential Solutions to the Impediments:	Use aluminium seated connections and bigger but fewer bolts if possible.
AEC Design Profession:	Civil / Structural Engineer
Project Features:	Member Connections
Stage of Design Phase:	Design Development

Back Save DFCS Measure and Details in Database

**Figure 43:** DFCS-TIPS Application: New DFCS Measure Page

- ii. There are also drop-boxes and textboxes to allow for the entry of the applicable ‘AEC Design Profession’, ‘Project Feature’, and/or ‘Stage of Design Phase’. For the inputs that define the outputs, all the data must be entered as well.
  1. The ‘AEC Design Profession’ entry utilizes a drop-box that restricts the selection to ‘Architect’, ‘Civil/Structural Engineer’, ‘Mechanical Engineer’, ‘Electrical Engineer’, and ‘Plumbing Engineer’.

2. The 'Project Feature' entry is a text-box that allows for any entry as appropriate.
  3. The 'Stage of Design Phase' entry also utilizes a drop-box that restricts the selection to 'Preliminary Design', 'Design Development' and 'Construction Documents'.
- iii. At the bottom of the page, there is a "Back" button to return to the DFCS-TIPS interface. There is also a "Save New DFCS Measure and Details in Database" button. This button saves the details in the database and returns the user to the DFCS-TIPS interface. Where the 'Project Feature' entry has not been entered before, a new checkbox is created with the new entry on the 'Input' page that is reached through the "Select DFCS Measures for Implementation" button on the DFCS-TIPS Project Interface page. The entry for the 'Tier of Feasibility of the DFCS Measure' for the new DFCS measures appears as N/A (Not Applicable) in the database. *Figure 44* shows a "new" DFCS measure and accompanying details on the DFCS-TIPS View Selected Measures Page.

## DFCS-TIPS

DFCS-TIPS Design For Construction Safety - Tool for Implementation on Projects and Systems

Tier	DFCSMeasures	ApplicableSafetyIncidents	PotentialImpediments	PotentialSolutionstothe
1A	Use a single size, or a minimum number of sizes possible, of bolts, nails, and screws. If more than one size is required, specify sizes which vary greatly and are easily distinguishable.	[Accident: 977314]: A 50 foot long steel girder, weighing 3500 pounds, was hoisted into place by a hydraulic boom crane. One end was bolted through the web to a flange that had been welded to a vertical beam. Two of the three 3/4 inch bolts and nuts were installed. The girder was supported approximately 12 feet from the other end by a vertical column which was shimmed one inch off the concrete floor by two 7/8 inch high nuts and 1/8 inch thick washers opposite each other, and 90 degrees from the two half inch bolts which		
N/A	Use seated connections for beam-to-column connections particularly where there are multiple beams connecting to the column.	During construction of the ABC building project, a beam collapsed though it had been visibly secured. This occurred in July 2011. Fortunately, only one construction worker was injured though there were five in close vicinity.	Increased Cost	Use aluminium seated connections and bigger fewer bolts if possible.

Record: 14
1 of 3
No Filter
Search

Back
Clear Selected DFCS Measures
Select More DFCS Measures

**Figure 44:** DFCS-TIPS Application: New DFCS Measure on the View Selected Measures Page

- d. Edit or Delete entered DFCS measures in Database.
- When this button is clicked on the interface, the application presents an “Edit Entered DFCS Measures” page which allows the user to edit DFCS measures and accompanying details that were entered earlier by the user. This includes the inputs and outputs. On the page, the earlier entered information is presented in editable drop-boxes and textboxes. The entered DFCS measures are to be navigable by forward and backward buttons on the page. This page is similar to the “New DFCS Measure” page.
  - There are textboxes for the editing of ‘DFCS Measure’, ‘Applicable Safety Incident’, ‘Potential Impediments to Implementation’, and ‘Potential Solutions to the Impediments’. There are also drop-boxes and textboxes to allow for the editing of the applicable ‘AEC Design Profession’, ‘Project Feature’, and ‘Stage of Design Phase’. The ‘AEC Design Profession’ utilizes a drop-box and so does the ‘Stage of Design Phase’ while the ‘Project Feature’ utilizes a textbox.
  - At the bottom of the page, there is a “Back” button to return to the DFCS-TIPS interface. There is also a “Save DFCS Measures and Details in Database” button. This button saves the details in the database and returns the user to the DFCS-TIPS interface. *Figure 45* shows the DFCS-TIPS Edit Entered DFCS Measures Page.

<b>DFCS-TIPS</b>	
DFCS-TIPS Design For Construction Safety - Tool for Implementation on Projects and Systems	
<b>DFCS Measure:</b>	Use seated connections for beam-to-column connections particularly where there are multiple beams
<b>Applicable Safety Incidents:</b>	During construction of the ABC building project, a beam collapsed though it had been visibly secured. This occurred in July 2011. Fortunately, only one construction worker was injured though there were five in close vicinity.
<b>Potential Impediments to Implementation:</b>	Increased Cost
<b>Potential Solutions to the Impediments:</b>	Use aluminium seated connections and bigger but fewer bolts if possible.
<b>AEC Design Profession:</b>	Civil / Structural Engineer
<b>Project Features:</b>	Member Connections
<b>Stage of Design Phase:</b>	Design Development
<div>← →</div>	
<div>Back Delete Entered Measure Save DFCS Measure and Details in Database</div>	

**Figure 45:** DFCS-TIPS Application: Edit Entered DFCS Measures Page

e. Add Potential Solutions to Impediments.

- i. When this button is clicked on the interface, the application presents the “Solutions Input” page. This page is similar to the “Input” page except for the absence of the capability to select DFCS measures by search term or from index. The page allows for the selection of the ‘AEC design Profession’, ‘Project Feature’, and/or ‘Stage of Design Phase’. This selection is done through checkboxes. One or all three inputs can be selected to yield the DFCS measures for which potential solutions to the implementation impediments are to be entered. At the bottom of the page, there is a “Back” button to return to the DFCS-TIPS interface, and a “Provide Applicable DFCS Measures” button. *Figure 46* shows the DFCS-TIPS Solutions Input Page.

**DFCS-TIPS**  
DFCS-TIPS Design For Construction Safety - Tool for Implementation on Projects and Systems

**AEC Design Profession:**

Select	AEC Design Professional
<input type="checkbox"/>	Architect
<input type="checkbox"/>	Civil / Structural Engineer
<input type="checkbox"/>	Mechanical Engineer
<input type="checkbox"/>	Electrical Engineer
<input type="checkbox"/>	Plumbing Engineer

Record: 1 of 5 | No Filter | Search

**Stage of Design Phase:**

Select	Stage Of Design Phase
<input type="checkbox"/>	Preliminary Design
<input type="checkbox"/>	Design Development
<input type="checkbox"/>	Construction Documents

Record: 1 of 3 | No Filter | Search

**Project Features:**

Select	Project Feature
<input type="checkbox"/>	Building Materials
<input type="checkbox"/>	Component Placement
<input type="checkbox"/>	Egress
<input type="checkbox"/>	Equipment Controls
<input type="checkbox"/>	Equipment Location
<input type="checkbox"/>	Equipment Support
<input type="checkbox"/>	Finishing
<input type="checkbox"/>	Fixture Design
<input type="checkbox"/>	Floor Design
<input type="checkbox"/>	Floor Openings
<input type="checkbox"/>	Foundation / Earthwork Design
<input type="checkbox"/>	Fueled Equipment
<input type="checkbox"/>	Member Connections
<input type="checkbox"/>	Member Design
<input type="checkbox"/>	Multi-level Project
<input type="checkbox"/>	Permanent Ladders
<input type="checkbox"/>	Dining System Placement

Record: 1 of 30 | No Filter | Search

**Back** **Provide Applicable DFCS Measures**

**Figure 46:** DFCS-TIPS Application: Solutions Input Page

- ii. From the “Solutions Input” page, once the input(s) are selected and the “Provide DFCS Measures” button is clicked, the “Solutions Output” page opens. Based on the selected inputs (‘AEC design Profession’, ‘Project Feature’, and/or ‘Stage of Design Phase’), the page provides the applicable outputs (‘Tier of Feasibility of the DFCS

Measures', 'DFCS Measures', 'Applicable Safety Incidents', 'Potential Impediments to Implementation', and 'Potential Solutions to the Impediments'). The "Solutions Output" page is visually identical to the "Output" page. The outputs appear in a tabular form with checkboxes by their (left) side. These checkboxes allow for the selection of those DFCS measures (with their corresponding details) for which the potential solutions to their impediments are to be entered. At the bottom of the page, there is a "Back" button to return the user to the previous "Solutions Input" page. There is also a "Complete Selection" button which allows the user to proceed to the next "Solutions Entry" page. *Figure 47* shows the DFCS-TIPS Solutions Output Page.

Tier	DFCS Measures	Applicable Safety Incidents	Potential Impediments to Implementation	Potential Solutions to the Impediments
2B	Consider the use of welded wire mesh for slab reinforcing to allow placement of the steel in large sections rather than the placement of many small pieces of reinforcing bars.	[Accident: 171058340]: At approximately 2:40 p.m. on November 3, 1999, Employee #1, a 19-year-old iron worker and rod buster for JD Steel, and a coworker were at the construction site in Salt Lake City, UT. They had just loaded approximately 300 lb of rebar onto the tray portion of a bottle cart and secured it with #9 wire. The coworker went to an upper level to receive the load and begin work. Employee #1 was moving the cart by himself to position it for a crane lift when it tipped over, resulting in a compound fracture of his lower right leg. The cart was not properly loaded, nor was the load adequately secured.	Decreased project quality and diminished design creativity	Identify alternative design features to address the associated safety hazards
1A	For elevated floors, use permanent metal formed decking with concrete fill rather than a concrete slab which requires temporary formwork.	[Accident: 14367064]: After Employees #1 through #6 finished a third floor pour of concrete, the southwest bay formwork collapsed. Employees finishing the edge of the bay fell 50 ft to the ground. The three in the center landed on the second floor among concrete and other materials. The six employees sustained broken bones, concussions, and bruises. An engineering study determined that various components of the formwork structure were underdesigned and overloaded.		

Record: 1 of 4 | No Filter | Search

Back | Complete Selection

**Figure 47:** DFCS-TIPS Application: Solutions Output Page

- iii. On the "Solutions Entry" page, the selected DFCS measure is provided along with its 'impediments to implementation' and the 'potential solutions to impediments' in the DFCS-TIPS database. Where there are none in the database, these appear blank. In addition, there is a textbox that allows for the user to enter 'new' potential solutions to the impediments. The user does not have the ability to edit or delete the potential solutions that are provided by the DFCS-TIPS application. The user can navigate through his/her

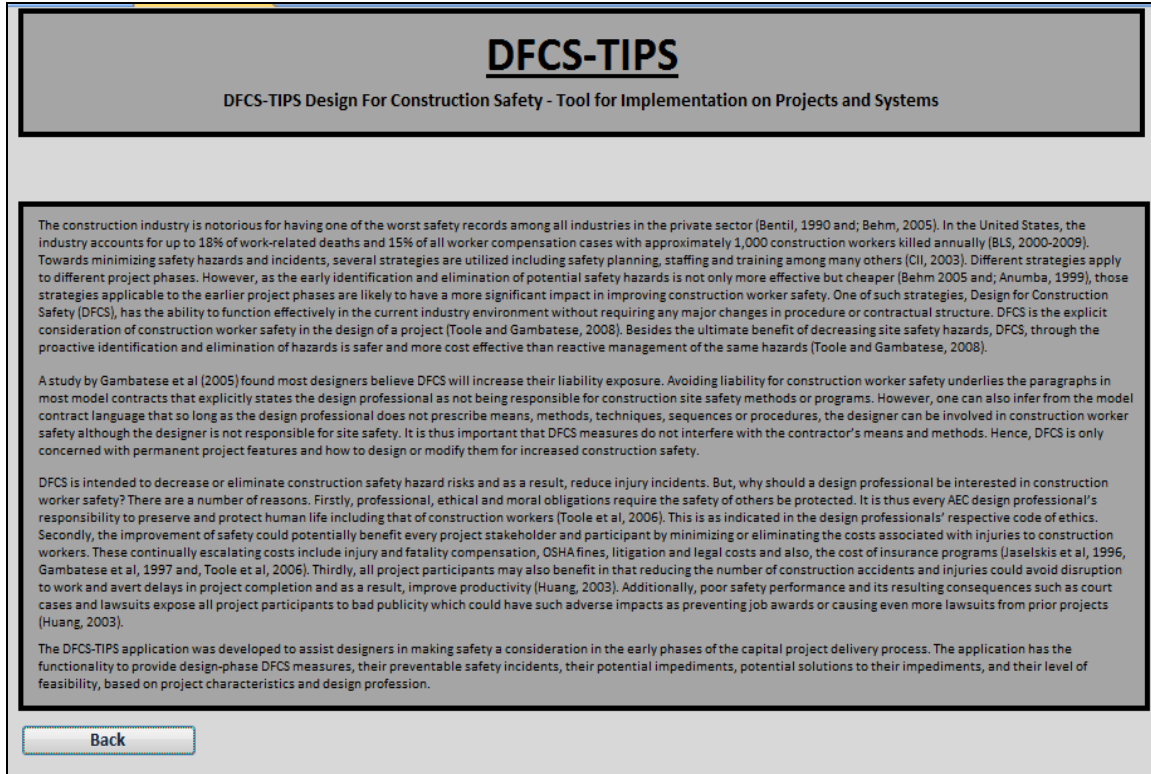
selected DFCS measures by the “Forward” and “Backward” buttons on the page. Also on the page, there is a “Save Potential Solutions to Impediments” button which accordingly saves the entries in the DFCS-TIPS database and returns the user to the DFCS-TIPS interface. There is also a “Back” button that returns the user to the previous “Solutions Input” page. *Figure 48* shows the DFCS-TIPS Solutions Entry Page.

**Figure 48:** DFCS-TIPS Application: Solutions Entry Page

- iv. To edit the entered and saved “Potential Solutions to Impediments”, the user follows the same procedure to locate and select the applicable DFCS measures. And, his/her entered solutions are provided in an editable textbox on the “Solutions Entry” page just as they were entered before. The user can then edit and save using the “Save Potential Solutions to Impediments” button.

f. Why Design for Construction Safety (DFCS)?

When the “Why Design for Construction Safety (DFCS)?” button is clicked, a page opens. This page contains the definition of DFCS and the motivation behind it along with other brief details. At the bottom of the page, there is a “Back” button to return to the DFCS-TIPS interface. *Figure 49* shows the DFCS-TIPS Why DFCS Page.



**Figure 49:** DFCS-TIPS Application: Why DFCS Page

g. Using the DFCS-TIPS Application.

When the “Using the DFCS-TIPS Application” button is clicked, a page opens. This page contains information on the application’s functionalities and features on two tabs. One tab provides information on how to use the DFCS-TIPS application while the other provides details on the tiers or categorization of DFCS measures based on the research results. At the top of the page, there is a “Back” button to return to the DFCS-TIPS interface. The DFCS-TIPS Using Application Page with the Using Tab is shown in *Figure 50* while with the Tiers Tab is shown in *Figure 51*.

h. Close DFCS-TIPS Application.

When the “Close DFCS-TIPS Application” button is clicked, the DFCS-TIPS application closes.

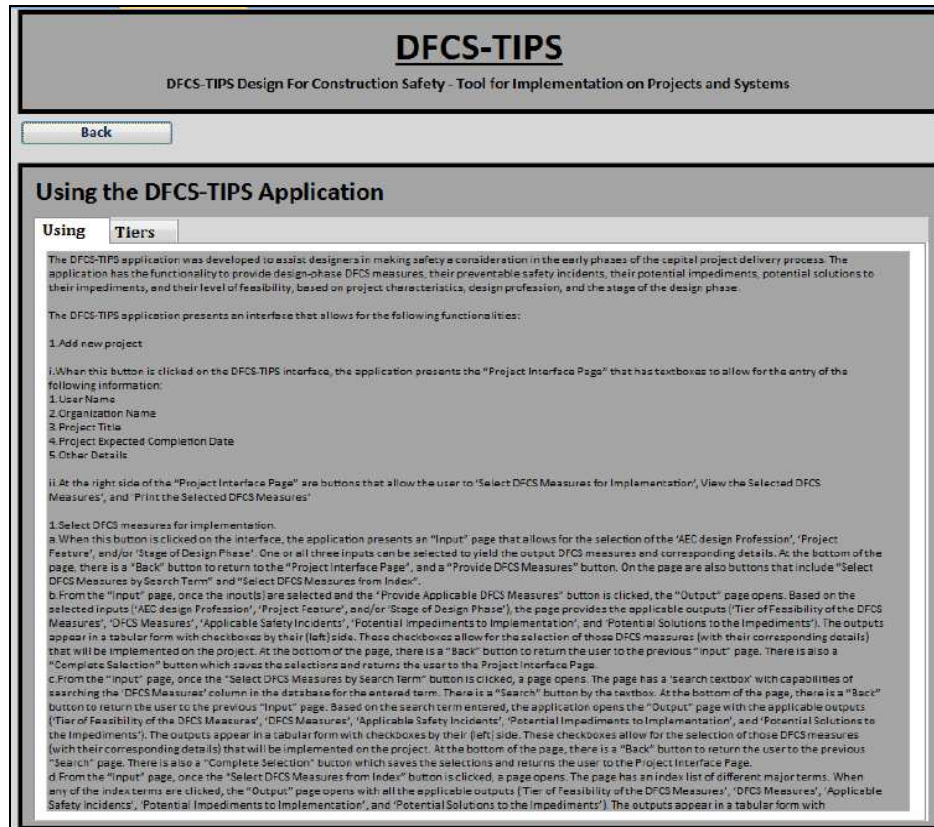


Figure 50: DFCS-TIPS Application: Using Application Page – Using Tab

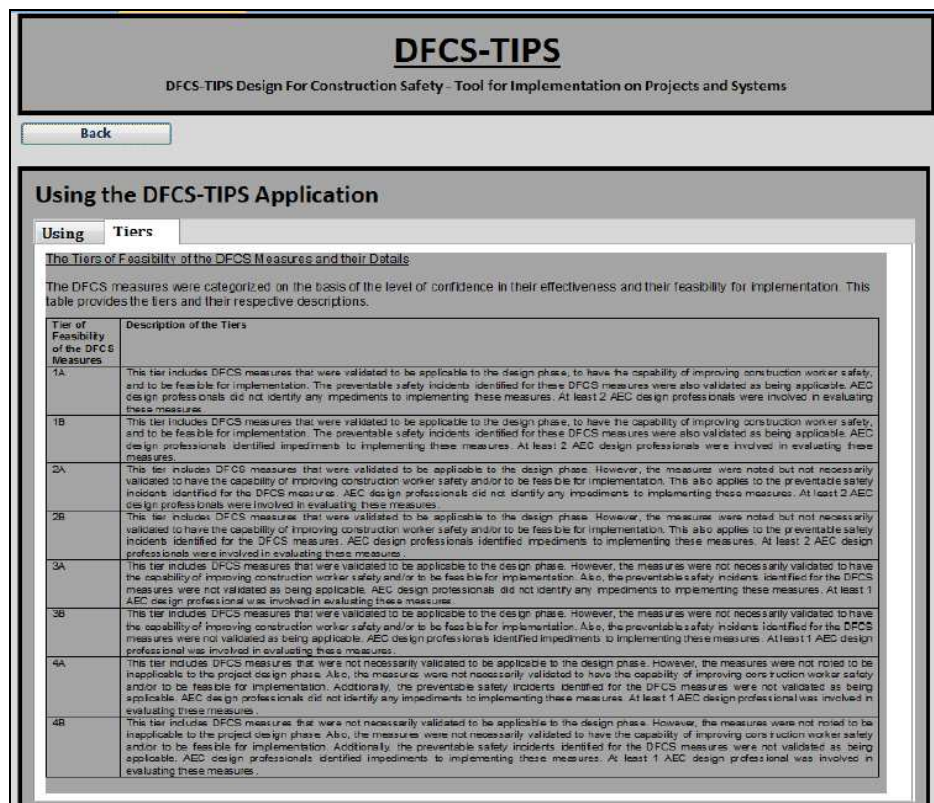


Figure 51: DFCS-TIPS Application: Using Application Page – Tiers Tab

## **Further Development of the DFCS-TIPS Application**

The DFCS-TIPS application was developed to assist designers in making safety considerations in the early phases of the capital project delivery process. The developed application has the functionality to provide design-phase DFCS measures, their preventable safety incidents, their potential impediments, potential solutions to their impediments, and their tier of feasibility, based on project characteristics, design profession, and the stage of the design phase. The application also allows for the addition of new DFCS measures, their preventable safety incidents, their potential impediments, and potential solutions to their impediments. This enables the adaptability of the software application to the user/organization and enables the incorporation of new knowledge particularly given that DFCS is still an emerging area. The user can also define the AEC design profession, project feature, and the stage of the design phase applicable to the newly entered DFCS measures. And, even for the DFCS measures included in the DFCS-TIPS application, the user can enter potential solutions to their impediments. On this basis, the DFCS-TIPS application was successfully developed to meet the indicated user requirements, software design specifications and system requirements.

The next research task involved testing the DFCS-TIPS application through interviews of AEC design professionals. By collecting their critique and commentary on its functionality and usability, and based on the information collected through the interviews, the DFCS-TIPS application was to be improved. The objective is to validate the relational database application as a viable tool that can assist designers in making safety considerations in the project design phase. As such, the DFCS-TIPS interfaces and forms would be further refined to have a more effective and presentable format.

### **4.1.6 Testing Interviews and Improvement of Relational Database Application**

#### **4.1.6.1 Objective**

The objective of this research task was to validate the relational database application as a viable tool that can assist designers in making safety considerations in the project design phase. This was to be achieved through the testing of the application on AEC design professionals and by collecting their critique and commentary on its functionality and usability. Based on the information collected through the interviews, the relational database application was then to be improved.

#### 4.1.6.2 Considerations and Development

A similar interview process to that defined in *Section 4.1.4.2* was to be utilized but with two key differences. Firstly, there was to be a period of time for software testing or use. Secondly, the interview questions were to primarily pertain to the software and not to the DFCS measures provided.

A consideration was made in designing this research task. This was the need for a benchmark that the relational database application, DFCS-TIPS, could be compared against. This was to serve towards the objective of this research task, validating the viability of the DFCS-TIPS application as a tool that can assist designers in making safety considerations in the project design phase. For this reason, the use of the DFCS-TIPS application in DFCS implementation was to be compared against manual DFCS implementation in the interviews. In order to facilitate this, a hypothetical project was to be presented at the interviews.

Additionally, the DFCS-TIPS application was developed to be without the inadequacies of existing tools to better aid or enhance the DFCS implementation process. For this reason, there was need for a DFCS tool to compare the DFCS-TIPS application against. The logical selection was the Design-for-Construction-Safety Toolbox that was developed by the Construction Industry Institute (CII). The comparative analysis in *Table 5* found the DFCS Toolbox to be the only tool that provided DFCS measures. This was though the provided measures were not exclusively situated in the project design phase and could thus expose designers to liability. The tool also does not provide implementation benefits, costs, impediments or other details on the DFCS measures. However, the design suggestions in the DFCS Toolbox were quite comprehensive and this was an important basis for utilizing them in this research. As the DFCS tool with the least inadequacies, comparing against it would prove most adequate in determining whether the DFCS-TIPS application does not possess the inadequacies of existing tools, and in identifying necessary improvements.

As the features and operation of the DFCS-TIPS application were fully discussed in the previous section, it is essential the features of the benchmark, DFCS Toolbox, are presented and discussed as well. The 2<sup>nd</sup> edition of the DFCS Toolbox was available as web-based software and situated at [<http://jamesmarini.com/dcws/>]. The initial screen allows for starting the application. This is seen in *Figure 52*.

Once the DFCS Toolbox is launched, the main interface opens. It provides the user with the options of taking a tour of the application, learning about the application, and starting the application. The main interface of the DFCS Toolbox is seen in *Figure 53*.

When the user selects the “Take Tour” button on the main interface, a screen opens with information on how to use the application. This screen is provided in *Figure 54*.



Figure 52: DFCS Toolbox – Initial Screen



Figure 53: DFCS Toolbox – Main Interface

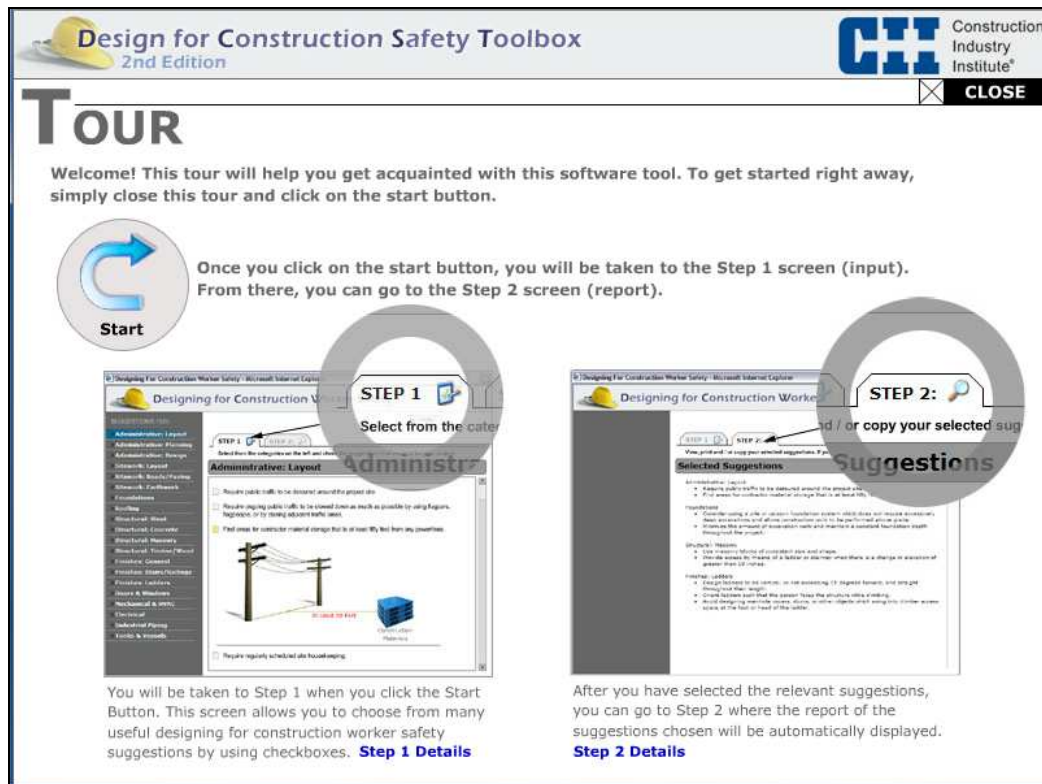


Figure 54: DFCS Toolbox – Tour Screen

And, when the user clicks on the “About” button on the main interface, a screen opens with information on the purpose and objectives of the DFCS Toolbox and of DFCS as a concept. For example, it provides the description of the DFCS Toolbox as a versatile easy-to-use tool to help plan and design projects for enhanced construction worker safety, indicating that it provides a means by which designers and others can address construction worker safety in their designs. It also discusses why and how a design professional should be involved in construction worker safety. This screen is seen in *Figure 55*.

When the user clicks on the “Start” button on the main interface, a screen opens with 20 vertical tabs that define the categories where the design suggestions were placed and with 2 horizontal tabs for Step 1 and Step 2. The vertical tabs include such categories as ‘Administrative: Layout’, ‘Roofing’, ‘Structural: Concrete’ and ‘Electrical’ among others. They define specific activities, design features, and project systems. It must be noted that several design suggestions were included in multiple categories. Under each category or vertical tab with the ‘Step 1’ horizontal tab selected is a list of design suggestions presented in a checklist format. The user is to go through the design suggestions in each category in Step 1 and select the appropriate design suggestions to his/her project. A sample of design suggestions and their applicable selected tab in ‘Step 1’ is seen in *Figure 56*.

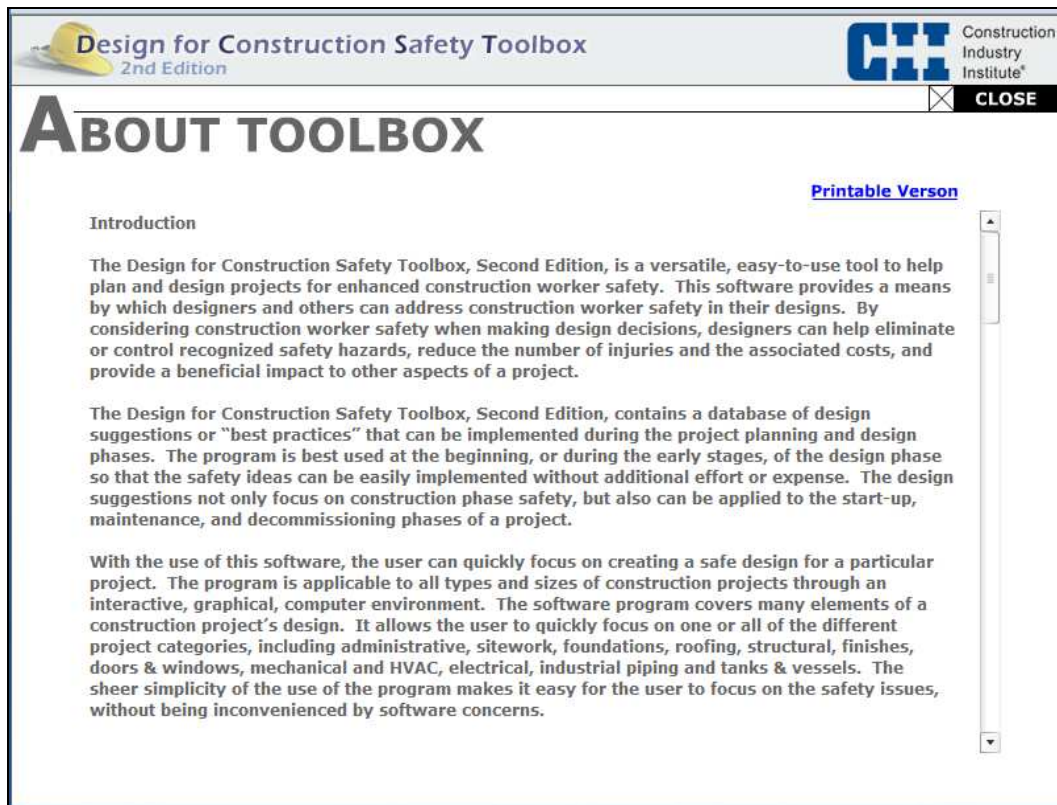


Figure 55: DFCS Toolbox – About Screen

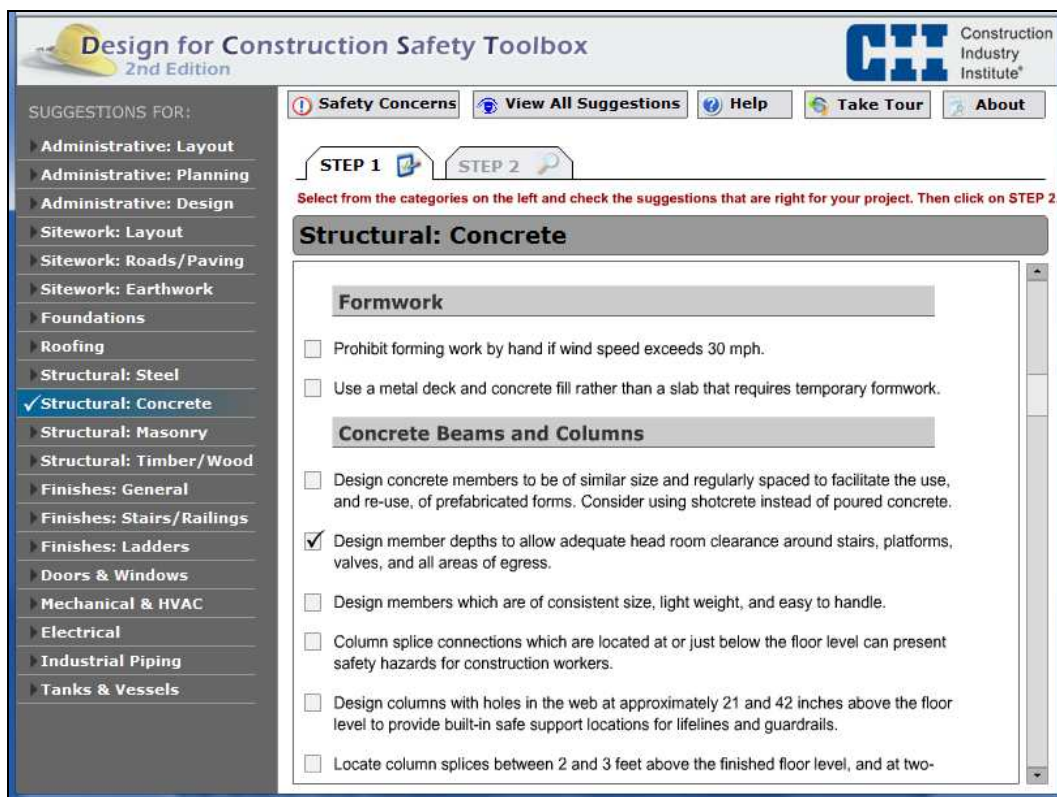


Figure 56: DFCS Toolbox – Design Suggestions Selection Screen – Step 1

There are also five buttons on the 'Step 1' tab or screen. These include the "Safety Concerns", "View All Suggestions", "Help", "Take Tour", and "About" buttons. The "Safety Concerns" button, when clicked, presents a PDF document with discussions on the important safety concerns of each suggestion category. A screenshot of the document is provided in *Figure 57*. Meanwhile, the "View All Suggestions" button, when clicked, presents a PDF document with all the over 400 design suggestions as placed in the different categories. A screenshot of this document is provided in *Figure 58*. And when the "Help" button is clicked, it presents a screen with detailed information on the function of each element on the 'Step 1' screen. This 'Help' screen is provided in *Figure 59*. When the "Take Tour" button is clicked, it takes the user to the 'Tour Screen' as seen in *Figure 54*. And, when the "About" button is clicked, it takes the user to the 'About Screen' as seen in *Figure 55*.

Once the user completes selection of the design suggestions in 'Step 1', he/she is then to click on the 'Step 2' tab. This provides all the selected design suggestions and their respective categories along with instructions to copy/paste, to print, or to edit the suggestions. Some selected design suggestions in 'Step 2' are seen in *Figure 60*.



**Figure 57:** DFCS Toolbox – Safety Concerns Document

### ADMINISTRATIVE: LAYOUT

## Traffic Control

- o Require public traffic to be detoured around the project site.
- o Require ongoing public traffic to be slowed down as much as possible by using flagcars, flaggers, or by closing adjacent traffic lanes.

## Underground Safety

- Use red concrete to encase newly-installed underground utility lines to mark their location.

## Materials and Material Storage

- o Schedule the release of engineering drawings such that sufficient time is allowed for materials to be purchased, delivered, and installed.
- o Find areas for contractor material storage that is at least fifty feet from any powerlines.
- o Require unused or unsecured materials to be stored in designated areas only, and not in areas of construction activity.
- o To preserve the structural integrity of existing reinforced concrete members, require the constructor to locate and mark existing reinforcing steel prior to cutting into the concrete.
- o Provide the constructor with a list and the location of toxic substances and other hazardous materials which may be located on the site, as these pose an obvious hazard for workers.
- o Ensure that specified materials of construction are appropriate for the flammability hazards which may be encountered on the work site.
- o Avoid specifying materials which contain asbestos or other known hazardous substances.
- o Ensure that all materials meet the expected environmental and work site conditions.

**Figure 58:** DFCS Toolbox – View All Suggestions Document



**Figure 59: DFCS Toolbox – Help Screen – Step 1**

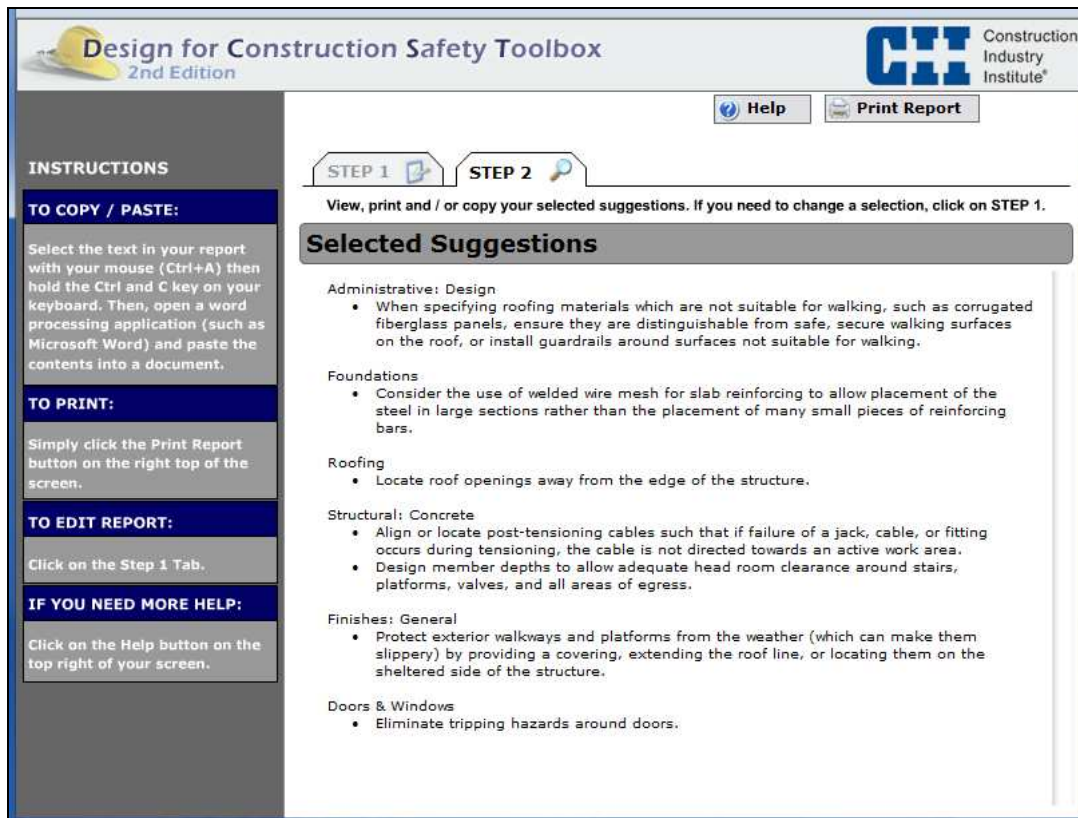


Figure 60: DFCS Toolbox – Selected Design Suggestions Screen – Step 2

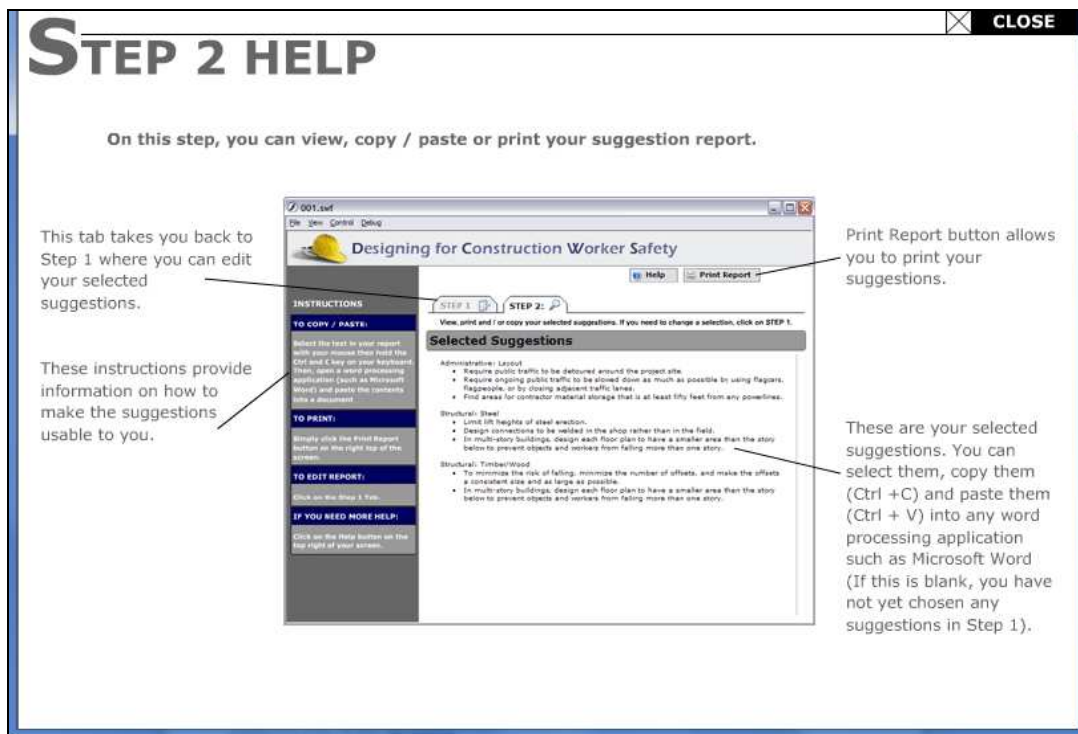


Figure 61: DFCS Toolbox – Help Screen – Step 2

This 'Step 2' tab or screen also has a "Help" button and a "Print Report" button. The "Help" button, when clicked, presents a screen with detailed information on the function of each element on the 'Step 2' screen. This 'Help' screen is provided in *Figure 61*. Meanwhile, when the user clicks on the "Print Report" button on the Step 2 screen, the selected suggestions are printed with the DFCS Toolbox header. This printed document with some selected suggestions is seen in *Figure 62*. This is the product of using the DFCS Toolbox which can be distributed or used in implementing DFCS on the applicable project. It must also be noted that there is no capability to save the selected design suggestions in the DFCS Toolbox neither is there the capability to enter and/or save user and project information or to include the information on the printed document. Hence, once closed, the information including the selections is cleared.



**Figure 62:** DFCS Toolbox – Printed Report with Design Suggestions

It was earlier established that DFCS implementation using the DFCS-TIPS application was to be compared in terms of effectiveness and usability against manual DFCS implementation and implementation using the DFCS Toolbox. However, it would have been infeasible to have an interviewee manually implement DFCS, implement DFCS using the DFCS Toolbox, and also implement DFCS using the DFCS-TIPS application for the hypothetical project in a single interview. This would have required an extended period of time and the interviewee would likely have been fatigued before the completion of the interview. Furthermore, the responses for the different DFCS tools would likely have depended on the sequence of use, which tool was utilized first, in the interview. Also, there may have been interviewer bias as the researcher is most likely favored towards the DFCS-TIPS application as it was developed in his research. This could have reflected in the interviews through leading questions. For these collective reasons, the two DFCS tools were not to be utilized in the same interview. Each interview was to include a manual DFCS implementation segment and a DFCS tool implementation segment in this particular order. This was the determined order because one could better assess if and how the tools assisted DFCS implementation after it was attempted manually. Additionally, the interviewee could have utilized knowledge gained from use of the DFCS tool in the manual implementation if sequenced after. The interviewee may also have exhibited unwillingness to proceed with manual implementation after having used the DFCS tool, as this may have been seen as tedious or time-consuming.

After implementing DFCS on the hypothetical project, questions on the process and how the DFCS tool assisted in the process were to follow. This is logical as it would have been ineffective or less productive to ask questions on the implementation process before it begins particularly since DFCS is still an emerging area and the design professionals or interviewees likely had not used a DFCS tool before. As the two tools were to be used by different interviewees, it was imperative that the interviewees were comparable. For this reason, there were to be at least two design professionals from each design discipline with one using the DFCS-TIPS application and the other using the DFCS Toolbox. Additionally, there were to be pre-testing questions to determine if the perceptions and knowledge of the two groups of interviewees with regards to DFCS were also comparable. If not comparable, the responses and their details might not have allowed for yielding direct contrasts between the DFCS-TIPS application and the DFCS Toolbox with regards to effectiveness and usability in implementing DFCS.

Gambatese et al (2005) administered face-to-face surveys on AEC design professionals to determine the extent of their knowledge on construction safety, as well as their capabilities in implementing DFCS, and their willingness to implement the DFCS concept. There were questions that were primarily used for these purposes. And considering the applicability of the study to this segment of the interview, several of such questions were considered for inclusion as pre-testing questions. They included the following:

1. Do you ever make design decisions that improve construction worker health and safety? (Yes or No)
2. Have you ever made modifications to a design in the design phase to eliminate a potential safety risk that would impact construction worker health and safety? (Yes or No)
3. Have you ever had discussions with contractors and/or owners that include the methods/practices employed by the contractor? (Yes or No)
4. Have you had any discussions with contractors and/or owners that include the features to be included in the design, to ensure construction worker health and safety during project construction? (Yes or No)
5. Have you ever been asked to address construction worker health and safety in the design phase? (Yes or No)
6. Have you ever worked with or hired a construction health and safety consultant in the design phase? (Yes or No)
7. What is your personal willingness to address construction worker health and safety in the design phase?
8. What priority do you place on the following criteria when designing a project? Please rank with 1 being the highest priority, 2 the second highest priority, and so forth.
  - a. Quality of the work
  - b. Project cost
  - c. Project schedule
  - d. Construction worker safety and health
  - e. Facility occupant safety and health
  - f. Aesthetics

In deciding which of the questions to include, a few considerations were made. Firstly, where there were two questions that were similar, the one with more clarity and/or relevance was retained while the other was eliminated. As a result, Question 1 and Question 3 were eliminated. Meanwhile, Question 7 and Question 8 were reworded for clarity and their response format modified to collect more precise and/or quantifiable information. In addition to the selected questions, there was need for questions that addressed software and DFCS tool use. One was to find out the familiarity of the interviewee with using software in the project design phase. The other was to find out if the interviewee had used a DFCS tool before. The responses to both questions would likely have a significant influence on the interviewees' responses to the 'post-testing' questions. *Table 64* provides the selected and developed interview questions along with their respective functions.

	<b>Pre-Testing Interview Questions</b>	<b>Question Functions</b>
1.	Have you ever made modifications to a project in the design phase to eliminate a potential safety risk that would impact construction worker health and safety? (Yes or No)	This question was to gauge if the AEC design professional had prior experience implementing DFCS. This could have influenced how the designer performed in the DFCS implementation segments of the interview.

	<b>Pre-Testing Interview Questions</b>	<b>Question Functions</b>
2.	Have you ever had any discussions with owners and/or contractors that include the features to be included in the design, to ensure construction worker health and safety during project construction? (Yes or No)	This question was to gauge if the AEC design professional had been involved in making safety considerations with knowledge of either or both the project owner and contractor. Ordinarily, designers would not have been willing to be involved with knowledge of both parties in order to avoid exposure to liability in event of related safety incidents. This could have also indicated how favorably or unfavorably the designer viewed DFCS implementation.
3.	Have you ever been asked to address construction worker health and safety in the design phase? (Yes or No)	This question was also to gauge if the AEC design professional had prior experience implementing DFCS but by the requirement of other project stakeholders or participants. This could also have influenced how the designer performed in the DFCS implementation segments of the interview.
4.	Have you ever worked with or hired a construction health and safety consultant in the design phase? (Yes or No)	This question was to gauge if the AEC design professional has had prior access to a large wealth of construction safety information through a consultant. This could also have influenced how the designer performed in the DFCS implementation segments of the interview.
5.	How willing are you to design for construction worker safety? [0 = Extremely Unwilling; 5 = Neutral; 10 = Extremely Willing]	This question was to quantitatively gauge the AEC design professional's willingness to implement the DFCS concept. This could also have influenced how the designer performed in the DFCS implementation segments of the interview.
6.	Have you ever used any tool to enhance or aid construction safety considerations on a project? (Yes or No)	This question was to find out whether the AEC design professional has had prior experience utilizing DFCS tools. This would likely determine how the designer viewed the tool to be used in the interview and even the manual implementation process.
7.	Do you use any AEC design software? (Yes or No)  Which design software do you use?	This question was to determine if the AEC design professional was familiar with utilizing software in the project design phase. Where the designer does not utilize software, he or she might consider both manual and tool-based implementation of DFCS to be tedious and he/she might have an unfavorable view towards both. Furthermore, non-use of software may not permit the designer to provide as useful responses. The second segment of the question was to gauge the type of software used by the designers.
8A.	Please rate the listed project issues/criteria relative to one another: Aesthetics; Construction Worker Safety; Final Occupant Safety; Project Cost; Project Schedule; Quality of Work	These questions were to determine the placement of construction worker safety as a priority in the project design phase by AEC design professionals. These also provide the perceptions of the design professionals towards addressing construction safety in the design phase and hence could have influenced how the designer performed in the DFCS implementation segments of the interview.
8B.	Please rank the listed project issues/criteria by importance: Aesthetics; Construction Worker Safety; Final Occupant Safety; Project Cost; Project Schedule; Quality of Work	

**Table 64:** Software Testing Interview Pre-Testing Questions and Question Functions

Seen in *Table 64*, Questions 8A and 8B were to serve the same purpose. Question 8B was utilized by Gambatese et al (2005) in their face-to-face surveys. Question 8A was developed to yield the priorities using pair-wise comparisons. This was expected to provide better refined responses than when using ranks. This is because direct comparisons are necessary to establish measurements for intangible properties that have no scales of measurement (Saaty, 2008). Question 8A utilizes the framework of the Analytic Hierarchy Process (AHP). AHP is a theory of measurement through pair-wise comparisons and relies on the judgments of experts to derive priority scales (Saaty, 2008). However, having to make 15 comparisons on a rating scale could prove tedious for the interviewees. Hence, the pilot interview was to be used in determining whether Question 8A was to be utilized in the software testing interviews or Question 8B. Even in the pilot interview, if the question proved unsuccessful, it was to be verbally converted to Question 8A.

The structure of the software testing interviews was to be the pre-testing questions first followed by the manual DFCS implementation, the tool-based DFCS implementation, and then the post-testing questions. The post-testing questions were to be generally identical regardless of the DFCS tool used in the interview. To determine the effectiveness and usability of the DFCS tools, a number of interview questions were developed. *Table 65* provides the developed post-testing interview questions along with their respective functions.

	<b>Post-Testing Interview Questions</b>	<b>Question Functions</b>
1.	How difficult/easy was the identification of design modifications for construction worker safety using the manual method as utilized in this session? [0 = Extremely Difficult; 5 = Neutral; 10 = Extremely Easy]  Why?	This question was to serve in assessing the viability of the software as tools that can aid in implementing DFCS on projects. The second segment of the question was to yield the basis for the responses.
2.	Did the software inhibit/improve the DFCS implementation process compared to the manual method as practiced in this experiment? [0 = Extremely Inhibited; 5 = Neutral; 10 = Extremely Improved]  Why?	This question was to serve in assessing the effectiveness of the software in aiding the implementation of DFCS on projects. The second segment of the question was to yield the basis for the responses.
3.	How difficult/easy was the identification of design modifications for construction worker safety using the software as utilized in this session? [0 = Extremely Difficult; 5 = Neutral; 10 = Extremely Easy]  Why?	This question was to serve in assessing the viability of the software as tools that can aid in implementing DFCS on projects. The second segment of the question was to yield the basis for the responses.

	Post-Testing Interview Questions	Question Functions
4.	What do you like about the software?	This question was to identify the features of the software that improved their usability. Where the features liked about the DFCS Toolbox were not present in the DFCS-TIPS application and could be implemented, they were to be considered for implementation. And where features liked about DFCS-TIPS were not present in the DFCS Toolbox, they serve towards validating the DFCS-TIPS application as a tool without the inadequacies of existing DFCS tools.
5.	To what extent did the details provided with the DFCS suggestions or modifications help in your selection of which to implement on the project? [0 = Not Helpful; 10 = Extremely Helpful]  How?	This question was to identify the usefulness of the details provided or not provided on the DFCS measures by the software. It would also serve towards validating the details produced through this research as useful in determining which DFCS measures to select or utilize. The second segment was to be used in determining the way in which the details assisted the user. This could have been in prioritization or in some other fashion.
6.	Would any additional details on the 'design suggestions' provided by the software be helpful in the selection of DFCS modifications for the project?  What details?	This question was to serve towards identifying the additional details, if any, that could be useful in determining which DFCS measures to utilize or select for implementation. It would also serve towards validating the details produced through this research and utilized in DFCS-TIPS as useful in determining which DFCS measures to select or utilize. The second segment of the question was to identify the particular details.
7.	Compared to other AEC design software you have used, how do you find using the software? [0 = Extremely Difficult; 5 = Neutral; 10 = Extremely Easy]  Why?	This question was also to serve in assessing the usability of the software and in determining potential improvements to the DFCS-TIPS application. It was also to serve towards identifying those improvements to the DFCS Toolbox that were already effected in the DFCS-TIPS application, thus serving in validating the tool as not possessing the inadequacies of existing tools.
8.	Should the software be integrated into other AEC design software such as Building Information Modeling (BIM) tools to enhance its effectiveness and use? (Yes or No)	Given the trend of integrating design software with BIM, it was found necessary to include this question so as to identify if it could potentially add value as earlier research by Ku and Mills (2010) suggested.
9.	What recommendations do you have for improving the software?	This question was to directly tackle the issue of identifying potential improvements to the DFCS-TIPS application. Where recommendations for improving the DFCS Toolbox were already reflected in DFCS-TIPS, they would serve towards validating DFCS-TIPS as not having the inadequacies of existing tools.

	Post-Testing Interview Questions	Question Functions
[10.]	To what extent did the following details help in your selection of 'DFCS suggestions or modifications' for the project (using the DFCS-TIPS software)?	This question was only applicable to the interviews in which the DFCS-TIPS application was utilized. It was to serve towards validating the individual details produced through this research, and utilized in DFCS-TIPS, as useful in determining which DFCS measures to select or utilize. As these details were not in the DFCS Toolbox, it would have proved ineffective and inapplicable to include the question in the respective interviews.
a.	Safety incidents considered preventable through implementation of the DFCS suggestions or modifications [0 = Not Helpful; 10 = Extremely Helpful]	
b.	Potential impediments to implementing the DFCS suggestions or modifications [0 = Not Helpful; 10 = Extremely Helpful]	
c.	Potential solutions to the impediments of implementing the DFCS suggestions or modifications [0 = Not Helpful; 10 = Extremely Helpful]	
d.	Tier of Feasibility (Amount of research on the DFCS suggestions or modifications and the level of confidence in the effectiveness of the suggestions) [0 = Not Helpful; 10 = Extremely Helpful]	

**Table 65:** Software Testing Interview Post-Testing Questions and Question Functions

As earlier stated, the responses to the interview questions were to be compared for the different interview groups, DFCS Toolbox and DFCS-TIPS. Only Question 10 in *Table 65* was applicable to the DFCS-TIPS group of interviews alone.

With regards to the hypothetical DFCS implementation project, a building plan was to be selected to offer low stringency and a broad setting for DFCS implementation. It was also to preferably have visible components that would allow for less tedious identification of potential DFCS modifications. On this basis, I identified an existing building belonging to Carnegie Mellon University to which I had access to the building plans for educational purposes. The building had three stories, a large atrium, large balcony areas, different types and locations of stairs, a large number of columns, and numerous rooms. To ensure comparability between the different interviews, I intended for the building to be unfamiliar to all the interviewees prior to the interview. As this building was not situated on campus and was earlier unknown to me as well, I believed it met the requirement. The building plan is provided in *Appendix H4*.

The parameters of DFCS implementation were also to be set for the project. This was to encourage the interviewee to participate, and not to balk at the whole process. For this reason, the parameters were to minimize impediments. Hence, the hypothetical scenario identifies the interviewee as an AEC design professional involved in the project. It also was to identify the interviewee's firm as the design-build company that was awarded the contract for the design and construction of the project. And that both the AEC design professionals and construction workers were employees of the company. Thus, the company was both responsible and liable for the safety of the construction workers. The parameters were then to specify that the project owner asked that DFCS be

implemented on the project, indicating willingness to accommodate the cost and schedule implications. The interviewee was then to be asked to supervise DFCS implementation on the project from the standpoint of his/her design discipline, to make safety constructability considerations in the design. And, this was to include designing features and making design modifications that could enhance the safety of workers during the construction of the project. Further aspects of the interview design and procedure are defined in the next section.

#### **4.1.6.3      Design and Procedure**

This section presents and discusses the features of the interviews that were conducted with selected AEC design professionals. These were partially based on the steps described by King and Horrocks (2010) and McNamara (2007).

1. The type of interview was selected.  
The type of interview was selected based on structure, format, mode of administration, number of participants and specialization.
  - Highly Structured / Standardized Interviews  
This type of interview was necessary to obtain the specific information sought through the interviews. An informal approach was utilized for each of the questions as they were flexible/exploratory (Merriam, 2009).
  - Qualitative and Quantitative Interviews and Questions  
As the interview was intended for validation of a specific research product, the type of qualitative interview used was the standardized open-ended interview. The exact wording and sequence of questions was determined in advance, and all groups of interviewees were to be asked the same basic questions in the same order. Majority of the qualitative questions also had quantitative components.
  - Face-to-face Interviewing  
Face-to-face interviewing was to be utilized. This is particularly since the applications could only be presented via a computer with the capability of opening and utilizing them. This could not be guaranteed for the interviewees' computers. Furthermore, the interviewees may not have the interest or ability to install the software. As such, I provided a computer with access to the software. Face-to-face interviewing was thus considered most appropriate. The interview sample was proximally situated to ensure feasibility.
  - One-to-one Interviews  
One-to-one interviews were to be used to obtain in-depth information from the individual participants on the DFCS software.

- Interviewing of Elites Specialization  
As in the case of the earlier research interviews, interviewees were selected on the basis of their expertise in areas relevant to the research. Thus, the interviewees were to be AEC design professionals for whom DFCS software is intended to aid in DFCS implementation.
2. The sample was defined and the participants and key informants were recruited.
- Sample Selection  
Here too, purposive sampling was to be utilized for appropriateness. The sample included AEC professionals for each design discipline. This was because the DFCS measures and the DFCS software are intended to serve them. Feedback from professionals in each design discipline was to serve in providing a well-rounded set of improvements for the software as well as data. The sample was thus to include at least an architect, a civil/structural engineer and an MEP engineer. Preferably, AEC professionals earlier elicited for data were to be included in the sample. Those earlier surveyed or interviewed were more likely to be better grounded in this DFCS study and could thus focus more on the operation of the application than topic issues. Those earlier participants that showed enthusiasm or indicated interest in further participation were selected as the interview sample. The AEC design professionals were from both industry and academia.
  - Sample Sizing  
In the interest of effectiveness and feasibility, a minimum of 6 interviews were planned. 6 potential interviewees were to be initially contacted and where some did not respond, the sample size was to be appropriately expanded. The 6 interviewees were to include 2 architects, 2 civil/structural engineers and 2 MEP engineers so as to enable comparison of the DFCS software and their features.
  - Gaining Access to the Selected Sample  
In earlier research tasks, access was gained to the selected sample through use of the internet, search engines and professional networking sites. The AEC design professionals for these interviews were to be selected from earlier research participants who are employed in design firms and universities situated in the Pittsburgh, PA metropolitan area. As such, they were all expected to have met my sample criteria though this was to be further confirmed.

- Sample Recruitment

The interview sample was contacted via email. In the email, I introduced myself and stated my status. I also provided the name of my advisor. I also stated the basis for the sample selection as being an AEC professional with experience in design and possibly, construction. As most participants had already participated in earlier research tasks, I thanked them again while expressing the value of their earlier input. I then requested input in my research with regards to software developed for DFCS implementation. I requested a face-to-face interview as the method for obtaining this input. I also indicated that the expected timeframe for the interview was 30-45 minutes. This seemed an appropriate range based on the earlier interviews. I then requested to know the potential interviewee's preferred location for the interview while noting my capability in being available at that location. Lastly, I requested a response or notification if the email recipient was willing to participate. I also included greetings and thanks while expressing the high value of the professionals' input to my research. I also tailored all my emails to the particular participants I contacted. A sample of the sent email is provided in *Appendix G3*.

- Email Responses

Where the email recipients responded and agreed to participate, I expressed my appreciation and clarified the timing and location of the interview. With this correspondence complete, I further sent a reminder email one day prior to the interview date.

The sample size was to be appropriately expanded where no potential interviewee from a design discipline responded to an interview request. Both purposive and snowball sampling were to be used towards this.

3. The interview guide was developed.

- Interview Guide based on Literature and Preliminary Work on the Research Area and Topic

The interviews were intended to validate the functionality and usability of the DFCS-TIPS application as a viable tool to aid in DFCS implementation. This software was developed based on literature and preliminary work on DFCS. The interview guide thus included questions on the DFCS software.

- Comprehensive Interview Guide

I was to lead the interview direction to some extent while providing opportunity for participants' perspectives. This was since certain questions needed to be answered while allowing for broad or detailed input on the DFCS software.

- Types of Questions on the Interview Guide  
The interview guide included all types of questions namely background, experience, opinion, feeling, knowledge and sensory questions.
- Limited Flexibility of Interview Guide to Change  
During the course of the study, flexibility for changing the interview guide was limited. This was since the same questions were intended to be asked of each AEC design professional with regards to the DFCS software.
- Full-Question Interview Guide Format  
As I was to take a directive role and interview flexibility was to be controlled, the full-question interview guide format was most appropriate.
- Probes or Prompts in the Interview Guide  
Probes were anticipated to provide more depth to the interviewees' or participants' responses. As such, probes were included on the interview guide. They were however to be controlled to ensure they adhered to time constraints. Also, prompts were used as necessary when the interviewee expressed uncertainty of an interview question. Over the course of an interview, both probes and prompts were to be formulated to obtain comprehensible and useful information from the interviewee.
- Interview Guide Versions  
There were four interview guide versions used in this research task. Two interview guides were for the DFCS-TIPS interviews while two were for the DFCS Toolbox interviews. The questions were identical for each type. There were two sub-versions for each interview type, one for architects and one for the engineers, civil/structural and MEP engineers. The difference was the discussion section on the liability for worker safety which either included model contract language relevant to architects or to engineers.
- Format and Structure of the Interview Guide
  - The interview guide has a cover page that provides the following information.
    - The research topic
    - The research purpose
    - The intended use of the collected information
    - The basis for selecting the respondents
    - The anonymity of responses
    - The expected length of the interview
    - Researcher's name and contact details
    - Research advisor's name and contact details

- The interview guide has 8 sections
  - Discussion Section: Liability for Worker Safety  
In this section, the issue of liability for worker safety and how DFCS can improve safety without violating model contract language is briefly discussed.
  - Section 1: General Information  
This section includes questions intended for confirmation of the participant's background and also to serve as an icebreaker. The following information was to be collected about the interviewee.
    - Profession
    - Job Title / Position
    - Years of Experience
  - Section 2: Pre-Testing Questions
    - i. Have you ever made modifications to a project in the design phase to eliminate a potential safety risk that would impact construction worker health and safety? (Yes or No)
    - ii. Have you ever had any discussions with owners and/or contractors that include the features to be included in the design, to ensure construction worker health and safety during project construction? (Yes or No)
    - iii. Have you ever been asked to address construction worker health and safety in the design phase? (Yes or No)
    - iv. Have you ever worked with or hired a construction health and safety consultant in the design phase? (Yes or No)
    - v. How willing are you to design for construction worker safety? [0 = Extremely Unwilling; 5 = Neutral; 10 = Extremely Willing]
    - vi. Have you ever used any tool to enhance or aid construction safety considerations on a project? (Yes or No)
    - vii. Do you use any AEC design software? (Yes or No)
      - Which design software do you use?
    - viii. Please rate/rank the listed project issues/criteria relative to one another: Aesthetics; Construction Worker Safety; Final Occupant Safety; Project Cost; Project Schedule; Quality of Work

- Section 3: Hypothetical DFCS Implementation Project  
This section presents the hypothetical DFCS implementation project and its context. The nature of the project and the interviewee's role on the project are all provided. This is the point when the plans of the hypothetical building project were to be provided.
- Section 4: Manual Implementation of DFCS on the Project  
In this section, the interviewee is asked to manually identify design modifications to the project that can be made to enhance the safety of construction workers.
- Section 5: DFCS Implementation using the DFCS Software  
In this section, the interviewee is asked to use DFCS software to identify design modifications or design features that can be utilized to enhance construction worker safety on the building project. This is the point when the appropriate DFCS tool was to be provided on the screen of a laptop computer.
- Section 6: Questions on the DFCS Implementation Process of the Project  
In this section, the interviewee is asked the post-testing questions.
  - i. How difficult/easy was the identification of design modifications for construction worker safety using the manual method as utilized in this session? [0 = Extremely Difficult; 5 = Neutral; 10 = Extremely Easy]
    - Why?
  - ii. Did the software inhibit/improve the DFCS implementation process compared to the manual method as practiced in this experiment? [0 = Extremely Inhibited; 5 = Neutral; 10 = Extremely Improved]
    - Why?
  - iii. How difficult/easy was the identification of design modifications for construction worker safety using the software as utilized in this session? [0 = Extremely Difficult; 5 = Neutral; 10 = Extremely Easy]
    - Why?
  - iv. What do you like about the software?

- v. To what extent did the details provided with the DFCS suggestions or modifications help in your selection of which to implement on the project? [0 = Not Helpful; 10 = Extremely Helpful]
  - How?
- vi. Would any additional details on the 'design suggestions' provided by the software be helpful in the selection of DFCS modifications for the project?
  - What details?
- vii. Compared to other AEC design software you have used, how do you find using the DFCS software? [0 = Extremely Difficult; 5 = Neutral; 10 = Extremely Easy]
  - Why?
- viii. Should the software be integrated into other AEC design software such as Building Information Modeling (BIM) tools to enhance its effectiveness and use? (Yes or No)
- ix. What recommendations do you have for improving the software?
- x. To what extent did the following details help in your selection of 'DFCS suggestions or modifications' for the project (using the DFCS-TIPS software)?
  - Safety incidents considered preventable through implementation of the DFCS suggestions or modifications [0 = Not Helpful; 10 = Extremely Helpful]
  - Potential impediments to implementing the DFCS suggestions or modifications [0 = Not Helpful; 10 = Extremely Helpful]
  - Potential solutions to the impediments of implementing the DFCS suggestions or modifications [0 = Not Helpful; 10 = Extremely Helpful]
  - Tier of Feasibility (Amount of research on the DFCS suggestions or modifications and the level of confidence in the effectiveness of the suggestions) [0 = Not Helpful; 10 = Extremely Helpful]

- Section 7: Other Questions  
This section includes three questions on the participation of the interviewee, on DFCS, and on the study respectively. These are the three questions.
  - Would you like your participation in this study to be confidential?
  - Do you have any general comments on DFCS?
  - Do you have any general comments on the interview or study?

#### 4. The pilot software testing interview was conducted.

- Sample Recruitment for Pilot Interview
  - Interview Guide Versions  
I created 2 versions of the interview guide for two different design disciplines, architects and civil/structural engineers, but for use with the DFCS Toolbox. As a completed product, glitches or errors were less likely to be encountered. This was to allow for collecting complete data and responses to all the interview questions with minimal risk of changing circumstances. Also, as the DFCS tool not developed by the researcher, using it offered the opportunity to practice being unbiased in the testing interviews.
  - Sample Selection and Contact
    - I used purposive and convenience sampling to select 2 AEC professionals in my university (Carnegie Mellon University). One is an architect and the other a civil/structural engineer. I applied these two criteria.
      - A minimum of 5 years in working experience
      - Some background in not just design but construction projects
    - I contacted the sample of 2 AEC design professionals via email. In the email, I introduced myself and stated my PhD student status. I also stated the name of my advisor. I then requested input in my research pertaining to DFCS and involving software testing. I did not state that the interview was to be a pilot interview. It was therefore an undeclared pilot test. I stated that the interview was expected to take 30-45 minutes. I also indicated the basis for the sample selection, AEC professional with experience in design and possibly, construction. Lastly, I requested that I be notified if the email recipient was willing to participate. Greetings and thanks were also included. As I had received research input from the architect before, I adapted his email to be in a reminder format.

- Sample Response and Recruitment
    - One email recipient responded and agreed to participate. I expressed my appreciation and requested for the respondent to provide me with a range of preferred times and a preferred location for the interview. I selected one of these times and confirmed that I would be present at the respondent's preferred location. The recruited pilot interviewee was the civil/structural engineer. The pilot interview guide that was used is provided in *Appendix H1*.
- The Interview Setting
 

The interview setting was the office of the interviewee. The location met the three important aspects of the physical interview environment which include comfort, privacy and quiet (King and Horrocks, 2010).
- Recording
 

Note-taking was used for recording the interview. These notes were written on the interview guide, which was designed with spaces to allow for data entry.
- Strategies used for Building Rapport
  - Provision of duplicate interview guide to the interviewee for reference and explanatory purposes.
  - Introduction of the interviewee to the project, the interview purpose and also, self-presentation.
- Probing
 

All types of probes were utilized in the interview including elaboration, clarification and completion to yield more useful information on the DFCS measures. The use of probes was not over-excessive to avoid lost time.
- Improvements to Research Interviews based on the Pilot Interview
 

The pilot interview was conducted in an identical manner to that intended for the research interview. Gillham (2000) recommended one or two pilot interviews. Based on the pilot, certain adjustments and alterations were determined to improve the effectiveness of the research interviews (Gillham, 2000). Two adjustments were made.

  - Question 8A in *Table 64* was eliminated in favor of using Question 8B for the interviews. The pair-wise comparison proved too tedious as the interviewee actually opted to rank the project criteria instead. I then asked if he felt the question should be modified or discarded. He indicated that it should be discarded thus implying an unfavorable view towards the pair-wise comparison question structure. Hence, Question 8 was to replicate that used by Gambatese et al (2005) in their face-to-face surveys.

- The responses to Question 7 in *Table 65* were modified to include Not Applicable (N/A) as an answer option. This was because the interviewee identified it as his response though the option was not provided. Also, this was a valid response as many interviewees may find the DFCS tools incomparable to other design software they have used.
- Pilot Interview Responses
 

Given the fact that the research interview was only very slightly modified due to the outcome of the pilot interview, and also, all the responses anticipated from the research interview were yielded in the pilot, I decided on utilizing the pilot interview responses with the research interview responses for interpretation as an output of this research task.

## 5. The software testing interview was conducted.

- Interview Guide Versions
 

Four interview guide versions were used in this research task with two for the testing of the DFCS-TIPS application and two for the testing of the DFCS Toolbox. The interview guide version for the architects in DFCS-TIPS and DFCS Toolbox testing interviews were to be used once each. Meanwhile, the interview guide version for the engineers in DFCS-TIPS and DFCS Toolbox testing interviews were to be used twice each, for the civil/structural engineer and the MEP engineer. The DFCS Toolbox testing interview guide for architects is provided in *Appendix H2*. The DFCS-TIPS testing interview guide for civil/structural and MEP engineers is provided *Appendix H3*.
- The Interview Setting
 

The interview setting for the face-to-face interviews was the preferred location of the interviewee which was to be comfortable, private and quiet. This included the interviewees' offices or alternate locations such as rooms on the campus of Carnegie Mellon University.
- Recording
 

Note-taking was used for recording the interview. These notes were written on the interview guide, which was designed with spaces to allow for data entry.
- Strategies used for Building Rapport
  - Provision of duplicate interview guide to the interviewee for reference and explanatory purposes.
  - Introduction of the interviewee to the project, the interview purpose and also, self-presentation.

- Probing  
All types of probes were utilized in the interviews including elaboration, clarification and completion to yield more useful information on the DFCS measures. The use of probes was not over-excessive to avoid lost time.
- Interview Administration Process  
The research interviews were administered similarly to the process and steps prescribed by McNamara (2007). These were however slightly modified in the cases where the participants had been interviewed in the earlier executed research tasks.
  - i. Greet and express appreciation for interviewee's participation.
  - ii. Introduce self.
  - iii. Briefly explain the research topic.
  - iv. Explain the purpose of the interview and the confidentiality of responses.
  - v. State the expected duration of the interview.
  - vi. Provide duplicate interview guide to the interviewee.
  - vii. Explain the format of the interview as indicated on the interview guide.
  - viii. Ask if there are any questions or concerns that pertain to the interview prior to starting.
  - ix. Ask and explain questions indicated on the interview guide.
  - x. Provide hypothetical project building plans at the appropriate stage of the interview.
  - xi. Provide laptop computer with the operational DFCS software installed at the appropriate stage of the interview.
  - xii. Record the interviewee's responses and comments while probing for additional details.
  - xiii. Collect the building plans from the interviewee.
  - xiv. Ask the interviewee if he/she would like to retain the duplicate interview guide. If not, collect the interview guide.
  - xv. Thank the interviewee.

## 6. The interview data was transcribed and analyzed.

- Transcription and Thematic Analysis Approach  
A detailed transcription was effective for collecting the information sought through the research interviews. Answers to all the specific questions were appropriately recorded either in entirety or using short phrases. Where any interviewee's response was unclear, I requested clarification. Also, the thematic analysis of the interview was aimed at balancing clarity and inclusivity to ensure the responses and details were appropriately collected.

- Interview Data Analysis  
The interview data was compiled and suggested improvements to the DFCS-TIPS application and the DFCS Toolbox were evaluated. I determined those improvements that were feasible to implement on the DFCS-TIPS application. This feasibility was with regards to the capability of the application development software and with regards to time and resources.
- Steps utilized in Analyzing the Research Interview Data  
The steps utilized in analyzing the collected interview data were to be similar to that indicated by McNamara (2007) but more applicable to this research approach. The steps are indicated.
  - i. Condense the information and present it in a clear format that indicates the findings using such visual displays as tables and figures.
  - ii. Evaluate the suggested and recommended improvements to the DFCS-TIPS application and determine those feasible to implement.

#### 7. The DFCS-TIPS application was to be improved.

Based on the collected interview data, the DFCS-TIPS application was to be improved. The specific improvements suggested by the interviewees were to be evaluated on the basis of feasibility and applicability. These improvements were to be identified not only through questions but through comments and actions of the interviewees or software users. The improvements were to enhance the functionality, format, structure and/or appearance of the application. As stated earlier, the emphasis of this research task was on the application itself and how it allowed for data entry and use, and the format it used in presenting the DFCS information. The improvements to the DFCS-TIPS application were to be made after completion of all the interviews.

#### **4.1.6.4      Results and Discussion**

##### **Response Rates and Characteristics of Interviewees**

There were 9 email recipients and out of these, 6 responded that they were willing to participate in the software testing interviews. 2 did not respond at all. And, 1 indicated he wasn't much of a software user and then referred me to another AEC design professional in his firm. I contacted this designer and was able to successfully conduct the interview. Thus, there were 7 interviewees yielded out of the 9 email recipients. This included the pilot interviewee. This represented an interview participation rate of 77.8%. Out of the 7 interviewees, 5 had previously been utilized for input in this research through the earlier surveys and interviews. They were selected for proximity to allow for face-to-face interviewing. As a matter of note, the interview location was my campus office for

only 1 interview while for the 6 other interviews, the locations were the offices of the interviewees. The potential interviewees were also selected based on their exhibited enthusiasm for participation in the earlier research tasks. This contributed to the high interview participation rate. Lastly, they were selected to offer adequate ground for comparing the features and capabilities of the DFCS-TIPS application and the DFCS Toolbox. On this basis, the interviewees included 2 architects, 3 civil/structural engineers, and 2 MEP (electrical) engineers. The additional civil/structural engineer was the pilot interviewee who was utilized in a DFCS Toolbox testing interview. The remaining 6 were split evenly with 1 architect, 1 civil/structural engineer, and 1 electrical engineer utilized for testing interviews of each of the DFCS tools.

As in the case of the earlier interviews, a criterion in the selection of the interview sample was at least 5 years of working experience. The interviewees averaged 16.7 years of experience. The least was 9 years while the most was 27 years of experience. Thus, no interviewee indicated less than 5 years of work experience. Furthermore, with the average years of experience of those testing the DFCS Toolbox and the DFCS-TIPS application at 15 and 19 years respectively, the disparity between the two groups was not considered significant enough to affect the interpretation of the interview results. *Table 66* provides the design profession and job titles of the interviewees, their years of experience, and the respective software tested in their interviews.

	Software Testing Interview	AEC Design Profession	Job Title / Profession	Years of Experience	Average Years of Experience
1.	DFCS Toolbox	Architect	Assistant Professor	12	15.0
2.		Civil/Structural Engineer (PILOT)	Lecturer / Assistant Engineering Manager	27	
3.		Civil/Structural Engineer	Associate	12	
4.		MEP – Electrical Engineer	Senior Engineer	9	
1.	DFCS-TIPS	Architect	Principal	26	19.0
2.		Civil/Structural Engineer	Assistant Professor	13	
3.		MEP – Electrical Engineer	Vice-President, Electrical Engineering	18	
				Average Years of Experience of All Interviewees	16.7

**Table 66:** Characteristics of Software Testing Interviews and Interviewees

## Responses to the Interview Questions

This section presents and discusses the responses to the interview questions. Where applicable, observations of the interviewees' actions along with their commentary are discussed.

## Responses to the Pre-Testing Interview Questions

As earlier stated, the pre-testing questions were to determine if the perceptions and knowledge of the two groups of interviewees with regards to DFCS were comparable to allow for direct contrasts between the DFCS Toolbox and the DFCS-TIPS application with regards to effectiveness and usability in implementing DFCS. *Table 67* provides the responses to the pre-testing interview questions.

The responses to Questions 1 and 2 in *Table 67* did not indicate a significant difference between the two groups of interviewees. However, the responses to Question 3 showed a significant difference. Majority of the DFCS Toolbox testing interviewees indicated they had never been asked to address construction worker health and safety in the design phase. Meanwhile, all the DFCS-TIPS testing interviewees indicated that they had been asked to address construction worker health and safety in the design phase. The responses to Questions 4 in *Table 67* did not indicate a significant difference between the two groups of interviewees.

	PRE-TESTING INTERVIEW QUESTIONS	DFCS Toolbox				DFCS-TIPS			OVERALL
1.	Have you ever made modifications to a project in the design phase to eliminate a potential safety risk that would impact construction worker health and safety?	Yes (2/4) No (2/4)				Yes (2/3) No (1/3)			Yes (4/7) No (3/7)
2.	Have you ever had any discussions with owners and/or contractors that include the features to be included in the design, to ensure construction worker health and safety during project construction?	Yes (3/4) No (1/4)				Yes (3/3) No (0/3)			Yes (6/7) No (1/7)
3.	Have you ever been asked to address construction worker health and safety in the design phase?	Yes (1/4) No (3/4)				Yes (3/3) No (0/3)			Yes (4/7) No (3/7)
4.	Have you ever worked with or hired a construction health and safety consultant in the design phase?	Yes (1/4) No (3/4)				Yes (1/3) No (2/3)			Yes (2/7) No (5/7)
5.	How willing are you to design for construction worker safety? [0 = Extremely Unwilling; 5 = Neutral; 10 = Extremely Willing]	A	CE (P)	CE	EE	A	CE	EE	6.6 (Average)
		10	5	5	8	0	9	9	
		7.0 (Average)				6.0 (Average)			

	PRE-TESTING INTERVIEW QUESTIONS	DFCS Toolbox					DFCS-TIPS				OVERALL
6.	Have you ever used any tool to enhance or aid construction safety considerations on a project?	Yes (0/4) No (4/4)					Yes (0/3) No (3/3)				Yes (0/7) No (7/7)
7.	Do you use any AEC design software?	Yes (4/4) No (0/4)					Yes (3/3) No (0/3)				Yes (7/7) No (0/7)
	Which design software do you use?	Rhino, Ecotect, AutoCAD, REVIT, RISA, STAAD, RAM, ERCALC, Various Spreadsheets, Lighting Design Software, Software for Short Circuits, Generator Software					REVIT, AutoCAD, Abacus, Ansys, proprietary software, SKM – Electrical Distribution Systems, AGI, Manufacturer published software for sizing generators by CAT and others, company spreadsheets, and panel-board calculations				N/A
8.	Please rank the listed project issues/criteria by importance.										
		A	CE (P)	CE	EE	<u>AVE</u>	A	CE	EE	<u>AVE</u>	AVERAGE
	Aesthetics	3	6	4	2	3.8 (3 <sup>rd</sup> )	5	6	6	5.7 (6 <sup>th</sup> )	4.6 (6 <sup>th</sup> )
	Construction Worker Safety	1	5	6	3	3.8 (3 <sup>rd</sup> )	6	5	3	4.7 (5 <sup>th</sup> )	4.1 (5 <sup>th</sup> )
	Final Occupant Safety	1	4	1	1	1.8 (1 <sup>st</sup> )	1	2	2	1.7 (1 <sup>st</sup> )	1.7 (1 <sup>st</sup> )
	Project Cost	5	1	5	5	4.0 (5 <sup>th</sup> )	2	3	5	3.3 (3 <sup>rd</sup> )	3.7 (3 <sup>rd</sup> )
	Project Schedule	6	2	3	6	4.3 (6 <sup>th</sup> )	3	4	4	3.7 (4 <sup>th</sup> )	4.0 (4 <sup>th</sup> )
	Quality of Work	3	3	2	4	3.0 (2 <sup>nd</sup> )	4	1	1	2.0 (2 <sup>nd</sup> )	2.6 (2 <sup>nd</sup> )

**Table 67:** Responses to the Pre-Testing Interview Questions

As for Question 5, the averages in terms of the willingness of the interviewee to design for construction worker safety are not significantly different, with that for the DFCS Toolbox testing interviewees at 7.0 (Willing) and that for the DFCS-TIPS testing interviewees at 6.0 (Willing). However, when considered by each interviewee's response, there are some significant differences. The architect for DFCS Toolbox testing interviews indicated he was extremely willing (10) to design for construction worker safety. He stated his reason as being that he was mostly involved in smaller building projects that he would characterize as design-build. He therefore typically employed the contractors as prescribed by his project owners in the project contracts. Thus, he possessed the ability to make such specifications with less opposition as compared to when the contractor answered separately to the owner. Furthermore, the interviewee also indicated that he maintained very cordial relationships with the contractor and construction workers involved on his projects. This was as the contractors were small-sized companies with small numbers of construction workers. And, he had been involved with his contractors on several projects. He thus indicated that it was to be expected that he would be concerned for the safety of the construction workers. This same issue had been documented in a study by Gambatese and

Hinze (1999). Meanwhile, the architect for the DFCS-TIPS testing interviews indicated he was extremely unwilling (0) to design for construction worker safety. He stated his reason as being that, as a principal in a relatively large design firm, he would be highly concerned if his employees were to be implementing DFCS as it would expose the firm to additional liability. Furthermore, it would go against recommendations by their lawyers and insurance company. He also stated that if there was to be no exposure to liability, he could be willing to design for construction worker safety. The responses of the civil/structural engineers in the DFCS Toolbox testing interviews indicated neutrality with regards to willingness to design for construction worker safety. Both indicated they would however be concerned about exposure to liability. Meanwhile, the response of the civil/structural engineer in the DFCS-TIPS testing interviews indicated extreme willingness (9) to design for construction worker safety. He stated that it was important to value the health and safety of the public and all those involved on the project. As for the responses of the MEP – electrical engineers, the difference was not significant with regards to their willingness to design for construction worker safety at 8.0 (very willing) for the DFCS Toolbox testing interviews and 9.0 (very willing) for the DFCS-TIPS testing interviews.

As for Question 6 in *Table 67*, all interviewees responded they had never used any tool to enhance or aid construction safety considerations on a project. And, the responses to Question 7 indicated that all interviewees used AEC design software. Additionally, the design software used by the two groups of interviewees was mostly similar with a few that were identical. In Question 8, where the project criteria were to be ranked based on design importance, the differences between the two groups of interviewees was also not significant. For both groups of interviewees, there were 3 that ranked construction worker safety 3<sup>rd</sup>, 5<sup>th</sup> and 6<sup>th</sup> (last). There was however 1 interviewee in the DFCS Toolbox testing interviews that ranked construction worker safety 1<sup>st</sup>, equal with final occupant safety. This was the same design professional that indicated extreme willingness (10) to design for construction worker safety, sighting close working relationships with the contractor and construction workers on his projects. He indicated that safety is of prime concern whether of the final occupant or of the construction worker. Ultimately, the interviewees in the DFCS Toolbox testing interviews ranked construction worker safety third while the interviewees in the DFCS-TIPS testing interviews ranked it fifth on average. This difference was not determined to be significant.

Conclusively, the collective responses to the pre-testing questions by the DFCS Toolbox testing interviewees and the DFCS-TIPS testing interviewees were considered comparable. As such, the responses to the interview questions along with other yielded details allowed for valid comparisons between the DFCS-TIPS application and the DFCS Toolbox with regards to effectiveness and usability in implementing DFCS. Hence, the interviews allowed for determining whether the DFCS-TIPS application is validated as a viable tool to aid in DFCS implementation, and also for yielding potential improvements to enhance its functionality.

### Observation and Results of the Manual Implementation of DFCS on the Hypothetical Building Project

The manual DFCS implementation segment of the interview was intended to provide a benchmark for comparing the tool-based implementation segment against. It was essentially to aid in determining whether and to what extent the software aid DFCS implementation. With the hypothetical project provided to the interviewees, I took note of their statements and recorded the design suggestions they provided in the interest of enhancing construction worker safety on the project.

The statements made by the interviewees are provided in *Table 68*. From the statements, it was clear the task proved difficult for all the interviewees. They either indicated they were not experienced enough to successfully execute manual DFCS implementation or they indicated that the building plans were not enough detail to enable them to provide the applicable design suggestions for construction safety. Many also indicated that they did not usually view plans with construction safety in mind.

The design suggestions for construction worker safety that were provided by the interviewees were recorded. They were not assessed to evaluate if they met all the criteria for DFCS measures such as being situated in the project design phase or being applicable to construction workers. The design suggestions provided in the respective interviews are indicated in *Table 69*. As seen, the difference between the average numbers of design suggestions provided by the design professionals in the DFCS Toolbox testing interviews and the DFCS-TIPS testing interviews was not significant. At 7.5 and 7.0 respectively, the two groups were clearly comparable with regards to their safety expertise.

When the interviewees are viewed by their disciplines, a clear difference is observed between the numbers of design suggestions provided by the architects in the DFCS Toolbox testing interviews and the DFCS-TIPS testing interviews at 12 and 1 respectively. The 12 suggestions were provided by the architect that indicated extreme willingness to design for construction worker safety while the 1 suggestion was provided by the architect that indicated extreme unwillingness to design for construction worker safety. This could have served as an early indicator of the manual implementation outcome. As for the civil/structural engineers in the two groups, those in the DFCS Toolbox testing interviews provided 1 and 6 design suggestions for construction worker safety which average to 3.5 design suggestions. This is compared to the 3 design suggestions provided by the civil/structural engineer in the DFCS-TIPS testing interviews. Thus, the difference was not significant. As for the MEP (electrical) engineers, both provided a relatively high number of design suggestions at 11 for the DFCS Toolbox testing interviews and 17 for the DFCS-TIPS testing interviews. This seemed to indicate high familiarity with safety-related matters. And given that the numbers were high relative to those for the other design disciplines, the difference between them was not considered significant. As the difference

between the average numbers of design suggestions provided by the design professionals in the two groups of software testing interviews were not significant, the significant difference for the architects was determined not to adversely impact the value of the interview responses and commentary. This was since it did not diminish the function of the manual implementation segment as a benchmark for the tool-based implementation segment. It just served to indicate that some design professionals need more assistance in DFCS implementation than others, based on their levels of construction safety expertise.

	Software Testing Interview	AEC Design Profession	Statements during Manual Implementation of DFCS
1.	DFCS Toolbox	Architect	"It's hard to tell from a plan. Sections might be better for the task." "The drawings might need an increased level of detail "I have problems with this building plan. I believe it needs more accessibility and also more windows for health and satisfaction"
2.		Civil/Structural Engineer (PILOT)	"This is a completely new thing for me" "I give up based on my discipline" "I would need a day to think about it" "I would want to talk to someone as part of my task list" "I would ask to hire a consultant before I agree"
3.		Civil/Structural Engineer	"This is a hard question to answer" "You want to be conscious of sequencing and what goes up in the different orders"
4.		MEP – Electrical Engineer	"This building has different services" "The electrical engineer is interested in exits" "As for electrical outlets, it's hard to tell at this point" "I don't see the spiral staircase as much of an issue"
1.	DFCS-TIPS	Architect	"I don't know if I am qualified. I believe they hired the wrong guy" "Part of my brain is focused on code review" "The construction worker is considered as an occupant prior to code adherence. The emphasis is on the construction sequence" "I don't have enough information" "Owners force you to operate in grey areas" "I neither have enough information nor am I qualified for the task. Perhaps, this has more to do with my process as I like to gather a lot of information" "I would need more review. Perhaps if better prepared" "I'm not thinking this way. It is a challenge"
2.		Civil/Structural Engineer	"I wouldn't know where to begin to be honest" "There is lots of nice open space in the building" "You can always build the project. You can always make it happen" "I don't see anything with regards to construction worker safety. It is the contractors responsibility" "At this stage, very few changes can be made architecturally or based on the design" "If in the design stage, I may have some preferences for certain types of construction based on cost and efficiency issues"
3.		MEP – Electrical Engineer	"We don't often sit down and look at it like that" "It is a consideration as we are designing it" "We will also determine the bare minimum code" "We look at safety and the placement of devices" "This plays into both occupant and construction safety" "We utilize the architects plan and the life safety plans" "A lot of safety is in the hands of the design team. It's a full design effort. There are a ton of design meetings on large projects" "We don't design in a vacuum. The types of footing, geotechnical reports, retaining walls are all considered by the design team with the civil/structural engineers and others" "You might have to do certain things"

**Table 68:** Statements of Interviewees during Manual DFCS Implementation

	Software Testing Interview	AEC Design Profession	Number of provided DFCS Suggestions provided	Design Suggestions for Construction Worker Safety provided by Interviewees	Average Number of provided DFCS Suggestions
1.	DFCS Toolbox	Architect	12	<ul style="list-style-type: none"> <li>- Eliminate the spiral staircase particularly if the building is high occupancy.</li> <li>- Provide guardrail</li> <li>- Provide rails for stairs</li> <li>- Ensure stair widths are appropriate</li> <li>- Ensure there are adequate means to get smoke out of building</li> <li>- Increase stairway access to the top floor</li> <li>- Make the stairs shorter</li> <li>- Make clearer paths to exits</li> <li>- Adjust some of the doors. Doors are pinch points that may be unnecessary</li> <li>- Fire stairs should be shifted more closely to the points of egress</li> <li>- Fire doors should not be present at the spiral stairs</li> <li>- Sprinklers should be appropriately placed throughout the building</li> </ul>	7.5
2.		Civil/Structural Engineer (PILOT)	1	<ul style="list-style-type: none"> <li>- Eliminate circular stairs</li> </ul>	
3.		Civil/Structural Engineer	6	<ul style="list-style-type: none"> <li>- Use the most efficient size members so are the least weight</li> <li>- Accessibility to the project site must be designed and detailed adequately</li> <li>- Design the layout to allow for field splices</li> <li>- You could specify different products such as metal deck with anti-slip surfaces. You could adjust material selection based on the time of year of construction.</li> <li>- Use panelized construction to lift up and fix rather than sending worker up to heights.</li> <li>- Allow for extensive use of prefabricated items.</li> </ul>	
4.		MEP – Electrical Engineer	11	<ul style="list-style-type: none"> <li>- Par IBC, you want to have a clear unobstructed direction of exit.</li> <li>- You should have more exits</li> <li>- The exits should be lit with emergency power</li> <li>- The doors should swing out in the direction of egress for electrical rooms</li> <li>- The elevator should have redundant light sources</li> <li>- Water service should be grounded within 6 inches</li> <li>- Place disclaimer to call for direction before you dig the ground</li> <li>- Emergency exit doors should also swing out</li> <li>- Use wall mounted alarm devices to ensure visibility</li> <li>- There should be enough building openings to ensure there is adequate smoke evacuation</li> <li>- The sprinklers should be placed to ensure adequate reach</li> </ul>	

	Software Testing Interview	AEC Design Profession	Number of provided DFCS Suggestions provided	Design Suggestions for Construction Worker Safety provided by Interviewees	Average Number of provided DFCS Suggestions
1.	DFCS-TIPS	Architect	1	- Make the door swing outward in the direction of exit	7.0
2.		Civil/Structural Engineer	3	<ul style="list-style-type: none"> <li>- I would avoid cantilevers</li> <li>- I would prescribe the spaces between columns to be adequate, at least 15 feet apart</li> <li>- I believe the points and means of egress should be increased to meet code requirements</li> </ul>	
3.		MEP – Electrical Engineer	17	<ul style="list-style-type: none"> <li>- Elevator machine room should be appropriately located</li> <li>- Electrical rooms should be located close to main service entrances</li> <li>- Keep live electrical elements protected and underground</li> <li>- Keep the transformer 10 feet or more from the building. Terminate inside the building.</li> <li>- No exposed wires and utilities</li> <li>- Keep electrical separate from other utilities</li> <li>- Follow code (NEC) Arc 100 worker safety clearance. Layout main electrical clearances to meet these requirements.</li> <li>- I will look at the ampage or voltage. If high, I must have double the clearance then I must have 2 points of exit in the electrical room.</li> <li>- Voltage will be 480V for this building so I will need an indoor transformer to be located in well-situated electrical rooms</li> <li>- Work to get the accurate fire ratings then consider if the building will have a sprinkler system</li> <li>- Layout the flashing and specification and height to follow the ADA guidelines for mounting devices</li> <li>- Design appropriate clearances for panels</li> <li>- Apply emergency lighting, egress lighting and exit signs. These can be powered by batteries. The owner would be responsible to check them. These are all part of public safety requirements</li> <li>- Layout the building to ensure a crane could get into the site and fit rooftop mechanical units on the roof</li> <li>- Check for pathways to ensure they are adequate to get things in and out</li> <li>- Check for switchgear access and removal</li> <li>- Have permanent scaffolding or lifting capabilities where lighting will go into high ceiling. In new construction, you might not have to say it</li> </ul>	

**Table 69:** Design Suggestions provided by Interviewees during Manual DFCS Implementation

## Observation and Results of DFCS Implementation using the DFCS Software

This was the tool-based segment of the interview that was intended to evaluate the effectiveness and usability of the DFCS tools in implementing DFCS on the hypothetical project. The interviewees were to use the DFCS Toolbox or DFCS-TIPS application to identify design modifications or design features that could be utilized to enhance construction worker safety on the building project. While they were performing this task, I took note and recorded their patterns of use, statements, and the number of DFCS suggestions they selected. I also took note of the issues or difficulties they encountered during software use. The patterns of software use of the interviewees are provided in *Table 70*. The pattern of software use was recorded to provide a picture as to how the DFCS tools were used. Through this, potential improvements to the functionalities and capabilities for both tools were able to be identified. These improvements were then to be assessed to determine which were feasible to implement on the DFCS-TIPS application. Some issues encountered during tool use are seen in the pattern of use data in *Table 70*. 2 out of 4 of the DFCS Toolbox testing interviewees did not use the tutorial while 3 out of 3 of the DFCS-TIPS testing interviewees did not use the tutorial. There were two potential reasons. The first was the visibility of the tutorial or “Tour” button in the DFCS Toolbox which was 1 of the 3 buttons on the main interface. This is as compared to the tour button of the DFCS-TIPS application which was 1 of the 9 buttons on the interface, and was labeled “Using the DFCS-TIPS Application”. The second reason may simply be that most software users prefer to use software and then check the tutorial or help sections when they encounter any difficulties during use.

The statements made by the interviewees while executing the tool-based implementation are provided in *Table 71*. In both the DFCS Toolbox and DFCS-TIPS testing interviews, the statements addressed various issues. In the DFCS Toolbox testing interviews, some interviewees stated that the tool and its provided suggestions were helpful in enabling execution of the task. Some stated that certain suggestions were applicable to AEC design professionals of other disciplines. Some interviewees made comments with regards to how some of the suggestions were OSHA and building code related and how the DFCS Toolbox could help them if integrated with code requirements. Some indicated familiarity and unfamiliarity with some of the design suggestions and made general commentary on them. Some also criticized the functionalities, features, and interface of the software. And some indicated that it would require a long time to complete evaluation and selection from the over 400 design suggestions as placed in checklists under the 20 categories or tabs. In the DFCS-TIPS testing interviews, the interviewees also stated that the tool and its provided DFCS measures were helpful in enabling execution of the task. Interviewees also discussed how the DFCS-TIPS application could help their process if integrated with code requirements. The interviewees identified functionalities, features, and the interfaces of the software they found useful. The interviewees also criticized the lack of certain capabilities along with other issues.

	Software Testing Interview	AEC Design Profession	Used Tutorial?	Pattern of Software Use
1.	DFCS Toolbox	Architect	No	<ul style="list-style-type: none"> <li>- He confirmed with me that clicking each DFCS suggestions corresponded to agreeing it is a good idea.</li> <li>- Stayed on the initial display of DFCS suggestions and was scrolling through despite most not being applicable to his discipline.</li> <li>- He kept selecting measures and scrolling through.</li> <li>- He then confirmed that clicking the side tabs corresponded to different sections with measures.</li> <li>- He selected a few more and indicated that he would need to take more time to concentrate and finish the task.</li> <li>- He then went to Step 2 and viewed the selected suggestions and said he was done.</li> </ul>
2.		Civil/Structural Engineer (PILOT)	Yes	<ul style="list-style-type: none"> <li>- Stayed on the initial display of DFCS suggestions and was scrolling through despite most not being applicable to his discipline.</li> <li>- Afterwards, he started quickly scrolling through the other categories.</li> <li>- Later started selecting measures in large number citing absence of liability.</li> <li>- He asked if there was a number requirement.</li> <li>- He then went back and de-selected the suggestions in the initial display.</li> <li>- He then went to Step 2 and viewed the selected suggestions and said he was done.</li> </ul>
3.		Civil/Structural Engineer	No	<ul style="list-style-type: none"> <li>- He stayed on the initial display of DFCS suggestions and went through each of them.</li> <li>- He asked if Step 1 was to be completed first for each measure across different sections before moving to Step 2, or whether it was to be individually done for each. I indicated the former.</li> <li>- He went down the different categories.</li> <li>- He did not go to structural directly. He went through the different structural categories.</li> <li>- He then went to Step 2 and viewed the selected suggestions and said he was done.</li> </ul>
4.		MEP – Electrical Engineer	Yes	<ul style="list-style-type: none"> <li>- He went through the initial display looking through and selecting DFCS suggestions to implement.</li> <li>- He then moved to the next section and selected a few more. After which, he returned to the initial display.</li> <li>- He did not move to the electrical section till after some time and indicated that it would take long to finish the task.</li> <li>- He then selected to view all suggestions.</li> </ul>

	Software Testing Interview	AEC Design Profession	Used Tutorial?	Pattern of Software Use
1.	DFCS-TIPS	Architect	No	<ul style="list-style-type: none"> <li>- He added a new project then went on to select DFCS measures.</li> <li>- He selected his profession and the preliminary design project stage, and then selected project characteristics.</li> <li>- He continued going through. He indicated he would retain the spiral staircase of the building.</li> <li>- He selected many DFCS measures.</li> <li>- He viewed the selected measures.</li> <li>- He opened the print page and with the print page out, he stopped.</li> </ul>
2.		Civil/Structural Engineer	No	<ul style="list-style-type: none"> <li>- He added a new project then went on to select DFCS measures.</li> <li>- He selected his profession and the preliminary design project stage, and then selected project characteristics.</li> <li>- He asked about the 'Provide Applicable DFCS Measures' button.</li> <li>- He then proceeded to select DFCS measures from those provided.</li> <li>- He viewed the selected measures and went on to select more measures.</li> <li>- The interviewee guided me on moving to the next print page on the software.</li> <li>- With the print page out, he stopped.</li> </ul>
3.		MEP Electrical Engineer –	No	<ul style="list-style-type: none"> <li>- He added a new project and then saved and closed.</li> <li>- He then selected the project for editing.</li> <li>- He identified his design discipline then clicked on 'Select DFCS measures from Index' instead of "Provide applicable measures". I corrected the interviewee.</li> <li>- He viewed the measures and took time to assess them.</li> <li>- He identified one as code that they would have to do.</li> <li>- He selected a few DFCS measures.</li> <li>- He viewed the selected measures.</li> <li>- He opened the print page.</li> <li>- With the print page out, he stopped.</li> </ul>

**Table 70:** Pattern of Software Use of the Interviewees

	Software Testing Interview	AEC Design Profession	Statements during Tool-based Implementation of DFCS
1.	DFCS Toolbox	Architect	<p>"I am going to do all these DFCS suggestions"</p> <p>"I'm not sure how some measures can be implemented"</p> <p>"This is going to take a long time"</p> <p>"I have many more measures to select and take into account"</p> <p>"To be continued"</p>
2.		Civil/Structural Engineer (PILOT)	<p>"Some of these suggestions don't belong in the categories"</p> <p>"These categories apply to architects and other engineers"</p>
3.		Civil/Structural Engineer	<p>"Some of these are not up to me to say. I won't pick some of these. Maybe it should be classified by profession and those that pertain to design"</p> <p>"A lot of things we have no say over. Skylights and parapets are all for the architect as with most of the suggestions I read. They need to be classified by profession"</p> <p>"Many of the suggestions were replicated in the different categories so I had to go through each one"</p> <p>"Some of these suggestions fall under OSHA requirements"</p> <p>"Nobody uses wood piles anymore"</p> <p>"Yeah! I did pretty good with the measures I identified manually. Some are here"</p>
4.		MEP – Electrical Engineer	<p>"This might take a while"</p> <p>"There were electrical DFCS suggestions in the initial display so I presumed there were electrical suggestions in the other sections too but they were scattered across"</p> <p>"It's really hard to find something to disagree with. Wish there was a button to select all. More than likely, most should be considered"</p> <p>"There are a few suggestions I have and haven't done before here"</p> <p>"I don't see classifications in terms of electrical requirements, hazards, or in terms of profession"</p> <p>"This may need a link to click on to check state, county or city. This should provide the gasoline type for ensure that tanks and vessels meet code requirements. Some places require containment"</p> <p>"Code will also prescribe the conduit, disconnect, and alarm specifications"</p> <p>"I am not saying the software is not good but I have suggestions"</p>
1.	DFCS-TIPS	Architect	<p>"I would do as many as I can"</p> <p>"The ability to add new potential solutions is useful"</p> <p>"There are cases where IBC would apply if the perimeter is nearby"</p>
2.		Civil/Structural Engineer	<p>"Why should I have to select my profession continuously?"</p> <p>"I am getting a hang of this"</p> <p>"I like that it can provide a list of measures which one can then check"</p> <p>"It is good that you end up with a laundry list. I might like such a checklist when considering DFCS implementation"</p>
3.		MEP – Electrical Engineer	<p>"I believe the intention is to continue building on the content"</p> <p>"I have a list of my own and would like to be referring to it"</p> <p>"It could be expanded to include code items"</p> <p>"There is no tool to consider IBC code and NFPA. It could link the user to the appropriate code documents"</p> <p>"It could include the building classification summary code sheet with all the specific code requirements"</p> <p>"The code is updated every 3 years"</p> <p>"The code defines space requirements with drawings and clearances as in NFPA 70 and NFPA 72"</p>

**Table 71:** Statements of Interviewees during Tool-based DFCS Implementation

Observed issues or difficulties during tool use were recorded for the two different groups of interviewees as seen in *Table 72*. Such issues as scrolling difficulties were noted. Other issues or features I did not address were also noted. The number of DFCS suggestions and measures identified in the DFCS Toolbox and the DFCS-TIPS application were also noted for each of the interviewees, and these averaged 39.0 and 9.3 respectively. This was a significant difference particularly if one considers that an interviewee in the DFCS Toolbox testing group selected 89 design suggestions while the most DFCS measures selected by an interviewee in the DFCS-TIPS testing interviews was 15. There were a number of reasons for this. Firstly, the DFCS Toolbox presents its over 400 design suggestions in 20 tabs which allowed for viewing a rough average of 20 suggestions per tab for selection. Meanwhile, the DFCS-TIPS application utilizes filtering to only provide DFCS measures that meet selected criteria. Thus, in some cases, only 1 to 3 DFCS measures are provided at a time for selection. This made it more difficult for the interviewees to select as many DFCS measures as in the case of the DFCS Toolbox. In the DFCS-TIPS application, there is the option to utilize no filters and therefore view all the DFCS measures. One may also just specify the AEC design profession and retrieve the DFCS measures accordingly. Secondly, the parameters that were set for DFCS implementation on the hypothetical project essentially insulated the designer from additional liability exposure and other impediments. As such, the interviewees in the DFCS Toolbox testing interviews selected design suggestions that were situated in the construction phase, applicable to other AEC design professionals, and applicable to project features that were not in their forte. Some of their statements indicated this.

	Software Testing Interview	AEC Design Profession	Issues / Difficulties from Observation	Number of DFCS Suggestions / Measures Selected	Average Number of DFCS Suggestions / Measures Selected
1.	DFCS Toolbox	Architect	None observed	27	39.0
2.		Civil/Structural Engineer (PILOT)	Scrolling difficulties on the interface with the DFCS suggestions	13	
3.		Civil/Structural Engineer	None observed	89	
4.		MEP – Electrical Engineer	None observed	27	
1.	DFCS-TIPS	Architect	Difficulty having to scroll both horizontally and vertically when selecting the DFCS measures	15	9.3
2.		Civil/Structural Engineer	Having to re-select the profession and project features over and over again	7	
3.		MEP – Electrical Engineer	He selected one DFCS measure twice and couldn't clear one without clearing all	6	

**Table 72:** Number of DFCS Measures Selected and Issues observed in Tool-based DFCS Implementation

While the DFCS implementation parameters were intended to encourage the interviewees to participate and not to balk at the whole process, it resulted in their relatively indiscriminate selection of design suggestions based on the number provided on the interface. Nevertheless, this did not counter the expected results of DFCS tool availability. With the availability of tools to aid DFCS implementation, more DFCS suggestions or measures were anticipated to be identified and/or selected by the interviewees. As seen in *Table 73*, this was mostly the case. Only 1 interviewee in the DFCS-TIPS testing interviews selected fewer DFCS measures. This was the same interviewee that identified the most DFCS suggestions in the manual implementation interview segment. Thus, the interviewee may have been fatigued at this point. He may also have felt that he had already demonstrated his DFCS expertise and had little need for the aid of a DFCS tool. Ultimately, the average differential between the numbers of DFCS suggestions manually identified by the interviewees and the numbers of DFCS suggestions selected in the software indicated that the DFCS tools aided the DFCS implementation process by addressing designer's lack of safety expertise as an impediment.

	Software Testing Interview	AEC Design Profession	Number of DFCS Suggestions identified in Manual Implementation	Number of DFCS Suggestions selected through Tool-based Implementation	Differential of DFCS Suggestions based on availability of Tool to aid DFCS Implementation	Average Differential of DFCS Suggestions based on availability of Tool to aid DFCS Implementation
1.	DFCS Toolbox	Architect	12	27	+15	+31.5
2.		Civil/Structural Engineer (PILOT)	1	13	+12	
3.		Civil/Structural Engineer	6	89	+83	
4.		MEP – Electrical Engineer	11	27	+16	
1.	DFCS-TIPS	Architect	1	15	+14	+2.3
2.		Civil/Structural Engineer	3	7	+4	
3.		MEP – Electrical Engineer	17	6	-11	

**Table 73:** Differential in Number of DFCS Measures Identified and Selected with availability of DFCS Tools

### Responses to the Post-testing Interview Questions on implementing DFCS on the Hypothetical Project

As earlier stated, the post-testing questions were to serve in assessing the viability and effectiveness of the software as tools that can aid in implementing DFCS on projects. This was also in the interest of identifying potential improvements to the DFCS-TIPS application. *Table 74* provides the responses to the post-testing interview questions.

	POST-TESTING INTERVIEW QUESTIONS	DFCS Toolbox				DFCS-TIPS			OVERALL
1.	How difficult/easy was the identification of design modifications for construction worker safety using the manual method as utilized in this session? [0 = Extremely Difficult; 5 = Neutral; 10 = Extremely Easy]	A	CE (P)	CE	EE	A	CE	EE	2.14 (Average)
		0	0	3	4	1	2	5	
		1.75 (Average)				2.67 (Average)			
	Why?	<ul style="list-style-type: none"><li>- “I don’t have enough information.”</li><li>- “I was not knowledgeable on it.”</li><li>- “It’s hard to think of or remember everything just looking at a plan.”</li><li>- “A little more difficult. More information is better and I had only little information.”</li></ul>				<ul style="list-style-type: none"><li>- “I did not have the information.”</li><li>- “I would need more information.”</li><li>- “It takes someone with experience.”</li></ul>			
2.	Did the software inhibit/improve the DFCS implementation process compared to the manual method as practiced in this experiment? [0 = Extremely Inhibited; 5 = Neutral; 10 = Extremely Improved]	A	CE (P)	CE	EE	A	CE	EE	8.43 (Average)
		10	10	8	8	8	8	7	
		9.00 (Average)				7.67 (Average)			
	Why?	<ul style="list-style-type: none"><li>- “This was in terms of information alone. The software method was not necessarily better. It was about information.”</li><li>- “It gives me suggestions as to what I could do.”</li><li>- “It made me think of things I did not think of. There should be a meeting across the design disciplines. It would be better to have a meeting and decide which to implement.”</li><li>- “It had more information and a few diagrams as well.”</li></ul>				<ul style="list-style-type: none"><li>- “By actually giving examples. The incidents justify selecting the measures.”</li><li>- “It jogs the memory. And, to consider things outside my realm. Some of what I pulled up was intuitive.”</li><li>- “It could be some benefit if more robust or input. A lot more could be added. It needs more content.”</li></ul>			
3.	How difficult/easy was the identification of design modifications for construction worker safety using the software as utilized in this session? [0 = Extremely Difficult; 5 = Neutral; 10 = Extremely Easy]	A	CE (P)	CE	EE	A	CE	EE	7.07 (Average)
		5	7.5	9	7	6	8	7	
		7.13 (Average)				7.00 (Average)			

	POST-TESTING INTERVIEW QUESTIONS	DFCS Toolbox	DFCS-TIPS	OVERALL
	Why?	<ul style="list-style-type: none"> <li>- "I don't think it helps the process. It was more of a checklist. It should be more applicable to a project. It might as well have been in text. It was only useful to remind me of things I could do."</li> <li>- "Some belonged to mechanical and other design disciplines. It would be easier if the extraneous stuff was not there. These are the things that do not pertain to me and things that I have no control over."</li> <li>- "There is just an itemized list to choose from. It's all in front of you."</li> <li>- "Just because it had a lot of information on improving construction safety. Before I was looking at electrical alone. It considers a more holistic approach to cover everyone's expertise."</li> </ul>	<ul style="list-style-type: none"> <li>- "I would like better user interface. It might need human psychiatry design."</li> <li>- "It was easy to use."</li> <li>- "There is not too much to get used to. Just like any other software and understanding what is available."</li> </ul>	
4.	What do you like about the software?	<ul style="list-style-type: none"> <li>- "I didn't really like it. Perhaps, if it was a far more interactive tool rather than just a reminder checklist. I wouldn't have gained anything from the software if familiar with DFCS."</li> <li>- "It was very easy to use. Descriptions and rationale for doing things were pretty straight forward."</li> <li>- "It brings up points I wouldn't have otherwise considered. The interface is easy."</li> <li>- "I like how it produces a specification that you can distribute for the safety of construction work."</li> </ul>	<ul style="list-style-type: none"> <li>- "It allowed me to realize that I had some of the background to do this work. I think you have the skill set. It helped me learn what I already knew."</li> <li>- "It jogs the thought process along the line of construction safety. Though I did not focus on the incidents much. The 'sob stories' are useful to remind us of the importance of the DFCS measures."</li> <li>- "There is a lot of potential. I like that you could build it and personalize it. With more content, it could be useful especially for the inexperienced AEC design professional. It may also point to the right document."</li> </ul>	N/A

	POST-TESTING INTERVIEW QUESTIONS	DFCS Toolbox				DFCS-TIPS			OVERALL
5.	To what extent did the details provided with the DFCS suggestions or modifications help in your selection of which to implement on the project? [0 = Not Helpful; 10 = Extremely Helpful]	A	CE (P)	CE	EE	A	CE	EE	6.43 (Average)
		0	9	7	8	7	8	6	
		6.00 (Average)				7.00 (Average)			
	How?	<ul style="list-style-type: none"><li>- "I think I should have known. The design suggestions seemed general."</li><li>- "Just providing the suggestions. If one became knowledgeable on DFCS, the software would not be useful."</li><li>- "Some of the descriptions were clarified using diagrams. A picture is worth a thousand words. I like the example with the diagram of four building floor stories and a falling worker."</li><li>- "The suggestions themselves."</li></ul>				<ul style="list-style-type: none"><li>- "It goes to features and allows specification by project characteristics. Through the incidents, it emphasized the importance of the measures. I understood the importance."</li><li>- "The measures jog the memory. The details may not help in prioritizing which measures to use."</li><li>- "I see the framework but content is everything. I prioritized which suggestions to utilize based on experience and what seems more pertinent to me."</li></ul>			
6.	Would any additional details on the 'design suggestions' provided by the software be helpful in the selection of DFCS modifications for the project?	<u>Yes</u> (3/4) No (1/4)				Yes (1/3) <u>No</u> (2/3)			N/A
	What details?	<ul style="list-style-type: none"><li>- "I would look for it to provide such information like how much it would cost me. I would need the checks and balances."</li><li>- "There is enough detail. I can look at the design suggestions and decide whether they would be useful or not."</li><li>- "Most of the stuff is cut and dry. There could be more pictorials. There could be videos too. If some of the measures could link you up with code requirements, it may be good too. This would serve to highlight code objectives."</li><li>- "There are only one set of diagrams per category. More diagrams would be better."</li></ul>				<ul style="list-style-type: none"><li>- "I would like more content."</li><li>- "I think you have enough. It only needs to be further fleshed out."</li><li>- "Drawings and diagrams could be useful."</li></ul>			

	POST-TESTING INTERVIEW QUESTIONS	DFCS Toolbox				DFCS-TIPS			OVERALL
7.	Compared to other AEC design software you have used, how do you find using the software? [0 = Extremely Difficult; 5 = Neutral; 10 = Extremely Easy]	A	CE (P)	CE	EE	A	CE	EE	7.80 (Average)
		10	N/A	9	5	7	N/A	8	
		8.00 (Average)				7.50 (Average)			
	Why?	<ul style="list-style-type: none"><li>- "This is compared to using 3D modeling programs. It was more like taking a test."</li><li>- "It is incomparable based on the software I use."</li><li>- "It utilizes a simple checklist and a simple interface."</li><li>- "You still have to do your work in checking off suggestions or codes."</li></ul>				<ul style="list-style-type: none"><li>- "I like all software to be have ease of use."</li><li>- "It only helped me identify limit states. There are none comparable."</li><li>- "It was fairly intuitive."</li></ul>			
8.	Should the software be integrated into other AEC design software such as Building Information Modeling (BIM) tools to enhance its effectiveness and use?	<u>Yes (2/4)</u>  No (1/4)  It should not be forced on. It would be better if the software could be used at the start-up meeting with the whole design team present. It would make my life more difficult with the software already utilized on a project.  <u>Other (1/4)</u>  Only if you can make it utilize such features as clash detection. If it utilizes artificial intelligence to automatically identify which to implement.				<u>Yes (3/3)</u> No (0/3) Other (0/3)			N/A
9.	What recommendations do you have for improving the software?	<ul style="list-style-type: none"><li>- "I would look for it to be more interactive. Perhaps the suggestions can be clicked to be applied in the design drawings and construction documents. I would like to be able to evaluate making the decision to implement the suggestions not just based on interest and morals. Economics come in to play."</li><li>- "I have no specific recommendations. It seems pretty useful at the moment."</li><li>- "You should have the option to say if you are a structural engineer so others disappear. It should have the ability to focus on specific disciplines. It should be adaptable to the project characteristics. If concrete is selected, steel and</li></ul>				<ul style="list-style-type: none"><li>- "The user interface can be better designed. It could start broader in generalities and dial down. If you have categories. Big buttons could be used to explain the categories. Clearly indicate the next buttons. Font sizes could be increased. It makes the DFCS measures easier to find. One may need some hand holding with graphics. You could collaborate with Human Computer Interaction to develop an improved interface design. This is because a bad user interface yields bad information."</li><li>- "Every time I went back, I had to re-enter the</li></ul>			

	POST-TESTING INTERVIEW QUESTIONS	DFCS Toolbox	DFCS-TIPS	OVERALL
		<p>wood should go away. There is a lot of redundancy. These would streamline the process. The checkmarks could be applicable based on your field and role on the project. You could make the font bigger too.</p> <p>I was lost with what to do with Step 1 and Step 2.</p> <p>It should have a save option to use on similar projects instead of reinventing the wheel every time.</p> <p>It should have a savable format to send out to other project participants for editing. It could also have a feature to print and email the selected measures.</p> <p>Maybe it should identify who made the changes with signing plus password capabilities.</p> <p>You want the software to provide suggestions based on when they are to be implemented. A lot of stuff may have to be implemented on Day 1. We must be conscious of when they come into play.</p> <p>I would like somewhere to type up new suggestions if something wasn't already in the software."</p> <p>- "It would be helpful if it was integrated with code or with software such as COMcheck. So, we have one tool with code and safety requirements. It would also be nice if it could pull up state information. It would also be nice if you could enter details of the project, occupancy, and building type. Such as education, wood or masonry building. COMcheck allows you to specify but here, you have to check each suggestion individually. Ability to indicate the project characteristics would be good. It would also be nice to save information that you can go back to later."</p>	<p>information. You could make the text bigger. It has to go into BIM in the future. It has great application. It reminds us of what we could do."</p> <p>- "I already commented. It needs increased content. The incidents could be developed to include code. The DFCS measures could also reference the code document."</p>	
10.	To what extent did the following details help in your selection of 'DFCS suggestions or modifications' for the project (using the DFCS-TIPS software)?			

	POST-TESTING INTERVIEW QUESTIONS	DFCS Toolbox	DFCS-TIPS			OVERALL
a.	Safety incidents considered preventable through implementation of the DFCS suggestions or modifications [0 = Not Helpful; 10 = Extremely Helpful]	N/A	A	CE	EE	N/A
			9	8	3	
			6.67 (Average)			
b.	Potential impediments to implementing the DFCS suggestions or modifications [0 = Not Helpful; 10 = Extremely Helpful]	N/A	A	CE	EE	N/A
			7	8	4	
			6.33 (Average)			
c.	Potential solutions to the impediments of implementing the DFCS suggestions or modifications [0 = Not Helpful; 10 = Extremely Helpful]	N/A	A	CE	EE	N/A
			7	8	4	
			6.33 (Average)			
d.	Tier of Feasibility (Amount of research on the DFCS suggestions or modifications and the level of confidence in the effectiveness of the suggestions) [0 = Not Helpful; 10 = Extremely Helpful]	N/A	A	CE	EE	N/A
			0	8	3	
			3.67 (Average)			

**Table 74:** Responses to the Post-Testing Interview Questions

The responses to Question 1 indicate all interviewees found the manual DFCS implementation process difficult. Only the electrical engineer in the DFCS-TIPS testing interviews indicated neutrality with regards to the difficulty/ease of the process. This was the same design professional that provided the most DFCS suggestions in the process. He noted that it took someone with experience to successfully execute the task. Ultimately, in both the case of the DFCS Toolbox testing interviews and the DFCS-TIPS testing interviews, the interviewees found manual DFCS implementation to be difficult on average and as the reason, they cited lack of DFCS information and/or lack of adequate information through the provided building plans.

The responses to Question 2 also collectively indicate that the design professionals found the software to have improved the DFCS implementation process compared to the manual method. This was even more so in the case of the DFCS Toolbox testing interviewees that provided the average rating of 9.00. However they noted that this was primarily in terms of information alone. One interviewee also noted that the few provided diagrams were useful. In comparison, the DFCS-TIPS testing interviewees provided an average rating of 7.67. Here too, the interviewees indicated that the provided DFCS measures along with their applicable incidents served to improve the DFCS implementation process on the hypothetical project. However, an interviewee also stated that the

software needed to be more robust and have more content. The DFCS-TIPS application utilizes filtering to provide applicable DFCS measures. Thus, when the user selects more input criteria, fewer DFCS measures are provided. This logic-based filtering was expected to improve the DFCS implementation process for users. On the contrary, with filtering, the content was indicated to be lacking. This highlights the cognitive complexity of user behavior. Such interviewees did not seem to be aware of the DFCS measures they were eliminating through the selection of filters. This causal aspect was likely missed.

My expectation was the DFCS-TIPS application would have a higher rating with regards to improving DFCS implementation. This was founded on the assumption of human rationality. However, a decision maker does not always act rationally. According to Tversky and Kahneman (1981), because of imperfections of human perception, changes of perspective often reverse the relative apparent size of objects and the relative desirability of options. Perhaps, the interviewees preferred the less structured nature of the DFCS Toolbox to the more structured nature of the DFCS-TIPS application. However, this does not mean they performed better with the DFCS Toolbox. This is particularly since the interviewees in the DFCS Toolbox testing interviews selected design suggestions that were situated in the construction phase, applicable to other AEC design professionals, and applicable to project features that were not in their forte. These suggestions would either be infeasible to implement or will expose the designer to liability if implemented. The central theme of the expected utility theory of Neumann and Morgenstern (1980) is that a rational decision maker chooses not the highest expected value, but rather the highest expected utility. The highest utility is most expected from the DFCS measures and details provided through the DFCS-TIPS application as these can be more feasibly implemented on actual projects.

The responses to Question 3 indicate that using the software made DFCS implementation easier for all interviewees. The average rating of difficulty/ease for the DFCS Toolbox was 7.13 (easy) while that for the DFCS-TIPS application was 7.00 (easy). These were approximately the same value though that of the former was higher. However, the DFCS Toolbox testing interviewees indicated that it just provided an itemized checklist with DFCS information for the design professional. That it might as well have been in text and not incorporated in software. Besides this, they indicated it that the DFCS Toolbox and design suggestions should be adaptable to project characteristics and to the AEC design profession of the user. An interviewee also appreciated that the DFCS Toolbox had suggestions that pertain to all design disciplines. Additionally, an interviewee indicated that the DFCS suggestions should be situated in project design as some were not in the control of the designer. On the other hand, the DFCS-TIPS testing interviewees indicated that DFCS-TIPS was easy to use and did not require much familiarity to be used effectively. One interviewee however indicated that he always advocates for better user interfaces and as such, he would recommend a better user interface for the DFCS-TIPS application.

If the responses to Question 3 are compared against the responses to Question 1, the increased difficulty or ease that resulted from use of both DFCS tools can be determined. To do this, the ratings in Question 1 were subtracted from the ratings in Question 3. The results are provided in *Table 75*. They individually and cohesively indicated increased ease in implementing DFCS due to the availability of the DFCS tools. At +5.38, the increased ease realized from the use of the DFCS Toolbox is higher than that from the use of the DFCS-TIPS application at +4.33. The reason for this arises from the capabilities and features of the software. In the case of the DFCS Toolbox, it has two main interfaces or screens, thus making it easy to use while lacking several desired features. In the case of the DFCS-TIPS application, it has several main screens and interfaces that have more advanced features. As such, it might not have been found as easy to use due to its more numerous capabilities. The fact that the absence of a feature or capability was not raised in the Question 3 responses serves as an indicator of the value or relative adequacy of the features.

	POST-TESTING INTERVIEW QUESTIONS (Question 3 versus Question 1)	DFCS Toolbox				DFCS-TIPS			OVERALL
	Changes in ease of identification of design modifications for construction worker safety using the software versus using manual method [+ = Increased Ease; - = Increased Difficulty]	A	CE (P)	CE	EE	A	CE	EE	+4.93 (Average)
		+5	+7.5	+6	+3	+5	+6	+2	
		+5.38 (Average)				+4.33 (Average)			

**Table 75:** Change in Ease or Difficulty due to the Availability of the DFCS Tools

Another potential reason for the ratings was that there were two tool-use stages for the interviewees after the 'difficult' manual implementation process. Firstly, they wanted the software to provide DFCS suggestions to aid them in making the safety considerations. Secondly, they wanted to evaluate the DFCS suggestions to determine if they would implement them. The DFCS Toolbox fulfills the first stage faster and easier than the DFCS-TIPS application though not necessarily more effectively. For the second stage, the DFCS Toolbox requires the user to execute it manually and this is tedious as the provided DFCS suggestions are poorly categorized, repeated, and may or may not even be situated in the project design phase. In comparison, the DFCS-TIPS application performs this second stage easier and more effectively. The ratings of the two groups of interviewees may have captured more of the first stage than the second.

The responses to Question 4 with regards to what is liked about the DFCS tools were intended to identify useful features in the software. Specifically, in the case of the DFCS Toolbox, the responses were intended to be evaluated to determine if the 'liked' features could be applied to the DFCS-TIPS application as improvements. That is if they were not already included. The DFCS Toolbox testing interviewees indicated that the interface was easy to understand and use.

They also indicated they appreciated the design suggestions provided by the software. Another interviewee indicated that he liked the ability of the software to produce a printed specification document with the selected DFCS suggestions which could then be distributed to project participants. Meanwhile, one interviewee indicated that he really didn't like the DFCS Toolbox. He stated that the software would not have been of any use to him if he was more familiar with DFCS. He stated that he would have liked if the DFCS Toolbox was more interactive and not just a reminder checklist.

The DFCS-TIPS testing interviewees also indicated that they appreciated the DFCS measures provided by the software. An interviewee also stated that the applicable safety incidents provided with the DFCS measures were also potentially helpful to inform the user of their importance. One interviewee also indicated that he appreciated the fact that it can be built on and personalized. He also indicated that with more content, it could be more useful for the inexperienced design professional. As earlier stated, this 'lack of content' was mostly perceived due to the filtering process. Lastly, an interviewee indicated that the DFCS-TIPS application could also be more helpful if it incorporated code requirements and pointed to the right code documents. This was however beyond the scope of this research. Thus, these potential improvements were not considered feasible. Also, all the 'liked' features about the DFCS Toolbox were already incorporated in the DFCS-TIPS application. It provides DFCS measures, its interface was indicated as being easy to understand and use, it has specification printing capabilities, and it is interactive.

The responses to Question 5 were to indicate the extent to which the details provided with the DFCS suggestions or modifications helped in the selection of which to implement. The DFCS Toolbox testing interviewees provided responses that averaged to 6.00 (helpful) while the DFCS-TIPS testing interviewees provided responses that averaged to 7.00 (helpful). A very notable entry by a DFCS Toolbox testing interviewee was 0 (not helpful). It must be noted that low ratings were anticipated for the DFCS Toolbox. This was because they were not provided with details besides their placement in categories and the single diagram provided in each category. The reasons provided by the DFCS Toolbox testing interviewees as to how the details helped included that the details provided were the DFCS suggestions themselves which served to provide access to knowledge for DFCS implementation. One interviewee indicated that the diagrams also helped as some of the DFCS suggestions were clarified through them. Lastly, a different interviewee indicated that if the design professional or user was knowledgeable on DFCS, the DFCS Toolbox would not be useful.

Meanwhile, the DFCS-TIPS testing interviewees provided ratings indicating that the details were generally helpful. As to how the details helped, the interviewees identified that the characterization by project features was helpful while the provided safety incidents served to emphasize the importance of the DFCS

measures. Here too, the details provided in terms of the DFCS measures themselves were indicated as helpful in jogging the memory and in providing safety knowledge. However, one interviewee indicated that the details, such as applicable safety incidents, would not help in prioritizing which measures to use. Another interviewee indicated that he prioritized which DFCS measures to implement based on experience and what seemed pertinent to him. This was contrary to my expectations as I had anticipated this would be the purpose. Instead, the safety incidents, impediments and other details just served as indicators of the importance and implications of the DFCS measures. Nonetheless, the value of the details was not diminished. Another interviewee indicated the DFCS-TIPS application needed more details but in terms of content. As earlier stated, this was a perception that arose due to the filtering process of the DFCS-TIPS application which provides DFCS measures based on the users' inputs or selected criteria.

As the diagrams in the DFCS Toolbox were identified as helpful, they were considered as potential improvements to be included in the DFCS-TIPS application. This was however determined to be infeasible. Even in the case of the DFCS Toolbox, there was only one diagram per category of design suggestions, adding up to a total of 20 diagrams. 20 out of the 430 design suggestions correspond to 4.7%. This was very likely due to scope as the research that developed the DFCS Toolbox was primarily concerned with developing design suggestions for construction worker safety (Gambatese et al, 1997). 212 DFCS measures were included in the DFCS-TIPS application. Even if the 20 diagrams from the DFCS Toolbox were considered applicable and utilized, there would need to be diagrams for 192 DFCS measures. These diagrams would have to be developed through research and validated. And, it would not have been within my capability to draw a majority of the diagrams. As such, I would have required AEC design professionals to first develop the diagrams. This would have proved very difficult. And given the scope, developing the diagrams by itself constitutes a research project. Additionally, utilizing the approach of the DFCS Toolbox where one diagram is placed in each category was inapplicable. This was because filtering would determine whether or not the diagram in each category would appear. A lesser potential reason why the study by Gambatese et al (1997) did not develop diagrams for all the DFCS suggestions could have been that not all the suggestions could be adequately represented in single or in simple diagrams. Additionally, some diagrams may require constant redesigning to represent the design suggestion and be applicable to different project scenarios, thus diminishing their value. Ultimately, the development of diagrams for each DFCS measure was categorized as a recommendation for future research.

In response to Question 6 which asked if any additional details on the 'design suggestions' provided by the software would be helpful in the selection of DFCS modifications for the project, 3 out of 4 of the DFCS Toolbox testing interviewees answered "Yes". This was expected as it was mostly a checklist of design

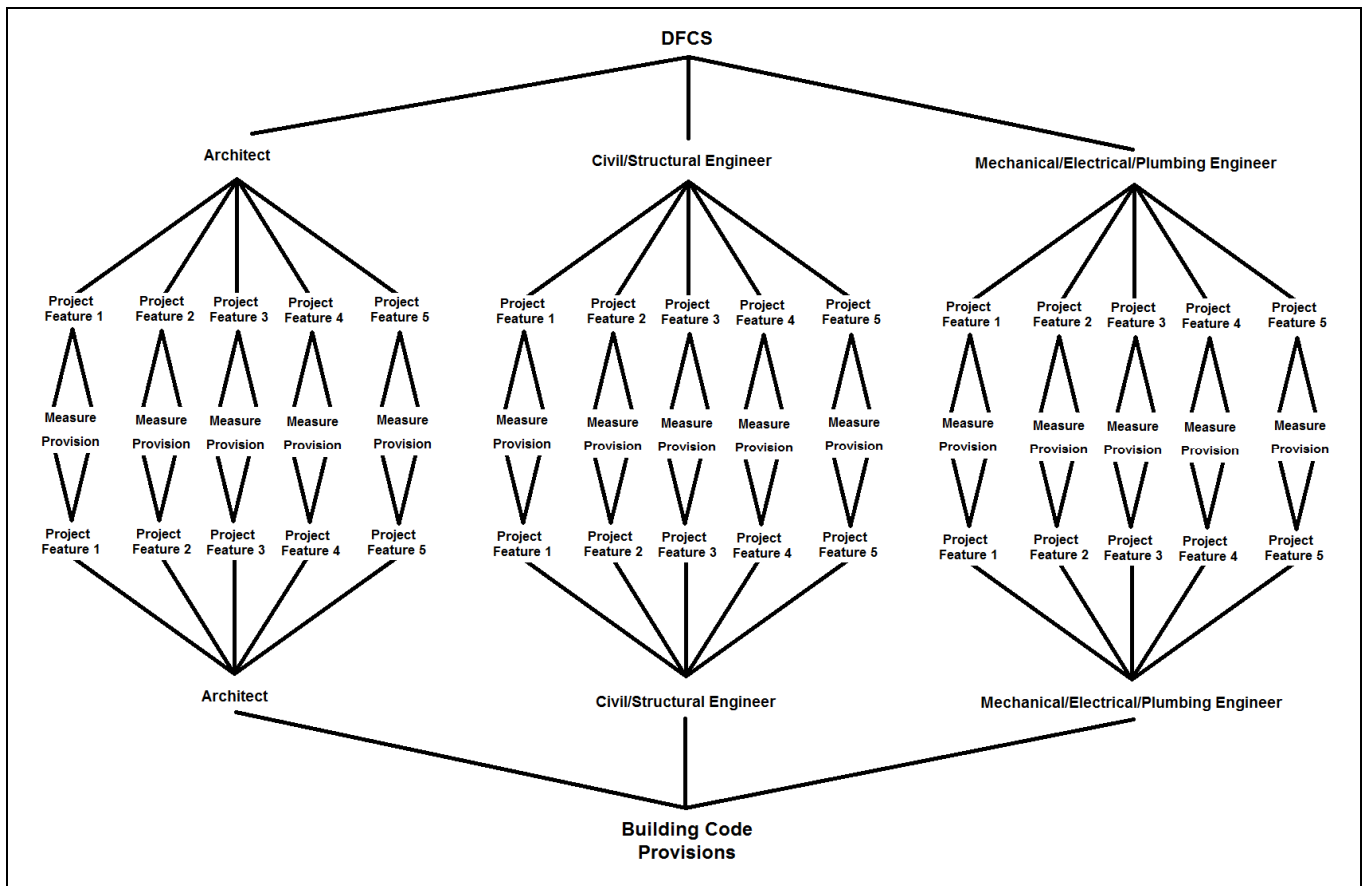
suggestions without accompanying details. When asked about the additional details, one indicated that checks and balances such as cost implications would be helpful. Two interviewees indicated that more diagrams and pictorials would be helpful as opposed to just one diagram per category. One of these interviewees indicated that videos could also prove helpful. He also indicated that if the DFCS measures could link the user to code requirements so as to be able to highlight code objectives while integrating the DFCS process with code checking, it would prove very helpful. The interviewee who indicated that no additional details were needed stated that there was enough detail as he could evaluate each DFCS suggestion and determine whether it would be useful and whether he would implement it. The response of the interviewee that checks and balances be included indicates the value of such details in the DFCS-TIPS application which provides the preventable safety incidents from implementation of the DFCS measures in addition to their impediments such as increased cost.

Meanwhile, in response to Question 6, 2 out of 3 of the DFCS-TIPS testing interviewees answered “No”. This was anticipated as all the DFCS measures provided such details as applicable safety incidents, potential impediments, and potential solutions to the impediments. This is particularly as compared to the DFCS Toolbox. When asked about the additional details, two interviewees indicated that it would only need more detail in terms of content. Once again, the filtering mechanism made it appear to them as though they were far fewer DFCS measures than actually included in the DFCS-TIPS application. Lastly, the interviewee that indicated additional details would be helpful identified drawings and diagrams as the additional details. The issue of diagrams was earlier discussed and found to be a research project of significant scope. As such, the development and incorporation of diagrams was considered infeasible, for the DFCS-TIPS application, in this research. The development of videos also falls in this category. Several considerations would have to be made such as what the videos would depict. Would they depict the angular views of the DFCS features, how the DFCS measures could prevent safety incidents, how the DFCS features are designed, or how the DFCS features were constructed? How long should the videos be? DFCS is still an emerging area. As such, projects where a multitude of DFCS measures were utilized would be difficult to locate or identify. In all likelihood, it may turn out to be more feasible to develop them in an experimental setting and then record the desired videos. Optionally and perhaps more easily, 3D and 2D animation may be used in place of the videos. Nonetheless, the development of the videos for each DFCS suggestion would likely prove even more tedious than the development of diagrams. As such, it too was infeasible. It was also categorized as a recommendation for future research. Another issue to consider is how the inclusion of diagrams and videos may impact a DFCS tool. It would likely make the tool very robust and with significant complexity. The software user who just wants access to a few brief details may find the tool to be complicated and tedious to use. And given that DFCS is not mandatory and is performance-based, he/she may easily lose interest.

With regards to building code requirements, it became a recurring theme that integrating the DFCS tools with code requirements could prove helpful. Overwhelming evidence suggested design professionals want to know how the tool can aid in their adherence to building codes. In the earlier research tasks, many research participants indicated that they found meeting building codes to be an inconvenience in their design process. Building codes are mandatory and mostly prescriptive-based. Non-adherence results in code violations which mean fines and legal costs. As noted by some interviewees, there were essentially no tools available to aid adherence to code besides checklists. A new dimension to improving and increasing DFCS implementation was identified. This was through the development of a tool that integrates building codes which are intended for occupant safety and maintenance worker safety with DFCS measures which are intended for construction worker safety to become a 'project safety' tool. As DFCS is not mandatory, it would likely be most effective if DFCS measures are linked to building codes and DFCS tools would more likely be used if they can aid in adhering to building codes.

The 'project safety' tool could provide DFCS measures based on the design profession, project features and/or stage of design phase as used in the DFCS-TIPS application. Alongside the DFCS measures would be related building code provisions with links to the sourced code document. The 'project safety' tool could also offer two points of access with one from the DFCS end and the other from the building code provisions end. If accessed from the building code end, it could then provide the building code provisions but with the related DFCS measures alongside. *Figure 63* provides the framework or structure of the proposed project safety tool. This however assumes the building code end is organized but it is not. Different elements are interconnected and code provisions are neither uniform nor static. This is as they are constantly being updated. They also differ by states and municipalities (ERDC, 2001). Many are inadvertently replicated as they are written differently. This in itself is a significant contributor to the intractable field of building code provisions. As a matter of fact, code writing appears to be more critical than the nature of the codes themselves. A study by Demir et al (2010) indicates that the users of engineering codes and standards are yet to benefit from the advanced processing and reasoning capabilities of web technologies and information systems partially due to the difficulty of finding appropriate syntaxes to represent the standards. These syntaxes are required to be easily understood and able to be processed by a computer, and also need to be testable and maintainable by standards writing organizations. Recent research developments are attempting to address the underlying issues with regards to vocabulary and code logic. Research by Demir et al (2010) is intended to eventually develop a tool for code writing to address overlaps. This and other research are ultimately to serve towards enabling the development of effective tools to aid the users of codes in identifying applicable code provisions and complying with them.

Given the nature of building code provisions and the current state of research in the development of tools to aid code compliance, it was infeasible to incorporate building code provisions in the DFCS-TIPS application as a potential improvement in this research. This was thus categorized as a recommendation for future research. It is also an important research finding that the adoption and implementation of DFCS would more likely increase if DFCS measures are linked to building codes, and the utilization of DFCS tools would more likely increase if they could also aid in complying or adhering to building codes.



**Figure 63:** Structure of the Proposed Project Safety Tool to Incorporate DFCS and Building Code Provisions

The responses to Question 7 in *Table 74*, with regards to difficulty or ease of use of the DFCS tools relative to other AEC design software, indicated ease of use on average. In both the DFCS Toolbox testing interviews and the DFCS-TIPS testing interviews, one interviewee provided a rating of N/A (not applicable). The averages were determined only based on those that provided ratings. The DFCS Toolbox testing interviewees provided an average rating of 8.00 (easy), while the DFCS-TIPS testing interviewees provided an average rating of 7.50 (easy). These did not differ significantly. The reasons for the rating provided by the DFCS Toolbox testing interviewees included that it utilizes a simple checklist and interface. And as compared to using 3D modeling software, this was easy. They also indicated that one would still have to go through the suggestions on the checklists. The interviewee that provided the N/A response stated that the DFCS

Toolbox was incomparable based on the software he used. As for the reasons provided by the DFCS-TIPS testing interviewees, they indicated that it was fairly intuitive and easy to use. The interviewee that provided an N/A response in this instance indicated that the DFCS-TIPS application only helped him identify limit states and he had not used any comparable AEC design software to it. The higher rating of ease in the case of the DFCS Toolbox was anticipated. As earlier stated, it has two main interfaces or screens, thus making it easy to use while lacking several desired features. This is as compared to the DFCS-TIPS application with its several screens and interfaces that have more advanced features that could make it relatively less easy to use.

Question 8 asked if the DFCS tools should be integrated into other AEC design software such as Building Information Modeling (BIM) tools to enhance their effectiveness and use. The responses of the four DFCS Toolbox testing interviewees varied. Two interviewees answered “Yes”. One interviewee answered “Other”. He then specified that only if it could be made to utilize such features as clash detection. And, only if it utilizes artificial intelligence to automatically identify which to implement. Essentially, this interviewee would only support such a development if it offered very advanced capabilities. One interviewee also responded “No”. He indicated that the DFCS Toolbox was adequate and he encouraged its use in the presence of the whole design team at the project start-up meeting. He also indicated that such a development would make his work more difficult given the software already utilized on his projects. This seems to highlight the competing priorities in project design. The design professional has to focus on design, meeting client requirements, accommodating structural and mechanical systems, minimizing project cost and schedule implications, aesthetics, meeting code requirements, and so on. During project design, he/she may need to use different software already. Having to use additional software with the complexity and features of BIM would likely be unwelcome. However, it must be noted that integrating the DFCS tools in BIM software would not necessarily require separate software. It could simply be a toolbar incorporated in such AEC software as Autodesk REVIT. When the user selects or specifies a project feature, the DFCS tool could indicate safe or unsafe locations to place the feature or indicate safe or unsafe sizes of the feature. The safer features and DFCS measures could even be visually applied automatically. It could request further details where necessary. It could also provide reports on the DFCS measures implemented while having the ability to incorporate the details in the construction documents. This is all while having the desirable features of both the DFCS Toolbox and the DFCS-TIPS application. The user should have the function to activate and to deactivate the DFCS toolbar. This hypothetical DFCS BIM tool should not require for changing the manner of use of the AEC design software it is incorporated in. It could thus be an additional optional capability. Such a tool would address the concerns of the interviewees that responded “Other” and “No” to Question 8. It must however be noted that its development in this research was infeasible. This would have required understanding the BIM software and their coding, then incorporating new

programming in the software. This then would be followed by incorporating the DFCS measures and software functionalities, and also creating the visual representations in the building information modeling software. This would require significant research work far surpassing the development of diagrams for each DFCS suggestion that was earlier discussed. Question 8 was only intended to identify if integrating DFCS tools with AEC design software such as BIM could potentially add value. All three DFCS-TIPS testing interviewees indicated that it could. Collectively the interviewees indicated that it could add value as earlier research by Ku and Mills (2010) suggested.

The responses to Question 9 were the recommendations for improving the DFCS software. For the DFCS Toolbox, the interviewees made recommendations such as more interactivity to include adaptability to AEC design profession, adaptability to project characteristics, and characterization by stage of the design phase. Other recommendations include interface improvements for clarity such as increased font size. Another recommendation was the inclusion of more details on the DFCS suggestions. Interviewees also recommended such capabilities as the ability to save selected DFCS suggestions for use on multiple and/or similar projects along with the capability to save project data. Other recommendations include the ability to personalize the DFCS Toolbox by inclusion of new DFCS suggestions and the capability to control access on an organization-level through passwords. Lastly, the interviewees recommended the integration of the DFCS Toolbox with code software so there is one tool that incorporates code provisions and DFCS suggestions. Among these recommendations were those that validated the functionalities of the DFCS-TIPS application as it already incorporated those particular proposed improvements. There were also proposed improvements that pertained to the DFCS Toolbox interface and as such, were not to be considered for the DFCS-TIPS application. Then, there were proposed improvements that were beyond the research scope such as the recommendation to integrate the DFCS Toolbox with code requirements. And then, there were proposed improvements that could apply to the DFCS-TIPS application. These were to be evaluated with regards to their feasibility.

On the other hand, for the DFCS-TIPS application, the interviewees made recommendations such as improved user interface and graphics for clarity through the use of big buttons and larger font sizes. Another recommendation was increasing the content in the DFCS-TIPS database. The interviewees also recommended the capability to store input criteria. They also recommended the incorporation of the DFCS-TIPS application in BIM. And lastly, the interviewees recommended the integration of the DFCS-TIPS application with code software so there is one tool that incorporates code provisions and DFCS measures. This integrated software was also recommended to have the ability to reference code documents. Among these recommendations were those beyond the research scope such as incorporating the DFCS-TIPS application in BIM, integrating the application with code software, and also, increasing the content of the DFCS-TIPS database. The remaining were potential improvements that apply to the

DFCS-TIPS application and interface. Accordingly, these were to be evaluated with regards to their feasibility.

Question 10 in *Table 74* collected responses on the helpfulness of the details provided with the DFCS measures in the DFCS-TIPS application. As such, this question was only applicable to the DFCS-TIPS testing interviews. For the safety incidents, potential impediments to implementation, potential solutions to the impediments, and tier of feasibility, average ratings of 6.67 (helpful), 6.33 (helpful), 6.33 (helpful), and 3.67 (not too helpful) were provided respectively. The rating was particularly low for the “Tier of Feasibility” because the architect indicated that it was of no use as he would rather determine the feasibility of implementing DFCS measures by himself. He thus rated it 0 (not helpful). He actually stated that some design professionals might resent being provided with indicators of feasibility on their own projects. I could understand the low rating as the “Tier of Feasibility” was not emphasized in the DFCS-TIPS application and during the interview. There is a tab/section that discusses the matter on the ‘Using the DFCS-TIPS Application’ screen and it is specified in the columns adjacent to the DFCS measures though not as boldly. The “Tier of Feasibility” was primarily developed to define the research results as not all DFCS measures were subjected to as many research tasks or yielded certain results through the research tasks. This was included primarily because of its relevance to my research. The ratings for the potential impediments and potential solutions to the impediments were identical, as expected, since they complement one another. The applicable safety incidents had the highest rating as expected since they provided an indication of the value or importance of the DFCS measures. Additionally, it must be noted that across the board, the MEP – electrical engineer mostly provided low or the lowest ratings. This was the same interviewee that provided the most design suggestions in the manual implementation interview segment. His low ratings seem to be associated with his level of safety expertise and experience which better enable him to evaluate DFCS measures without as much need for accompanying details. The overall average of the Question 10 ratings is 5.75 (helpful) indicating that the details developed through this research aided the DFCS implementation process.

Conclusively, the DFCS-TIPS application was determined to be a viable tool to aid and improve DFCS implementation. However, this was also the case for the DFCS Toolbox. The hypothesis was that the DFCS Toolbox is much less structured than the DFCS-TIPS application and was therefore likely to have been considered less effective and be less preferred. Essentially, the more refined application was expected to be superior. As it turned out from the interview responses, this was only partially true.

The interviewees found the DFCS Toolbox to improve the DFCS implementation process more than the DFCS-TIPS application when compared to the manual method. The interviewees also found it slightly easier to identify design modifications for construction worker safety using the DFCS Toolbox than the

DFCS-TIPS application. And, the interviewees found using the DFCS Toolbox to be easier than using the DFCS-TIPS application as compared to other AEC design software they had used. In all cases where ease was a factor, the DFCS Toolbox had more positive results. Additionally, there was no situation where increased content was cited as necessary to enhance the software. This is as compared to the DFCS-TIPS application where invisible content gave the users the perception that there were only few DFCS measures in its database. There was a high likelihood that the users found the unstructured and relatively simple user interface of the DFCS Toolbox to be easier to use and preferred it because they could impose their structure on it since it is essentially a categorized set of checklists.

Regardless, the DFCS-TIPS application was developed to be without the inadequacies of existing tools including the DFCS Toolbox. And in all cases where the details provided by the two DFCS tools were evaluated, the DFCS-TIPS application had higher ratings or more positive responses. This meant the details provided by the DFCS-TIPS application were found to be more adequate than those provided by the DFCS Toolbox. When the interviewees were asked what they liked about the software, the focus for the DFCS Toolbox was only on the provided DFCS suggestions. And in the case of the DFCS-TIPS application, the focus was on not only the DFCS measures but their accompanying details and also the software capabilities. And when asked to what extent the details provided with the DFCS measures aided in their selection, the rating for the DFCS-TIPS application was higher. Furthermore, when asked if any additional details on the DFCS measures would be helpful in their selection, majority of the interviewees answered in the negative for the DFCS-TIPS application while majority answered in the positive for the DFCS Toolbox. And several of the recommended additional details and other recommendations provided for improving the DFCS Toolbox were already incorporated in the DFCS-TIPS application. Lastly, when it's provided details including the safety incidents, potential impediments, potential solutions to impediments, and tier of feasibility were collectively considered, they had a rating that indicated they were helpful in the selection of which DFCS measures to implement.

Hence, when it came to questions concerning ease of use, the DFCS Toolbox was rated higher but when it came to questions on details, the DFCS-TIPS application rated higher. And when the additional details to enhance the DFCS Toolbox were collected, most were found to have already been incorporated in the DFCS-TIPS application. Thus, there appears to be a tradeoff between ease of use and the possession of certain DFCS tool inadequacies. For a DFCS tool to possess fewer inadequacies of existing tools, it must likely be less easy or more difficult to use. As the DFCS-TIPS application was developed to be without the inadequacies of existing tools, this tradeoff was considered acceptable. After all, the difference in ease of use between the DFCS Toolbox and the DFCS-TIPS application was not significant in most cases.

## Interviewee Commentary on DFCS and Discussion

At the last page of the interview guide is the question; “Do you have any general comments on DFCS?” This section presents the interviewees’ responses as categorized based on the topics addressed. There is also a brief discussion with regards to the matters raised.

### 1. Potential exposure to liability is the main deterrent to DFCS implementation.

- “For me, the issue of liability constitutes 80% of the obstacles to DFCS.”
- “To further protect ourselves from liability, we even include a note that states that we, as structural engineers, are not responsible for the stability of the structure until it is complete. We no longer approve shop drawings. For increased protection, we state that we only review for general conformance.”
- “The big question is does it affect our liability? As long as it does not add liability, I would be willing to implement DFCS.”
- “I believe the direction I am given is not to be involved in construction safety.”

These commentaries highlight the fact that exposure to liability is the most significant barrier to DFCS (Gambatese et al, 2005). An interviewee indicated it accounted for up to 80% of the obstacles to DFCS. Many design professionals are thus directed to not be involved in construction safety. Additionally, the fact that some structural engineers go through such great lengths to avoid exposure to liability from construction site hazards seems to suggest that their voluntary adoption of DFCS would require significant effort. Potential solutions to address this barrier include revised contract language and legislation to facilitate DFCS without shifting liability to designers (Toole, 2005). A more immediate solution is the implementation of design measures for construction safety that pertain to permanent project features and are fully situated in the project design phase.

### 2. Design professionals may be unwilling to implement DFCS due to the nature of their insurance programs and by advice of the insurance companies.

- “Attending an insurance seminar causes a discount in our insurance costs. And they specify that we should not be involved in construction worker safety. Though we need to be responsible for each other, I don’t think designers could be participatory.”

- “Personal liability insurance does not cover for it. We expect the contractor to take care of construction worker safety.”

These commentaries highlight the fact that the insurance policies of design firms typically do not cover for DFCS implementation as construction safety is considered the exclusive realm of the contractor. As such, designers may not be able to be involved without being concerned about the liability implications. As an interviewee noted, they are incentivized to attend insurance seminars and at such seminars, they are continually advised to not be involved in construction worker safety. Overcoming such issues would likely prove difficult. If involved, designers may experience increased costs in the form of insurance premiums due to DFCS implementation (Toole, 2005). If designers begin explicitly attempting to contribute to worker safety, plaintiff lawyers may claim designers are at least partially responsible for preventing worker injuries (Toole, 2005). Insurance carriers providing designers with liability insurance could legitimately increase their premiums to cover increased costs associated with defending lawsuits against the designers. Cost increases associated with DFCS implementation may ultimately require design firms and designers to increase their professional fees. This would in turn make them less competitive with those still utilizing the traditional design process without DFCS implementation (Toole, 2005).

On the other hand, the costs of litigation and lawsuits are another motivating factor for improving construction safety that applies to all project participants. In event of an injury incident, there is typically buck-passing among all project participants where each attempts to avoid liability. Expectedly, all parties incur some legal costs. Furthermore, these court cases may prove time-intensive. The only sure way of reducing potential liability of all parties for worker injuries is by reducing the frequency and severity of construction injuries (Levitt and Samelson, 1993). And, where accident rates are lower, insurance programs will be less costly for all project participants (Toole et al, 2006). Additionally, a proposed solution to addressing the matter of increased insurance premiums is to engage insurance experts to assist in developing insurance policies that protect designers from excessive legal liability for incorporating safety features in their designs (Gambatese et al, 2005).

3. DFCS can be considered for implementation if it also addresses occupant safety alongside construction worker safety.
  - “Our focus is on occupant safety. Construction workers use these things before occupant safety is established. Perhaps if they can be mixed then it could be considered for implementation.”

This commentary emphasizes the fact that design professionals are primarily concerned with occupant safety. It is their responsibility and it is also mandatory by building code provisions. Hence, DFCS measures that not only improve the safety of construction workers but that of occupants are more likely to be implemented by design professionals. This is a valid point.

4. The AEC industry is resistant to change. As such, DFCS is likely to be opposed and/or its adoption is likely to be very slow.

- “Like a lot of things in the industry, good luck making change. The AEC industry moves at a glacial pace. It is exceedingly resistant to change. It was only in the case of adopting AEC design software that this occurred. This was primarily between 1995 and 1998.”

The AEC industry is resistant to change. As an interviewee noted, it was only in the case of AEC design software use that change was not just adopted but quickly adopted. And this was mostly in the interest of efficiency and cost-effectiveness as it meant that drafting and editing became easier, faster and more effectively done. Hence, it offered a competitive advantage. Perhaps if DFCS offered a competitive advantage, it too would be widely adopted.

As noted by earlier research, DFCS may provide a marketing advantage. Design professionals who choose to implement DFCS could market themselves as progressive, team-oriented professionals (Toole et al, 2006). Additionally, key project participants typically incur legal costs in event of injury incidents. And the only sure way of reducing such costs and the potential liability of all parties is by reducing the frequency and severity of construction injuries (Levitt and Samelson, 1993). This is the goal of DFCS. Insurance programs are also less costly where accident rates are lower (Toole et al, 2006). With less costs, design firms could utilize the savings in gaining competitive advantages through such acquisitions as advanced software and modeling equipment. Construction companies could also use the cost savings in gaining competitive advantages.

5. DFCS can be considered for implementation depending on budget and time constraints and the cost implications of implementation.

- “We have a limited budget and unless we have the time and cost allowance, we may not consider implementing DFCS.”

This commentary highlights two impediments of DFCS, increased cost, and schedule problems and time constraints. Certain DFCS measures have significant cost and/or time implications. Several

others have minimal cost and time implications. These can be considered for implementation when there are significant budget and time constraints. This commentary also emphasizes the fact that the project owner could play a significant role in the diffusion and implementation of DFCS. This is by requiring DFCS on his/her projects and by making cost and schedule provisions to allow for its implementation.

6. Construction worker safety can be considered when the client specifies it or after other project priorities have been addressed.

- “Project priorities are client driven.”
- “Some project owners, particularly institutions, have safety standards for the contractor to adhere to. In one instance, our insurance company insisted on reviewing and approving the owner’s prescribed safety policies.”
- “Construction safety is not at the top of the list in the design phase.”
- “If someone was breathing down my neck or if the project size justified it, I could consider DFCS implementation.”
- “As for project schedule, it is up to the contractor to decide number of workers and number of shifts as necessary for project completion.”
- “Aesthetics are a concern because when people are not happy, they will let you know.”

Project owners or clients can profoundly impact construction safety (Huang, 2003). However, this is primarily when they identify it as a project priority. Project owners such as universities usually have safety standards that they provide to design professionals and contractors as well. These usually include regulatory and code requirements in addition to other guidelines expected to result in safer projects for occupants, maintenance workers, construction workers, and the public. If these safety standards were to include DFCS measures, the measures would be required for implementation and the design professional would be protected from liability. However, as an interviewee noted, the design firms’ insurance companies can evaluate the standards and advise against certain aspects. This could then require revised contractual agreements and other complications that may be unwelcome by the client. But this will likely be a rare occurrence for as the saying goes, the client is king.

Where the owner does not specify construction worker safety as a project priority, it will likely not be considered till after other project criteria have been addressed if at all. One interviewee indicated that he would consider construction safety before considering project schedule while another indicated he would consider aesthetics before he considered construction safety.

7. DFCS involves making tradeoffs particularly cost tradeoffs. It can thus be implemented if found to be feasible.

- “We mostly make modifications to projects in the interest of minimizing cost.”
- “For me, it is dollars first then construction safety.”
- “My decision on the measures to implement will not be based solely on safety.”
- “My decision will not ultimately be based on safety.”
- “And if there is a cheaper way to design but more dangerous. Who is to decide the tradeoff?”

These commentaries indicated that project cost takes priority over construction safety in project design. Furthermore, the decision on which DFCS measures to implement was indicated not to be solely based on the improved safety they could provide but on other factors. Such factors could include the cost and schedule implications along with implications on project form and function. It is up to the design professional to decide the tradeoffs as they must not compromise the value of the project.

8. Design professionals would require more safety expertise to successfully implement DFCS.

- “I would prefer to implement DFCS with someone else’s knowledge or input.”
- “I would like to think a lot is common sense but I don’t think it is.”
- “It is relatively new to me.”

Designers’ lack of safety expertise is a critical impediment to DFCS. This is as emphasized by an interviewee who indicated that he would prefer to use the DFCS knowledge of a more experienced designer to assist in the process. As DFCS is still an emerging area, many design professionals are not as familiar with it. And while some DFCS measures may be relatively simple in their design, others are more complex and would require specific safety expertise. This further highlights the need for effective guidelines and tools to aid DFCS implementation.

9. DFCS should be considered for implementation and adoption.

- “DFCS could be helpful for both the design and construction side. It can help guide us in the right direction.”
- “DFCS should be considered more. It’s good to consider more things outside your environment.”

- “I think DFCS is interesting. I like it.”
- “I believe DFCS is a good idea.”

These commentaries are indicative of support for the DFCS concept and/or support for enhancing the safety of construction workers. An interviewee indicated that DFCS could serve as a guide towards meeting moral, professional, and ethical obligations in protecting and improving the safety of all. An interviewee also noted that DFCS enables addressing construction safety from the design angle and not just from the construction angle as was traditionally the case. This is essentially the basis of DFCS.

10. DFCS will be more accepted for implementation in projects where there is an established safety culture.

- “I work on large scale laboratory facilities and there is an established safety culture on such projects.”

This is an interesting commentary. Projects that place an emphasis on safety during the operations phase seem more likely to adopt DFCS. Such types of projects may include nuclear facilities, laboratories, and industrial facilities. For such projects, any element that could improve safety regardless of project phase is more likely to be considered. The respective project owners are also more likely to make cost and schedule provisions to allow for such safety considerations.

11. Safety consultants are mostly involved with mandatory hazardous material abatement and not construction safety and DFCS.

- “I have worked with a safety consultant but it was focused primarily on asbestos removal and abatement.”
- “I have worked with a safety consultant during the design phase but not to establish construction safety parameters. It was more about hazardous material and its abatement. This was particularly with regards to asbestos. We identified materials and specifications for dealing with it.”

As noted by the interviewees, safety consultants are engaged mostly with regards to asbestos, lead and other hazardous materials. These are mandatory issues to address or abate. This is likely why there is cost justification for engaging the consultants. Currently, as DFCS is not mandatory, safety consultants are not likely to specialize in DFCS. However, with increased adoption and implementation of DFCS, this would change. Prime candidates for the consultant position are likely to be design professionals that are employed or contracted by construction companies, particularly those that are safety directors. Such professionals would likely have the knowledge base to serve as DFCS consultants.

12. With more construction safety education, designers will be better able to implement DFCS with or without tools.

- “Constructability would be very useful as a learning tool. DFCS could probably become second nature for design professionals. Once it does, the software may not be useful.”
- “Cost is taught in civil engineering and now, sustainability.”

These commentaries indicate that safety education is necessary to enable design professionals implement DFCS successfully. As earlier stated, designers’ lack of safety expertise is a critical impediment to DFCS implementation. To address this impediment, DFCS guidelines and tools were developed. Hence, when design professionals become accustomed to DFCS implementation, the tools may not be of much benefit.

A benefit of constructability is improved construction safety (Gambatese et al, 2007). If professional courses and educational curricula place an emphasis on construction safety under the realm of constructability, this would serve as a useful learning tool for design professionals on DFCS. This is as noted by an interviewee. Another interviewee indicated that cost management and value engineering were the relevant topics for a time, and now it is sustainability. Courses were offered accordingly. If DFCS gains more ground, courses on it would likely be offered as well.

13. Certain DFCS measures are already common practice.

- “There are DFCS measures that are already common practice.”
- “Use of metal deck is now standard industry practice.”

These commentaries indicate the feasibility of implementing DFCS in the current construction and contractual environment. Certain DFCS measures have become common practice. Such DFCS measures provide for safer, cheaper and faster construction than traditional, and hence they became industry practice. It is however important to note that safety was mostly an added benefit.

14. Construction safety will most likely be improved with more automation.

- “The more automated they can make the construction process, the better. There was the case of a building in Japan that was robotically constructed in its entirety. The ATLSS connection was designed for such a purpose. This will get rid of high risk jobs.”

This commentary is very valid. Increased automation is most likely to improve construction safety, far more than DFCS. This is because automated construction technologies can assemble

certain project components and systems with little or no use of construction workers. Thus, the risk of worker injuries and/or fatalities during construction could actually be eliminated. Where no workers are involved, there are no worker safety risks, and where there are no safety risks, one only needs to design for automated construction and not at all for construction safety. ATLSS beam-to-column connections are uniquely designed to possess the capability of being erected by automated construction techniques as well as manually. Thus, they are an example of structural systems intended for automated construction.

15. Certain DFCS measures address safety hazards of lesser risk.

- “There are more accidents associated with tilt-ups than with masonry.”

This commentary indicated that certain hazards are riskier than others. Where the riskier hazards can be mitigated through design, they should be mitigated. And where they can't be mitigated through design but only through construction means and methods, they should be avoided as they are part of contractor responsibilities. They will therefore expose the design professional to liability if he/she specifies them. This is also the case with tilt-ups which are a type of building and construction technique. Meanwhile, there are several design-phase DFCS measures that are applicable to masonry design.

16. Certain project delivery methods may better allow for safety consideration and DFCS implementation.

- “I am usually based on small scale. Our projects are mostly design-build. We give the contractors a lot of freedom. We don't push for speed at the expense of risk.”

This commentary emphasized that the design-build project delivery method offers more opportunity and fewer barriers for DFCS implementation. This is due to the fact that liability for worker safety would apply to both the contractor and the design professional. And this is typically whether or not they are employees of the same company.

The interviewee also indicated that construction safety takes a higher priority in his projects than schedule. And given that they are mostly design-build projects with non-stringent owners, he has the ability to make significant schedule provisions. And with regards to being based on small scale, familiarity with the few construction workers that work on his projects likely made him value their safety more. This in turn seems to have made him very supportive of the DFCS concept.

17. There are currently few available tools to aid in adherence to code and regulatory requirements.

- “There is no code software. The closest to it is COMcheck. But it is not for the design phase.”
- “OSHA essentially utilizes a checklist for meeting its requirements.”

Demir et al (2010) indicate that the users of engineering codes and standards are yet to benefit from the advanced processing and reasoning capabilities of web technologies and information systems partially due to the difficulty of finding appropriate syntaxes to represent the standards. And to further exacerbate the situation, code provisions are neither uniform nor static as they are constantly being updated. They also differ by states and municipalities (ERDC, 2001). As an interviewee noted, the closest to code software is COMcheck but it is not for the design phase. The COMcheck software simplifies energy code compliance by offering a flexible computer-based alternative to manual calculations.

When it comes to OSHA, there are products for compliance assistance which are essentially training tools that visualize how certain OSHA standards could prevent injuries to construction workers. Contractors use checklists to ascertain if requirements have been met. Short of artificial intelligence performing this task, site observation and use of checklists may currently be the most practical approach to checking and assuring OSHA compliance.

### **Interviewee Commentary on Interview and Study**

At the last page of the interview guide is the question; “Do you have any general comments on the interview or study?” This section presents the interviewees’ responses as categorized based on the topics addressed. There is also a brief discussion with regards to the matters raised.

1. The interview was identified as being professionally conducted.

- “The interview was fine.”
- “I think the interview is worthwhile. It was pretty straightforward.”
- “It was well thought out.”
- “The interviewer was professional.”

These commentaries indicate positive perceptions of interviewees with regards to the design and execution of the interviews. I was particularly pleased it was found to be worthwhile.

2. Some adjustments to the interview aids and process were suggested.

- “The drawings could be more detailed. They could probably read better.”

The hypothetical project building plans were intentionally utilized with their levels of detail. The building plans were selected to offer a broad setting for DFCS implementation. They also had very visible components to allow for less tedious identification of potential DFCS modifications. An increased level of detail would have meant increased interview time needs which in turn could have meant less useful interview results. This is as fatigue would likely have set in before the end of the interview. The interviewees would have spent more time evaluating the building plans and their highly detailed features. With regards to reading better, I could have used larger sized paper. This would have allowed for greater visibility and perhaps, more effective assessment. But to maintain uniformity, I retained the same paper size (8.5” x 11”) and used it for all the interviews.

3. There was commentary on the nature of the DFCS Toolbox software.

- “The DFCS Toolbox requires lots of time to go through.”

This commentary represents the prevailing view of multiple interviewees on the nature of the DFCS Toolbox software with its checklist system. The over 400 design suggestions were placed in 20 tabs and several were replicated across the different categories. Furthermore, the suggestions were not categorized by AEC design profession and project features. As such, the user has to go through each suggestion to identify whether it is applicable to him or the project and whether it is situated in the project design phase. He then has to determine whether or not he would implement the design suggestions based on project constraints. This would require quite some time to execute.

4. There was commentary on the details provided with the DFCS measures in the DFCS-TIPS application.

- “Some project participants might prefer to determine the feasibility of implementing the DFCS measures by themselves though the identification of impediments and their solutions could be useful. Thus, the tier of feasibility might not be effective.”

The interviewee noted that the impediments to the DFCS measures and their solutions as provided by the DFCS-TIPS application were

useful. He also indicated that some design professionals might prefer determining the feasibility of implementing the DFCS measures by themselves. And as such, the tier of feasibility entry would not be useful. The tier of feasibility was primarily developed to define the research results as not all DFCS measures were subjected to as many research tasks or yielded certain results through the research tasks. This commentary made no mention of the applicable safety incidents of the DFCS measures. Ultimately, the commentary served in validating the value of this research in developing the additional details for DFCS.

5. There was commentary on the rating of the project criteria that was done in the pre-testing questions segment of the interview.

- “I believe the rating of the project issues/criteria depends on how much you’ve been exposed to construction.”

This is an agreeable commentary. Indeed, the ratings of project issues/criteria depend on the experiences of the interviewees, whether in design or in construction. As such, one could rate construction safety last as a priority while another could rate it differently. All the interviewees’ responses alluded to this.

6. There was commentary on the development of the research and the potentials for the DFCS-TIPS application.

- “It is interesting to see how the study developed from the initial interviews to software. You did a good job developing a tool that could be expanded. If integrated with code, there would be nothing else on the market. It could prove very useful to the industry.”

At the end of a DFCS-TIPS testing interview, the interviewee asked if the application was developed as part of my research. When I answered “Yes”, he commended me on how the study developed through the interviews to the DFCS-TIPS application. He also complimented the dynamic nature of the tool, its ability to be expanded with more content. The interviewee also indicated that integrating the DFCS-TIPS application with code software would prove very useful to the industry and market. But given the current nature of building code provisions and the current state of research in the development of tools to aid code compliance, incorporating building code provisions in the DFCS-TIPS application was considered infeasible as a potential improvement in this research.

#### **4.1.6.5      Interpretation of Results and Improvements to the DFCS-TIPS Application**

##### **Proposed Improvements to the DFCS Toolbox from the Interviews**

Potential improvements to the DFCS Toolbox were identified from the different segments of its four testing interviews. These are provided accordingly.

##### **Potential Improvements identified during DFCS Implementation using the DFCS Toolbox**

Certain improvements were identified from the pattern of use, statements, and difficulties observed during DFCS implementation using the DFCS Toolbox. This was based on the task specified in Section 5 of the respective interview guides, the details of which were provided in the earlier section. The potential improvements are listed.

1. Clearly indicate that the different categories of DFCS suggestions contain different checklists of suggestions.
2. Make the checklists adaptable to the user's profession.
3. Make the checklists adaptable to project characteristics.
4. The steps of software use should be clearer. It should specify that Step 1 must be completed for all tabs/categories of DFCS suggestions before proceeding to Step 2 which allows the user to view the selected suggestions.
5. There should be software capability to select all DFCS suggestions.
6. There should be a link to state and county code requirements to enable integration with code assessment.
7. The DFCS suggestions that are included should pertain to design.
8. The DFCS suggestions should not be replicated in the different tabs/categories.
9. The DFCS suggestions that are included should not include those that are OSHA requirements as they are the contractors' responsibility.
10. Scrolling capabilities should be adequately activated for the user interface.

##### **Potential Improvements from Responses to the Post-testing Interview Questions**

Certain potential improvements were identified from the responses of the interviewees to the post-testing questions, after DFCS implementation using the DFCS Toolbox. These were responses received through Section 6 of the respective interview guides, which were provided and discussed in the earlier section. While the potential improvements primarily came from the question that asked interviewees to provide recommendations for improving the software, they also came from responses to other questions where certain inadequacies were noted. These potential improvements are listed.

1. Include the capability to retrieve the DFCS suggestions based on project characteristics.
2. Include the capability to specify the design profession so only applicable DFCS suggestions are yielded.
3. Include the capability to save information so one can return to it later. One could also be able to send the saved information to other project participants.
4. Include the capability to enter or specify details of the project such as occupancy, and building type.
5. Include code requirements in the software so there is one tool with both code and DFCS measures. The code could be specified by the states.
6. The font size could be made more readable.
7. The steps of using the software could be better clarified.
8. It should have the capabilities to allow project participants with passwords to edit the selections and for the editor to be identified in the software.
9. Include the capability to retrieve suggestions based on when they are to be implemented in the project design phase.
10. Include the capability to include new DFCS suggestions based on knowledge and lessons learned.
11. Include the capability for the suggestions to be clicked and automatically applied to the design drawings and construction documents.
12. The design suggestions could include details such as economic and other implications.
13. Make the software more interactive.

### Categorization of the Potential Improvements to the DFCS Toolbox

The potential improvements were integrated and categorized. This was to determine which could be feasibly utilized in improving the DFCS-TIPS application. Additional to these were commentaries made identifying certain features as being useful.

#### 1. Potential Improvements pertaining to the DFCS Toolbox Interface

These improvements pertained to the interface features of the DFCS Toolbox. As such, they could not be applied to improving the DFCS-TIPS application since it has different interface features.

- Clearly indicate that the different categories of DFCS suggestions contain different checklists of suggestions.
- The steps of using the software could be better clarified.
- The steps of software use should be clearer. It should specify that Step 1 must be completed for all tabs/categories of DFCS suggestions before proceeding to Step 2 which allows the user to view the selected suggestions.

## 2. Potential Improvement beyond the Research Scope

This potential improvement was categorized as being beyond the research scope as this research is primarily concerned with DFCS and its measures and not building codes and their provisions. Additionally, Demir et al (2010) indicate that the users of engineering codes and standards are yet to benefit from the advanced processing and reasoning capabilities of web technologies and information systems partially due to the difficulty of finding appropriate syntaxes to represent the standards. And to further exacerbate the situation, code provisions are neither uniform nor static as they are constantly being updated. They also differ by states and municipalities (ERDC, 2001). Hence, the current nature of building code provisions and the current state of research in the development of tools to aid code compliance made the incorporation of building code provisions in the DFCS-TIPS application infeasible as a potential improvement in this research.

- Code requirements should be integrated in the software so there is one tool with both code and DFCS measures. The code could be specified by the states. There could also be a link to state and county code requirements to enable integration with the code assessment process.

## 3. Potential Improvements and Observations that Validate the Functionalities of the DFCS-TIPS Application

These potential improvements to the DFCS Toolbox were not to be applied to the DFCS-TIPS application as they were already among its functionalities. Such recommended improvements were anticipated as the DFCS-TIPS application was developed to not have certain inadequacies of existing tools including the DFCS Toolbox. Hence, these potential improvements validate the DFCS-TIPS application as a more effective tool to aid and improve the DFCS implementation process.

- Make the checklists adaptable to the user's profession. The software should include the capability to specify the design profession so only applicable DFCS suggestions are yielded.
- Make the checklists adaptable to project characteristics.
- The DFCS suggestions that are included should pertain to design.
- The DFCS suggestions that are included should not include those that are OSHA requirements as they are the contractors' responsibility.
- The DFCS suggestions should not be replicated in the different tabs/categories.
- The software should be more interactive and not just a reminder checklist.

- The software should produce a specification that can be distributed to project participants: “I like how it produces a specification that you can distribute for the safety of construction work”.
- The software should provide checks and balances such as how much it would cost to implement the DFCS suggestions along with other potential implications.
- The software should have the capability to enter or specify details of the project such as occupancy, and building type.
- The software should have the capability to retrieve suggestions based on when they are to be implemented in the project design phase.
- The software should have the capability to include new DFCS suggestions based on knowledge and lessons learned.
- The software should include the capability to save information so one can return to it later. One could also be able to send the saved information to other project participants.

#### 4. Potential Improvements that could apply to the DFCS-TIPS Application

These potential improvements were those that could be considered for the DFCS-TIPS application. This is as they could improve its functionalities and features. However, they were to be further evaluated for feasibility in this research.

- There should be software capability to select all DFCS suggestions.
- Scrolling capabilities should be adequately activated for the user interface.
- Use diagrams to clarify all the DFCS suggestions.
- Use videos to clarify all the DFCS suggestions.
- The font size could be made more readable.
- The software should have the capabilities to allow project participants with passwords to edit the selections and for the editor to be identified in the software.
- The software should include the capability for the suggestions to be clicked and automatically applied to the design drawings and construction documents.

#### **Proposed Improvements to the DFCS-TIPS Application from the Interviews**

Potential improvements to the DFCS-TIPS application were identified from the different segments of its three testing interviews. These are accordingly provided. And in this instance, the recommended improvements were directly applicable to the application.

### Potential Improvements identified during DFCS Implementation using the DFCS-TIPS Application

Certain improvements were identified from the pattern of use, statements, and difficulties observed during DFCS implementation using the DFCS-TIPS application. This was based on the task specified in Section 5 of the respective interview guides, the details of which were provided in the earlier section. The potential improvements are listed.

1. The buttons that should take the user to the 'Next' page should be better defined.
2. The content including the DFCS measures and their corresponding details should be built on.
3. The content should be expanded to include code requirements.
4. The software should link the user to the appropriate code documents and requirements.
5. The software should allow for the updating of the code requirements which is done every 3 years.
6. The software should allow for de-selecting or clearing individual selected DFCS measures without clearing them all.
7. The software should prevent the selection of the same DFCS measure multiple times.
8. The software should retain the criteria selected to provide the DFCS measures for each project. This should be saved with each added project until de-selected or selection is completed by the user. They include the profession, stage of design phase, and project features.
9. The interface should be expanded horizontally to provide better visibility of the data. This would decrease or eliminate the need for scrolling both vertically and horizontally.

### Potential Improvements from Responses to the Post-testing Interview Questions

Certain potential improvements were identified from the responses of the interviewees to the post-testing questions, after DFCS implementation using the DFCS-TIPS application. These were responses received through Section 6 of the respective interview guides, which were provided and discussed in the earlier section. While the potential improvements primarily came from the question that asked interviewees to provide recommendations for improving the software, they also came from responses to other questions where certain inadequacies were noted. These potential improvements are listed.

1. The software should have increased content.
2. Code requirements could be included in the software. The requirements could also reference the respective code document.
3. The font size could be made more readable.
4. Incorporate the software into BIM.

5. Include capabilities to save the criteria used in selecting the DFCS measures so they do not have to be continuously specified.
6. The user interface could be enhanced by using big buttons to clearly indicate the next step.

### Categorization of the Potential Improvements to the DFCS-TIPS Application

The potential improvements were integrated and categorized. This was to determine which could be feasibly utilized in improving the DFCS-TIPS application.

#### 1. Potential Improvement beyond the Research Scope

The potential improvements that addressed the content of the DFCS-TIPS application and its integration with building code provisions were categorized as being beyond the research scope. With regards to increasing the content, the filtering capabilities of the application gave the interviewees the perception that there were only a few DFCS measures and corresponding details in the database. They were apparently unaware of the invisible content they eliminated by selecting the criteria for the DFCS measures they sought. Nonetheless, it was not within the scope of this research to develop new DFCS measures. Instead, the scope included refining the DFCS process by eliminating those DFCS suggestions that did not meet the criteria for DFCS. Hence, increasing content through the inclusion of new DFCS measures and their corresponding details was beyond the research scope.

And with regards to incorporating building code provisions in the DFCS-TIPS application, the current nature of building code provisions and the current state of research in the development of tools to aid code compliance make it infeasible in this research. Code provisions are neither uniform nor static as they are constantly being updated and they also differ by states and municipalities (ERDC, 2001). It would thus require significant research effort to incorporate building code provisions and provide links to their respective code documents and requirements. As for capability to automatically update code provisions when incorporated, this too is infeasible. Significant research would have to be completed to streamline and standardize both code writing and code provisions. It must also be noted that this research was primarily concerned with DFCS and its measures and not building codes and their provisions.

As for incorporating the DFCS-TIPS application in BIM software, this was also infeasible for this research. This would require understanding the BIM software and their coding, then incorporating new programming in the software. This then would be followed by incorporating the DFCS measures and software functionalities, and also creating the visual representations in the building information modeling software. This is considerable research work that is worthy of its own dissertation. Even the

post-testing interview question in this regard was only intended to identify whether integrating DFCS tools with AEC design software such as BIM could potentially add value as earlier research by Ku and Mills (2010) suggested. The potential improvements beyond the research scope are listed.

- The software content including the DFCS measures and their corresponding details should be built on. The database content should be more robust to be helpful to the inexperienced AEC design professional.
- The software database content should be expanded to include code requirements. The software could link the user to the appropriate code documents and requirements.
- The software should allow for updating the code requirements which is done every 3 years.
- The software should be incorporated into Building Information Modeling (BIM) to make it easier to use and more effective.

## 2. Potential Improvements that apply to the DFCS-TIPS Application and Interface

These potential improvements were those that could be considered for the DFCS-TIPS application. This is as they could improve its functionalities and the features of its interface. However, they were to be further evaluated for feasibility in this research. The potential improvements are listed.

- The buttons that should take the user to the 'Next' page should be better defined. Bigger buttons or bolder text could be used.
- The software should allow for de-selecting or clearing individual selected DFCS measures without clearing them all.
- The software should prevent the selection of the same DFCS measure multiple times.
- The software should retain the criteria selected to provide the DFCS measures for each project. This should be saved with each added project until de-selected or selection is completed by the user. They include the profession, stage of design phase, and project features.
- The interface should be expanded horizontally to provide better visibility of the data. This would decrease or eliminate the need for scrolling both vertically and horizontally.
- The software should utilize drawings, diagrams and pictorials to clarify the DFCS measures.
- The font size could be made more readable.

## **Improvements to the DFCS-TIPS Application**

From the earlier section, a number of improvements were identified as applicable for the DFCS-TIPS application and applicable to this research scope. These were to be evaluated for feasibility and those found to be feasible were to be implemented.

### Infeasible Improvements to the DFCS-TIPS Application

This section encompasses the recommended improvements that were determined to be infeasible in this research. The reasons are briefly discussed.

1. Use diagrams, drawings and pictorials to clarify all the DFCS suggestions.

This was considered infeasible for scope reasons. As there are 212 DFCS measures included in the DFCS-TIPS application, an equal number of diagrams would need to be developed. These diagrams would have to be developed through research and validated. And, it would not have been within my capability to draw a majority of the diagrams. As such, I would have required AEC design professionals to first develop the diagrams. This would have proved very difficult. And given the substantial scope, developing the diagrams by itself constitutes a research project. Additionally, utilizing the approach of the DFCS Toolbox where one diagram is placed in each category was found inapplicable. This was because filtering would determine whether or not the diagram of a DFCS measure in each category would appear. Also, there was the possibility that not all the DFCS measures could be adequately represented in single or simple diagrams. Additionally, some diagrams may require constant redesigning to represent the DFCS measure and be applicable to different project scenarios, thus diminishing their value. Ultimately, the development of diagrams for each DFCS measure was categorized as a recommendation for future research.

2. Use videos to clarify all the DFCS suggestions.

The development of videos, as in the case of diagrams, was also considered infeasible. Several considerations would have to be made such as what the videos would depict. Would they depict the angular views of the DFCS features, how the DFCS measures could prevent safety incidents, how the DFCS features are designed, or how the DFCS features were constructed? How long should the videos be? DFCS is still an emerging area. As such, projects where a multitude of DFCS measures were utilized would be difficult to locate or identify. In all likelihood, it may turn out to be more feasible to develop them in an experimental setting and then record the desired videos. Optionally and perhaps more easily, 3D and 2D animation may be used in place of the videos. For example, OSHA utilizes 3D animation in their products for compliance assistance.

These are essentially training tools that visualize how certain OSHA standards could prevent injuries to construction workers.

Ultimately, the development of videos for each DFCS measure would likely prove even more tedious than the development of diagrams. As such, it was considered infeasible. It was thus categorized as a recommendation for future research. Another issue to consider is how the inclusion of videos may impact the DFCS-TIPS application. It would likely make the application very robust and with significant complexity. The software user who just wants access to a few brief details may find the tool to be complicated and tedious to use. And given that DFCS is not mandatory and is performance-based, he/she may easily lose interest.

3. The software should include the capability for the suggestions to be clicked and automatically applied to the design drawings and construction documents.

The capability to automatically apply DFCS measures to drawings and construction documents lies in the integration of the DFCS-TIPS application with Building Information Modeling (BIM) tools. And this was infeasible because it would require significant research work. These include understanding the BIM software and their coding, and incorporating new programming in the software. It would also include incorporating certain functionalities and the DFCS measures along with creating their visual representations in the software. This would require research effort that far surpasses the development of diagrams for each DFCS measure.

4. The software should have the capabilities to allow project participants with passwords to edit the selections and for the editor to be identified in the software.

This potential improvement is more applicable to an organization level tool where the software is accessed by multiple individuals and where there is need to control access and capabilities. The DFCS-TIPS application was developed to be a personal level tool and not an organizational level tool or a project organizational level tool. Thus, the controls were appropriate to this specification. This is also in line with the most popular design software, AutoCAD and REVIT, which are both personal level tools. To convert the DFCS-TIPS application to an organizational level tool, its database architecture would need to be transformed from stand-alone (single-tier) to client-server (two-tier) architecture at the very least. It would thus need to be placed on a database server and also on personal computers. Security controls would also need to be established. As this was not part of the specifications of the DFCS-TIPS application, and given the fact that its development was not to reach such a stage, this 'improvement' was considered infeasible.

An adjustment that was considered feasible but neither listed nor implemented was with regards to the tutorial of the DFCS-TIPS application. All the DFCS-TIPS testing interviewees did not view it. Two potential reasons were identified. Firstly, the “Using the DFCS-TIPS Application” button of the DFCS-TIPS application was 1 of the 9 buttons on the main interface and was therefore not easily identified. The second reason was that most software users may prefer to use software and then check the tutorial or help sections when they encounter any difficulties during use. One interviewee actually stated that he was not one to view tutorials before software use. He therefore gave some validity to the second reason whereas none was given to the first. As such, no changes were made to the structure or location of the tutorial but to the font which was made more readable. This was a recommended improvement that was considered feasible.

### Feasible Improvements to the DFCS-TIPS Application

This section provides all the recommended improvements that were determined to be feasible. Most of these improvements pertained to the interface and functionalities of the DFCS-TIPS application.

1. The buttons that should take the user to the ‘Next’ page should be better defined. Bigger buttons or bolder text could be used.

This was necessary to ensure that users know which buttons to select in order to appropriately advance in the software. This is particularly since there were multiple similar buttons on each screen and certain users exhibited uncertainty on how to advance to the relevant ‘next’ screen.

2. The software should allow for de-selecting or clearing individual selected DFCS measures without clearing them all.

This capability allows users to edit their selections with minimal implications.

3. The software should prevent the selection of the same DFCS measure multiple times.

This capability is essential to prevent redundancies in both the software and the printable specifications document.

4. There should be software capability to select all DFCS measures.

This capability makes software use more efficient. Some users may want to select all DFCS measures in a specified category. Having to select each measure individually would prove unnecessarily time-intensive and as such, this capability is essential.

5. The software should retain the criteria selected to provide the DFCS measures for each project. This should be saved with each added project until de-selected by the user or until the selection process is complete. They include the profession, stage of design phase, and project features.

An interviewee indicated that he found it tedious to be continually selecting criteria anytime he wanted to consider a set of DFCS measures or when he returned to the previous screen. This recommended improvement was thus to serve in making time-use more efficient and software use less tedious.

6. The interface should be expanded horizontally to provide better visibility of the data. This would decrease or eliminate the need for scrolling both vertically and horizontally.

Certain interviewees found it inconvenient to be constantly scrolling both vertically and horizontally to read through the provided DFCS measures and their accompanying details. This improvement would serve towards addressing the matter.

7. The font size could be made more readable.

While one cannot be assured that all users can conveniently read a certain font size, one should make the font size such that it can be read by most. For this reason, the text font sizes in the software were increased in all cases to be at least size 10. No text of such a size were identified as being too small during the DFCS-TIPS testing interviews.

These feasible improvements were effected in the DFCS-TIPS application towards making it a more viable and effective tool to aid and improve DFCS implementation on capital projects.

#### **4.1.6.6      Unexpected Findings and Implications**

This research task, the testing of the relational database application in interviews of AEC design professionals, was intended to validate it as a viable tool to assist designers in making safety considerations in the project design phase. Through the interviews and then improvements, this validation was achieved by data triangulation. Furthermore, the relational database application, named DFCS-TIPS, was validated as not possessing the inadequacies of existing tools that limit their effectiveness in the current construction and contractual environment of the United States. An indicator of this was the significantly longer list of recommended improvements for the DFCS Toolbox relative to that of the DFCS-TIPS application. And a large number of the improvements were already incorporated in the DFCS-TIPS application.

There were however two main unexpected findings from this research. Firstly, the DFCS-TIPS application was expected to rate higher across the categories of both effectiveness and usability. However, this was not the case. When it came to questions concerning usability or ease of use, the DFCS Toolbox was rated higher but when it came to questions on details, the DFCS-TIPS application rated higher. And when the additional details to enhance the DFCS Toolbox were collected, most were found to have already been incorporated in the DFCS-TIPS application. Thus, there appeared to be a tradeoff between usability and effectiveness. But given the minute difference in usability ratings and that the DFCS-TIPS application lacked several inadequacies of the DFCS Toolbox, the tradeoff was considered acceptable and perhaps in favor of the DFCS-TIPS application.

The second unexpected finding was the identification of a new dimension towards improving and increasing DFCS implementation. This was through the development of a tool that integrates building code provisions intended for occupant safety and maintenance worker safety with DFCS measures intended for construction worker safety. There is unavailability of tools to effectively aid in meeting building code requirements due to the intractable nature of building code provisions and the current state of research in the development of such tools. And, overwhelming evidence from the interviews suggested design professionals were very interested to know how the DFCS tools could aid in their adherence to building codes. Building codes are mandatory and mostly prescriptive-based. Non-adherence results in code violations which mean liability, fines and legal costs. As DFCS is not mandatory, it would likely be most effective if DFCS measures are linked to building codes, and DFCS tools would more likely be used if they can aid in designers' adherence to building codes. Such a development would not only minimize impediments to DFCS implementation but serve towards increasing its adoption in the AEC industry.

## **4.2 Research Deliverables**

This section discusses the outcome of the research tasks with regards to yielding each of the research deliverables.

### **4.2.1 Applicable DFCS Measures to the Project Design Phase**

For design suggestions to be considered viable for implementation in DFCS, they must not prescribe means, methods, techniques, sequences or procedures for the contractor. They must be applicable to the project design phase and only pertain to permanent project features (Gambatese et al, 2005). Where design suggestions meet these criteria for DFCS, they would most likely not expose the design professional to additional liability. And this is imperative as fear of liability constitutes a uniquely strong barrier to DFCS (Toole, 2005). This is the justification for this research deliverable.

The 430 design suggestions for construction worker safety produced through earlier research by the Construction Industry Institute (CII) were successfully categorized through the research tasks to yield those applicable to the project design phase. Ultimately, DFCS measures that were identified and validated as being situated in the project design phase numbered 212. The measures considered to be validated include those indicated by the research participants to be situated in the design phase and those indicated to be possibly or likely situated in the design phase. *Table 76* provides the numbers of design-phase DFCS measures by AEC design profession.

AEC Design Profession		Number of Design-phase DFCS Measures
Architects		91
Civil/Structural Engineers		50
M/E/P Engineers		71
	<i>Mechanical</i>	17
	<i>Electrical</i>	20
	<i>Plumbing</i>	34
<b>TOTAL</b>		<b>212</b>

**Table 76:** Number of Design-phase DFCS Measures by AEC Design Profession

The DFCS measures were also categorized based on their applicable stage of design phase and project features. *Table 77* provides the number of design-phase DFCS measures by their stage of the design phase. *Table 78* provides the numbers of design-phase DFCS measures by project features.

AEC Design Profession		Number of Design-phase DFCS Measures by Stage of Design Phase			Total
		<u>Preliminary Design</u>	<u>Design Development</u>	<u>Construction Documents</u>	
Architects		20	54	17	<b>91</b>
Civil/Structural Engineers		13	30	7	<b>50</b>
M/E/P Engineers		19	46	6	<b>71</b>
	<i>Mechanical</i>	6	10	1	<b>17</b>
	<i>Electrical</i>	5	13	2	<b>20</b>
	<i>Plumbing</i>	8	23	3	<b>34</b>
<b>TOTAL</b>		<b>52</b>	<b>130</b>	<b>30</b>	<b>212</b>

**Table 77:** Number of Design-phase DFCS Measures by Stage of Design Phase

The DFCS measures were also categorized into different tiers. This was to enable the identification of design-phase DFCS measures validated to have no identified impediments and the identification of those with some identified impediments. It was also to classify measures based on confidence in their level of effectiveness as determined through this research. This could aid the design professional in determining the feasibility of implementing specific DFCS measures. The tiers define the research results as not all DFCS measures were

subjected to as many research tasks or yielded certain results through the research tasks. The description and basis for each tier are presented in *Table 53* and *Table 54*. *Table 79* provides the numbers of design-phase DFCS measures by the different tiers and by the applicable design professions.

	<b>Project Features</b>	<b>Number of Design-phase DFCS Measures</b>
1.	Building Materials	3
2.	Component Placement	4
3.	Egress	5
4.	Equipment Controls	4
5.	Equipment Location	11
6.	Equipment Support	2
7.	Finishing	4
8.	Fixture Design	3
9.	Floor Design	4
10.	Floor Openings	3
11.	Foundation / Earthwork Design	13
12.	Fueled Equipment	2
13.	Member Connections	10
14.	Member Design	11
15.	Multi-level Project	3
16.	Permanent Ladders	30
17.	Piping System Placement	17
18.	Pressurized Equipment	2
19.	Project / Site Orientation	4
20.	Protective / Safety Guards	2
21.	Relief Valves	5
22.	Roof	11
23.	Stairs / Railings	1
24.	Stairways / Ramps	21
25.	System Design	20
26.	Tank Design	3
27.	Underground Equipment	1
28.	Walkways	8
29.	Wall / Masonry Design	3
30.	Windows	2
	<b>TOTAL</b>	<b>212</b>

**Table 78:** Number of Design-phase DFCS Measures by Project Feature

As part of this research, information was also collected on each design-phase DFCS measure. These include potential impediments to their implementation, and safety incidents preventable by their implementation. All these details are included alongside all the design-phase DFCS measures in *Appendix J*. Meanwhile, the design suggestions for construction safety that were either identified as not being situated in the project design phase or identified as not meeting the criteria for DFCS are provided in *Appendix B*.

AEC Design Profession	Number of Design-phase DFCS Measures by Tiers of Feasibility								Total
	1A	1B	2A	2B	3A	3B	4A	4B	
Architects	12	7	13	11	23	10	11	4	91
Civil/Structural Engineers	8	6	2	17	10	1	5	1	50
M/E/P Engineers	19	8	10	11	16	3	1	3	71
<i>Mechanical</i>	5	3	2	3	2	2	0	0	17
<i>Electrical</i>	6	3	6	3	1	1	0	0	20
<i>Plumbing</i>	8	2	2	5	13	0	1	3	34
<b>TOTAL</b>	<b>39</b>	<b>21</b>	<b>25</b>	<b>39</b>	<b>49</b>	<b>14</b>	<b>17</b>	<b>8</b>	<b>212</b>

**Table 79:** Number of Design-phase DFCS Measures by Tiers of Feasibility

#### 4.2.2 Impediments to Implementing DFCS Measures Applicable to the Design Phase

Earlier research identified the most critical impediments to DFCS to include designers' concern about increased liability, increased cost, and designers' lack of safety expertise. Others included concerns about schedule problems, diminished design creativity, and designers' lack of interest. These are impediments to the DFCS concept which were not considered to determine whether they applied to individual DFCS measures. An earlier study by Gambatese et al (2005) identified impediments to implementing six DFCS measures. The scope of this research included identifying impediments to implementing all the DFCS measures that are situated in the project design phase. The impediments provide a means for evaluating the DFCS measures for potential implementation thus presenting the issues that should be surmounted by AEC design professionals to enhance the feasibility of implementing the measures.

This research was successful in yielding the impediments for the list of 212 DFCS measures that were validated as being situated in the project design phase. This was where applicable as not all the DFCS measures were indicated to have impediments. In most cases, the impediments were only yielded while in some cases, they were also validated. The number of times the impediments were identified for the design-phase DFCS measures is provided in *Table 80*.

Certain observations were made from *Table 80*. Firstly, increased cost was identified as the most critical impediment to DFCS. And, this was the case for the design-phase DFCS measures that are applicable to civil/structural engineers, mechanical engineers, and electrical engineers. This was anticipated as engineers strive to design economical solutions. In the case of plumbing engineers, designers' lack of safety expertise was identified as the most critical impediment. And, in the case of architects, the most critical impediment was clearly identified as being decreased project quality and diminished design creativity. Aesthetics is situated in project quality and as architects factor it

significantly more than other AEC design professionals, they are certainly very likely to be concerned with regards to how implementing the DFCS measures could impact their design or the appearance of their project. Nonetheless, increased cost placed second for architects. Another important observation is the fact that exposure to liability was not identified as the most critical impediment for the design-phase DFCS measures either as applicable to any design profession or in total. This serves as an indicator that the categorization of DFCS measures to yield those applicable to the design phase was effective in minimizing this impediment. And, when the total numbers of times the impediments were identified for each profession was considered, they were seen to follow the number of design-phase DFCS measures in each profession category. As such, there were no deductions in this regard.

Impediments to DFCS Implementation	Number of Times the Impediments were identified for the Design-phase DFCS Measures as categorized by AEC Design Profession					Total
	Architects	Civil/Structural Engineers	MEP Engineers			
			Mechanical	Electrical	Plumbing	
Exposure to liability	6	8	2	2	5	23
Increased cost	12	17	6	5	1	41
Schedule problems and time constraints	3	10	2	1	0	16
Decreased project quality and diminished design creativity	18	5	1	1	0	25
Designers' lack of safety expertise	8	3	0	0	6	17
Absence of designer interest and motivation	5	1	1	0	2	9
TOTAL	52	44	12	9	14	131

**Table 80:** Number of Times the Impediments were Identified for the Design-phase DFCS Measures applicable to each AEC Design Profession

The impediments to implementing the design-phase DFCS measures are provided alongside the measures in *Appendix J*. And those that were validated through the research were appropriately indicated. Additionally, though not a research deliverable, the potential solutions to the impediments are also provided. These were derived from earlier research.

#### 4.2.3 Revised DFCS Measures based on Impediments to Implementation

The scope of this research included yielding the revisions of design-phase DFCS measures, where applicable, to be both more viable for implementation and for improving construction safety. Certain design-phase DFCS measures could be poorly specified, inaccurate, and/or incomplete. This research deliverable was to fine-tune such DFCS measures.

Revisions of design-phase DFCS measures were successfully yielded through this research. This was where applicable as a significant majority of the DFCS measures were not identified to require revision. The revisions that were

obtained through the research tasks numbered 13. They are provided alongside their respective unrevised design-phase DFCS measures in *Table 81*. The revised design-phase DFCS measures are included in *Appendix J* in place of their original unrevised versions.

	Design-phase DFCS Measures	Revisions of the Design-phase DFCS Measures
	<b>ARCHITECTS</b>	
1.	Locate exterior stairways and ramps on the sheltered side of the structure to protect them from rain, snow, and ice to minimize fall hazards.	Locate exterior stairways and ramps on the sheltered side of the structure or fully enclose them to protect them from rain, snow, and ice to minimize fall hazards.
2.	Provide access by means of a ladder or stairway between horizontal surfaces when there is a change in elevation exceeding 19 inches.	Provide access by means of a ladder or stairway between horizontal surfaces when there is a change in elevation exceeding 15 inches.
3.	Design intermediate vertical members on stairrails and guardrails to be at most 19 inches apart.	Design intermediate vertical members on stairrails and guardrails to be at most 19 inches apart while the space between pickets should be such that a 6" sphere cannot pass through.
4.	In the design of permanent ladders and ladder wells, design the inside width of ladder wells to be at least 30 inches for ease of ascent/descent.	In the design of permanent ladders and ladder wells, design the inside width of ladder wells to be at least 36 inches for ease of ascent/descent.
5.	In areas which receive snow, provide a covering, overhang, or extend the roof line over exterior ramps.	In areas which receive snow, provide a covering, overhang, or extend the roof line over exterior ramps and where not feasible, specify a snow melt system.
6.	Build stair landings up above an uneven grade.	Build stair landings up above an uneven grade or slope the stair landing.
7.	In the design of permanent ladders, design vertical bars to be on the inside of the horizontal bands and fastened to them.	In the design of permanent ladders, design vertical bars to be on the outside of the horizontal bands, clear and projecting from the wall.
	<b>CIVIL / STRUCTURAL ENGINEERS</b>	
8.	In the design of stairs/railings, design handrails and the top rails of stairrail systems to withstand at least 200 lbs. applied within 2 in. of the top edge in any downward or outward direction, at any point along the top edge.	In the design of stairs/railings, design handrails and the top rails of stairrail systems to withstand at least 200 lbs. applied within 2 in. of the top edge in any downward or outward direction and/or 50 lbs/linear foot applied at any point along the top edge.
9.	Design each rung on fixed permanent ladders to be capable of supporting a load of at least 250 lbs. applied in the middle of the rung.	Design each rung on fixed permanent ladders to be capable of supporting a load of at least 300 lbs. applied in the middle of the rung.
10.	Provide column splices at two-floor intervals and locate them at approximately 4 feet above the finished floor level to facilitate safe and accessible splice work.	Locate column splices at approximately 4 feet above the finished floor level to facilitate safe and accessible splice work.
	<b>MEP ENGINEERS – MECHANICAL ENGINEERS</b>	
11.	Locate valves such that they can be operated easily, or so that a standard type of operating device can be installed. Consider using remote valve operators.	Locate valves such that they can be operated easily, or so that a standard type of operating device can be installed. Consider using easily-accessible remote valve operators.
12.	To reduce fall hazards, locate rooftop mechanical/HVAC equipment away from the edge of the structure.	To reduce fall hazards, locate rooftop mechanical/HVAC equipment away from the edge of the structure and where not possible, use railings.
	<b>MEP ENGINEERS – ELECTRICAL ENGINEERS</b>	
13.	Provide permanent electrical outlets on the roof to allow for easy tie-in during construction and future roof maintenance.	Provide permanent electrical outlets on flat roofs to allow for easy tie-in during construction and for future roof maintenance.

**Table 81:** Revisions of the Applicable Design-phase DFCS Measures

#### 4.2.4 Preventable Construction Hazard Incidents from Applicable DFCS Measures

For a majority of DFCS measures, potential benefits of their implementation were neither determined nor provided. This was though some earlier studies conducted research in this direction. Behm (2005) reviewed 224 fatality investigation reports to establish a link between DFCS and fatalities. The study results found the risk associated with 42% of the fatalities would have been reduced or eliminated had DFCS been utilized. A successive study by Gambatese et al (2008) validated 71% of the cases reviewed. Another study by Behm (2006) yielded the number of construction safety incidents that could have been prevented through implementation of 73 design suggestions. In this research, preventable construction hazard incidents were to be identified for all 212 DFCS measures that were identified and validated as being situated in the project design phase. This deliverable is to provide illustrative cases for the implementation of the measures. The incidents were to be identified from the publicly accessible OSHA database which is fairly comprehensive in documenting the accidents that led to fatalities and serious injuries.

This research was successful in yielding the preventable construction hazard incidents for all the design-phase DFCS measures. However, not all the incidents were validated as being preventable by implementing the measures. Those that were not validated were related but other factors beyond design features were identified as the key contributors to the incidents. Such primarily included unsafe practices by the construction workers. Additionally, not all the safety incidents were subjected to validation through the research tasks. *Table 82* provides the numbers of safety incidents that were validated for the design-phase DFCS measures as categorized by AEC design profession.

AEC Design Profession	Number of Design-phase DFCS Measures	Validation of the Safety Incidents as Preventable by the Design-phase DFCS Measures		
		Number of DFCS Measures for which Safety Incidents were subjected to Validation	Number of DFCS Measures for which Safety Incidents were Validated	Percentage of Safety Incidents Validated as being Preventable by the DFCS Measures
Architects	91	43	35	81.4%
Civil/Structural Engineers	50	33	23	69.7%
M/E/P Engineers	71	51	35	68.6%
	<i>Mechanical</i>	17	14	92.9%
	<i>Electrical</i>	20	10	52.6%
	<i>Plumbing</i>	34	12	66.7%
<b>TOTAL</b>	<b>212</b>	<b>127</b>	<b>93</b>	<b>73.2%</b>
<b>Percentage of all the yielded Safety Incidents that were Validated</b>				<b><u>43.9%</u></b>

**Table 82:** Number of Safety Incidents validated as being preventable by the Design-phase DFCS Measures

As seen in *Table 82*, 73.2% of the safety incidents that were subjected to validation through the research tasks were validated as being preventable by their respective design-phase DFCS measures. And, when all the yielded safety incidents are considered whether subjected to validation or not, 43.9% were validated as being preventable by their respective DFCS measures.

The applicable safety incidents are provided alongside the design-phase DFCS measures in *Appendix J*. And those that were validated through the research tasks were appropriately indicated. Demonstrable evidence of the effectiveness of the DFCS measures show the benefit of their implementation, injuries prevented and lives saved. This research deliverable serves towards justifying DFCS implementation.

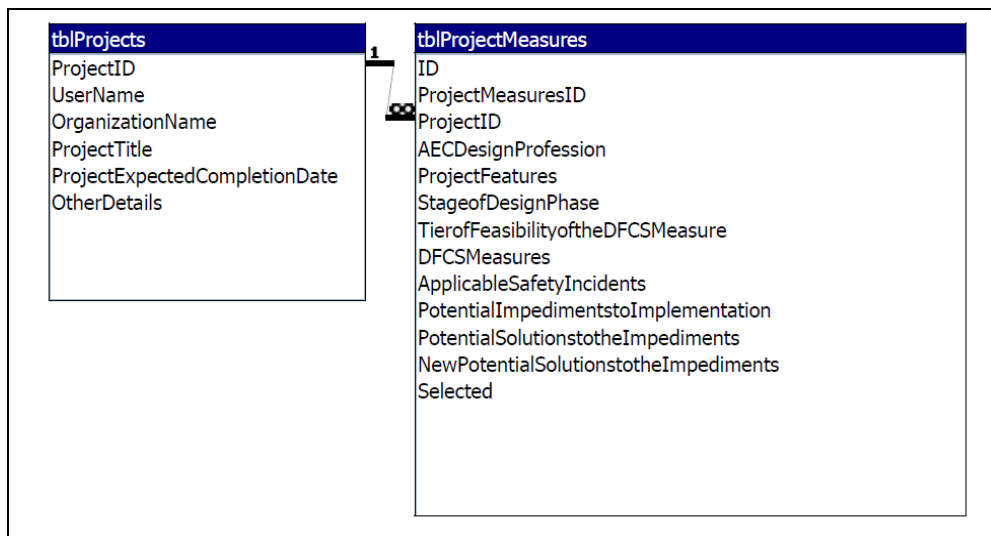
#### **4.2.5 Computer Application to aid implementation of design phase DFCS Measures**

A number of computer tools have been developed and proposed to aid in the implementation of DFCS. These included the Design-for-Construction-Safety (DFCS) Toolbox, ToolSHeD, Construction Hazard Assessment and Implication Review (CHAIR), and the Design-for-Safety-Process tool. A comparative analysis of these tools identified a need for a more effective DFCS tool that can function effectively in the current contractual environment of the United States AEC industry while not providing a means for increased exposure to liability. The tool must therefore exclusively provide design-phase DFCS measures and implications of their implementation to aid designers' decision-making process and to motivate DFCS implementation, considering regulations and current contractual structures do not require designer involvement in construction safety. This research was to develop a tool to meet all these requirements and to be without the inadequacies of existing DFCS tools. Hence, the tool is to encapsulate the research findings and serve as a vehicle for utilizing the research data to enhance DFCS implementation. Based on the expected functions of the tool, it was to be a relational database application and in line with the most widely used tools in the AEC industry, it was to be a desktop application. Relational database applications can be developed using several existing software packages but the wide use of Microsoft Access along with my familiarity using it made it my preferred choice for developing the tool.

The research was successful in developing the computer application to aid DFCS implementation. The relational database application was named DFCS-TIPS. This is an abbreviation for Design for Construction Safety - Tool for Implementation on Projects and Systems. The DFCS-TIPS application has the functionality to provide design-phase DFCS measures, their preventable safety incidents, their potential impediments, potential solutions to their impediments, and their tier of feasibility, based on project characteristics, design profession, and the stage of the design phase. The application thus incorporates the other research deliverables. It also allows for the addition of new DFCS measures,

their preventable safety incidents, their potential impediments, and potential solutions to their impediments. This enables the adaptability of the software application to the user and enables the incorporation of new knowledge particularly given that DFCS is still an emerging area. The user can also define the AEC design profession, project feature, and the stage of the design phase applicable to the newly entered DFCS measures. And, even for the DFCS measures included in the DFCS-TIPS application, the user can enter potential solutions to their impediments. The application also has the capability to produce a printable specifications document with the selected DFCS measures and their accompanying details, and also with entered user and project data.

The DFCS-TIPS application utilizes one-to-many joins for its database system. This type of join is very common and requires a primary key and a field set up to be a foreign key on a table. These foreign keys should be primary keys of tables at the 'many' end of the relationships. In this case, this is the 'ProjectID' field. This is as seen in *Figure 64* which shows the database relationships for the DFCS-TIPS application. The information entered in the fields of the database with the respective design-phase DFCS measures are provided in *Appendix J*.



**Figure 64:** Database Relationships for the DFCS-TIPS Application

The programming environment used in building the user interface for the DFCS-TIPS application was Visual Basic. Specifically, the Visual Basic for Application (VBA) included in Microsoft Access was utilized. A sample of the Visual Basic coding used to enable the functionalities of the DFCS-TIPS application is provided in *Appendix I*.

To demonstrate the operation of the DFCS-TIPS application, a use case is presented. This use case is to encompass a majority of the application's capabilities. In the relatively simple use case, the user is an AEC design professional employed by an architecture and engineering firm. The user is required to implement DFCS as per client demands. The user is new to DFCS and as such, he/she was provided with the DFCS-TIPS application to assist in its implementation.

1. The user opens the DFCS-TIPS application and the 'Interface' is presented. The interface is seen in *Figure 65*.

The screenshot shows the DFCS-TIPS application interface. At the top, the title "DFCS-TIPS" is displayed in a large, bold font, followed by the subtitle "DFCS-TIPS Design For Construction Safety - Tool for Implementation on Projects and Systems". Below the title bar, there are two main sections. On the left, a button labeled "Why Design for Construction (DFCS) Safety?" is visible. On the right, a button labeled "Using the DFCS-TIPS Application" is present. The central area contains several buttons: "Add New Project" and "Add New DFCS Measures" at the top; "Edit or Delete Entered DFCS Measures" and "Add or Edit Potential Solutions to the Impediments of DFCS Measures" in the middle; and "Edit Existing Project" and "Delete Existing Project" at the bottom. A "Close DFCS-TIPS" button is located at the bottom right. A form area on the left is labeled "Select Project and Click Edit" and contains input fields for "OrganizationName" and "ProjectTitle".

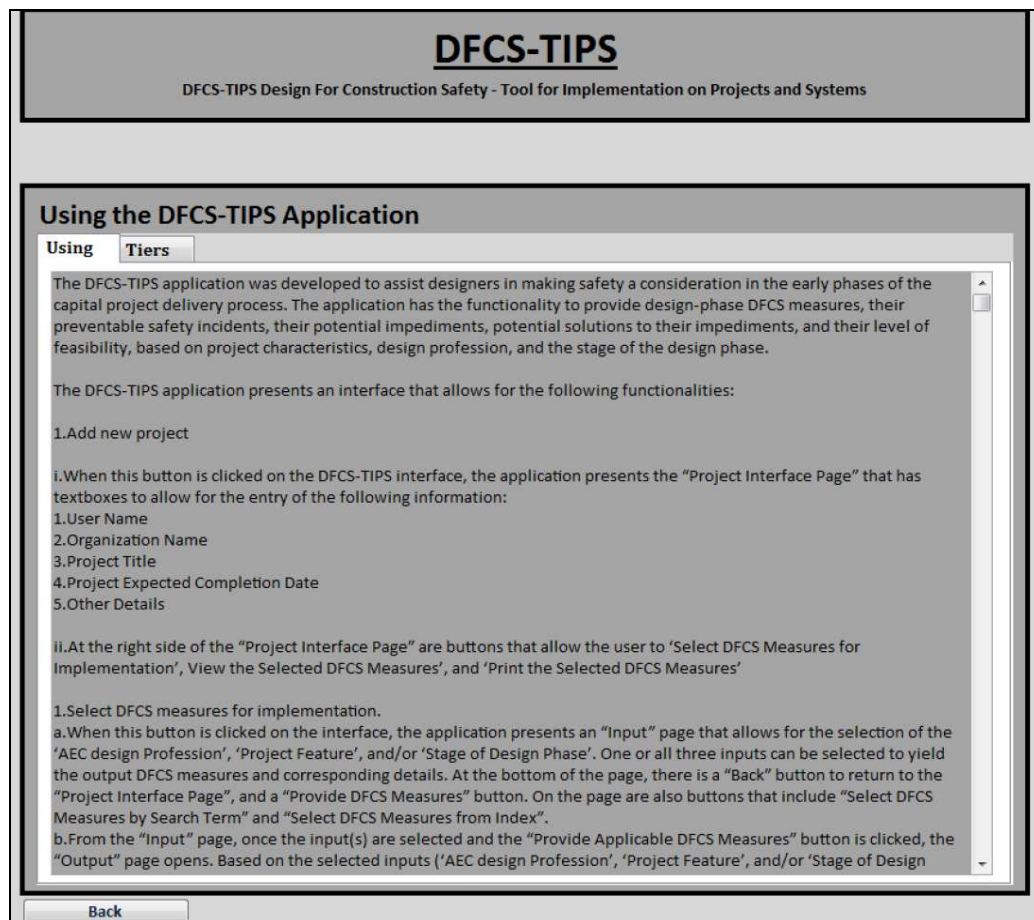
**Figure 65:** DFCS-TIPS Application Operation – Opening Application Interface

2. The user clicks on the “Why Design for Construction Safety?” button on the 'Interface' to read through the basis for DFCS implementation and what it entails. The 'Why DFCS' page is seen in *Figure 66*. Once the user is done reading, he clicks the “Back” button to return to the 'Interface'.

The screenshot shows the 'Why DFCS' page within the DFCS-TIPS application. The title bar at the top reads "DFCS-TIPS" and "DFCS-TIPS Design For Construction Safety - Tool for Implementation on Projects and Systems". The main content area contains a detailed explanation of the DFCS concept. It starts with a paragraph stating that the construction industry has one of the worst safety records among all industries in the private sector, citing statistics from Bentil (1990) and Behm (2005). It then discusses various strategies for minimizing safety hazards and incidents, including safety planning, staffing, and training. The text emphasizes the importance of early identification and elimination of potential safety hazards. A second paragraph discusses the role of DFCS in improving construction worker safety and the benefits of proactive identification and elimination of hazards. A third paragraph mentions a study by Gambatese et al (2005) and discusses the liability exposure of designers. A fourth paragraph explains the intent of DFCS to decrease or eliminate construction safety hazard risks and reduce injury incidents. The page concludes with a paragraph about the development of the DFCS-TIPS application to assist designers in making safety a consideration in the early phases of the capital project delivery process. At the bottom left, there is a "Back" button.

**Figure 66:** DFCS-TIPS Application Operation – Understanding the DFCS Concept

3. The user then clicks on the “Using the DFCS-TIPS Application” button on the ‘Interface’ to understand how to use the DFCS-TIPS application and to grasp its capabilities. Towards this, the user clicks the two tabs on the page, the ‘Using’ tab and the ‘Tiers’ tab. These are seen in *Figure 67* and *Figure 68* respectively. Once the user is done reading, he clicks on the “Back” button to return to the ‘Interface’.
4. From the ‘Interface’, the user clicks on the “Add New Project” button. Once on the ‘Project Interface’ page, the user enters his name, organization name, the project title, the project expected completion date and other details. This is as seen in *Figure 69*.
5. Once the user is done entering project and user data on the ‘Project Interface’ page, he then clicks on the “Select DFCS Measures for Implementation” button. The ‘Input’ page opens. On this page, the user selects the criteria for the DFCS measures he would like to consider implementing. These selected criteria include the design profession, stage of design phase, and anticipated project features. The user appropriately selects the criteria as seen in *Figure 70*.



**Figure 67:** DFCS-TIPS Application Operation – Understanding DFCS-TIPS Application Use

## DFCS-TIPS

DFCS-TIPS Design For Construction Safety - Tool for Implementation on Projects and Systems

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Using

Tiers

The Tiers of Feasibility of the DFCS Measures and their Details

The DFCS measures were categorized on the basis of the level of confidence in their effectiveness and their feasibility for implementation. This table provides the tiers and their respective descriptions.

Tier of Feasibility of the DFCS Measures	Description of the Tiers
1A	This tier includes DFCS measures that were validated to be applicable to the design phase, to have the capability of improving construction worker safety, and to be feasible for implementation. The preventable safety incidents identified for these DFCS measures were also validated as being applicable. AEC design professionals did not identify any impediments to implementing these measures. At least 2 AEC design professionals were involved in evaluating these measures.
1B	This tier includes DFCS measures that were validated to be applicable to the design phase, to have the capability of improving construction worker safety, and to be feasible for implementation. The preventable safety incidents identified for these DFCS measures were also validated as being applicable. AEC design professionals identified impediments to implementing these measures. At least 2 AEC design professionals were involved in evaluating these measures.
2A	This tier includes DFCS measures that were validated to be applicable to the design phase. However, the measures were noted but not necessarily validated to have the capability of improving construction worker safety and/or to be feasible for implementation. This also applies to the preventable safety incidents identified for the DFCS measures. AEC design professionals did not identify any impediments to implementing these measures. At least 2 AEC design professionals were involved in evaluating these measures.
2B	This tier includes DFCS measures that were validated to be applicable to the design phase. However, the measures were noted but not necessarily validated to have the capability of improving construction worker safety and/or to be feasible for implementation. This also applies to the preventable safety incidents identified for the DFCS measures. AEC design professionals identified impediments to implementing these measures. At least 2 AEC design professionals were involved in evaluating these measures.
3A	This tier includes DFCS measures that were validated to be applicable to the design phase. However, the measures were not necessarily validated to have the capability of improving construction worker safety and/or to be feasible for implementation. Also, the preventable safety incidents identified for the DFCS measures were not validated as being applicable. AEC design professionals did not identify any impediments to implementing these measures. At least 1 AEC design professional was involved in evaluating these measures.
3B	This tier includes DFCS measures that were validated to be applicable to the design phase. However, the measures were not necessarily validated to have the capability of improving construction worker safety and/or to be feasible for implementation. Also, the preventable safety incidents identified for the DFCS measures were not validated as being applicable. AEC design professionals identified impediments to implementing these measures. At least 1 AEC design professional was involved in evaluating these measures.
4A	This tier includes DFCS measures that were not necessarily validated to be applicable to the design phase. However, the measures were not noted to be inapplicable to the project design phase. Also, the measures were not necessarily validated to have the capability of improving construction worker safety and/or to be feasible for implementation. Additionally, the preventable safety incidents identified for the DFCS measures were not validated as being applicable. AEC design professionals did not identify any impediments to implementing these measures. At least 1 AEC design professional was involved in evaluating these measures.
4B	This tier includes DFCS measures that were not necessarily validated to be applicable to the design phase. However, the measures were not noted to be inapplicable to the project design phase. Also, the measures were not necessarily validated to have the capability of improving construction worker safety and/or to be feasible for implementation. Additionally, the preventable safety incidents identified for the DFCS measures were not validated as being applicable. AEC design professionals identified impediments to implementing these measures. At least 1 AEC design professional was involved in evaluating these measures.

Back

Figure 68: DFCS-TIPS Application Operation – Understanding the ‘Tiers’ in the DFCS-TIPS Application

## DFCS-TIPS

DFCS-TIPS Design For Construction Safety - Tool for Implementation on Projects and Systems

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User Name:

John Doe AIA PE

Organization Name:

A+E Firm

Project Title:

Major Building Complex

Project Expected Completion Date:

5/20/12

Other Details:

This project is situated in Pittsburgh, PA. It is mixed-use. DFCS implementation is part of client requirements.

Select DFCS Measures for Implementation

View the Selected DFCS Measures

Print the Selected DFCS Measures

Save and Close

Figure 69: DFCS-TIPS Application Operation – Entering User and Project Data

## DFCS-TIPS

DFCS-TIPS Design For Construction Safety - Tool for Implementation on Projects and Systems

Select DFCS Measures  
by Search Term

Select DFCS Measures  
from Index

**AEC Design Profession:**

Select	AEC Design Professional
<input checked="" type="checkbox"/>	Architect
<input checked="" type="checkbox"/>	Civil / Structural Engineer
<input type="checkbox"/>	Mechanical Engineer
<input type="checkbox"/>	Electrical Engineer
<input type="checkbox"/>	Plumbing Engineer

Record: 2 of 5    No Filter    Search

**Stage of Design Phase:**

Select	Stage Of Design Phase
<input checked="" type="checkbox"/>	Preliminary Design
<input checked="" type="checkbox"/>	Design Development
<input type="checkbox"/>	Construction Documents

Record: 2 of 3    No Filter    Search

**Project Features:**

Select	Project Feature
<input type="checkbox"/>	Equipment Support
<input type="checkbox"/>	Finishing
<input checked="" type="checkbox"/>	Floor Design
<input checked="" type="checkbox"/>	Floor Openings
<input type="checkbox"/>	Foundation / Earthwork Design
<input type="checkbox"/>	Member Connections
<input checked="" type="checkbox"/>	Member Design
<input type="checkbox"/>	Multi-level Project
<input type="checkbox"/>	Permanent Ladders
<input checked="" type="checkbox"/>	Project / Site Orientation
<input type="checkbox"/>	Roof
<input type="checkbox"/>	Stairways / Ramps
<input type="checkbox"/>	Tank Design
<input type="checkbox"/>	Walkways
<input type="checkbox"/>	Wall / Masonry Design
<input checked="" type="checkbox"/>	Windows

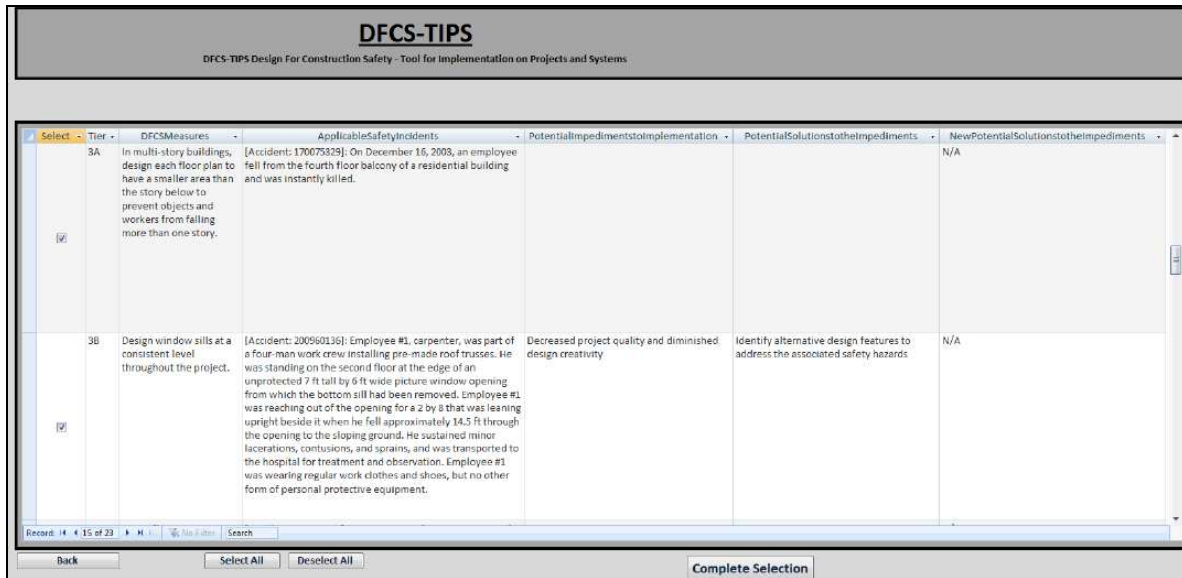
Record: 18 of 18    No Filter    Search

Back

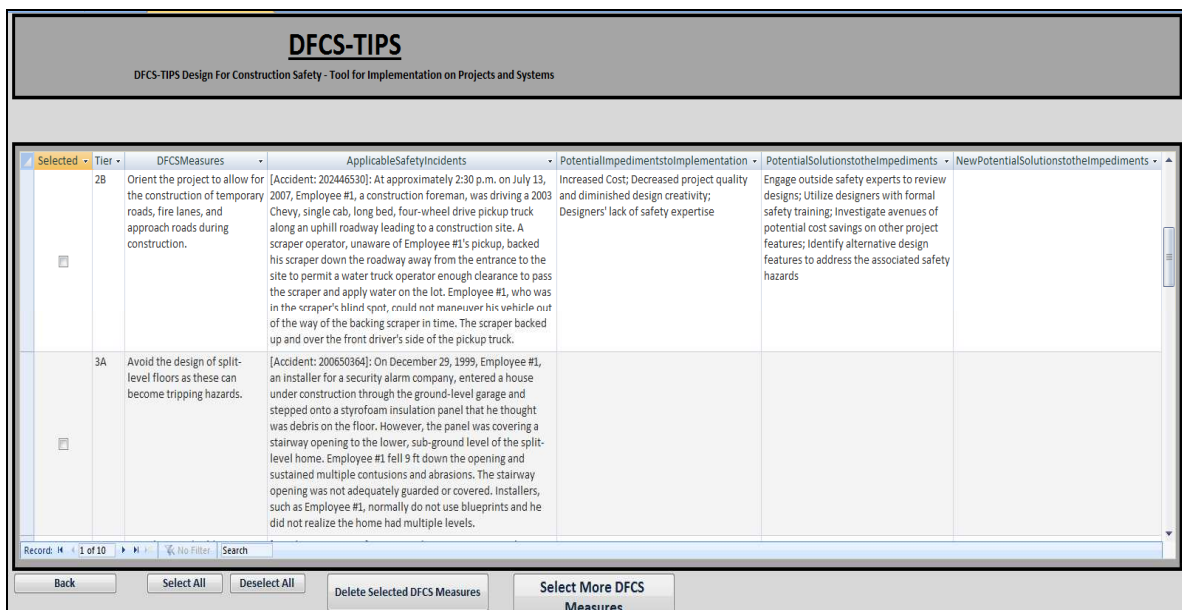
Provide Applicable DFCS Measures

**Figure 70:** DFCS-TIPS Application Operation – Selecting Input Criteria for the DFCS Measures

6. Once the user is done selecting the criteria on the 'Input' page, he clicks on the "Provide Applicable DFCS Measures" button. This opens the 'Output' page which provides the applicable DFCS measures with checkboxes to allow for their selection. Alongside the DFCS measures are applicable safety incidents and their 'Tier' categories. There are also potential impediments to implementation of the DFCS measures and potential solutions to the impediments where applicable. The user goes through the DFCS measures selecting those he considers appropriate for implementation on the project. This is as seen in *Figure 71*. Once done, the user clicks the "Complete Selection" button which returns him to the 'Project Interface' page.
7. Once the user returns to the 'Project Interface' page as seen in *Figure 69*, he then clicks on the "View the Selected DFCS Measures" button. This opens the 'View Selected Measures' page as seen in *Figure 72*. This is to view and assess if all the DFCS measures were appropriate and sufficient for the project. In this instance, they were not. Hence, the user clicks on the "Select More DFCS Measures" button which takes him to the 'Input' page as seen in *Figure 70*.



**Figure 71:** DFCS-TIPS Application Operation – Selecting DFCS Measures for Implementation on Project



**Figure 72:** DFCS-TIPS Application Operation – Viewing and Assessing the Selected DFCS Measures

- From the 'Input' page, the user clicks on the "Select DFCS Measures by Search Term" button which opens the 'Search' page. The user had realized he wanted to select DFCS measures that pertained to wall design. On the 'Search' page, the user enters "wall" as the search term and clicks on the "Search" button. This is as seen in *Figure 73*. This takes the user to the 'Output' page as seen in *Figure 71*. But in this instance, the DFCS measures that appear are only those with "wall" in the body of their text. This means the application queries the 'DFCSMeasures' field to yield those with the search term.

The screenshot displays the DFCS-TIPS application interface. At the top, a header bar contains the title "DFCS-TIPS" in bold, followed by the subtitle "DFCS-TIPS Design For Construction Safety - Tool for Implementation on Projects and Systems". Below this, a large central area is titled "Search for DFCS Measures by Term". Inside this area, there is a text input field containing the word "wall" and a "Search" button to its right. At the bottom of the interface, there is a "Back" button.

**Figure 73:** DFCS-TIPS Application Operation – Selecting DFCS Measures using Search Terms

9. In this instance, the user was not satisfied with the DFCS measures provided using the “wall” search term. He then clicks the “Back” button on the ‘Output’ page which returns him to the ‘Input’ page. From the ‘Input’ page, the user clicks on the “Select DFCS Measures by Index Term” button. This takes the user to the ‘Index’ page. On the ‘Index’ page, the user selects “Block” as the index term. This is as seen in *Figure 74*. This takes the user to the ‘Output’ page as seen in *Figure 71*. But in this instance, the DFCS measures that appear are only those with “block” in the body of their text. The user then selects a few more measures he considers appropriate for implementation from the ‘Output’ page and clicks on the “Complete Selection” button which returns him to the ‘Project Interface’ page as seen in *Figure 69*.
10. From the ‘Project Interface’ page, the user clicks on the “Print the Selected DFCS Measures” button. This provides the print preview of the report with the project and user data, the selected DFCS measures, their applicable safety incidents, along with their potential impediments to implementation and the potential solutions to the impediments where applicable. The tier of feasibility is also included. This is as seen in *Figure 75*. The user then prints this recommendation document for DFCS implementation on the project, using the “Print” button. When the user closes the print preview page, he is returned to the ‘Project Interface’ page as seen in *Figure 69*.

## DFCS-TIPS

DFCS-TIPS Design For Construction Safety - Tool for Implementation on Projects and Systems

Select DFCS Measures from Index

area  
attachment  
backfilled  
bar  
block  
bolt  
cable  
cage  
clearance  
column  
component  
concrete  
operation

**Figure 74:** DFCS-TIPS Application Operation – Selecting DFCS Measures using Index Terms

## DFCS-TIPS

**User Name** John Doe AIA PE

**Organization Name** A+E Firm

**Other Details** This project is situated in Pittsburgh, PA. It is mixed-use. DFCS implementation is part of client requirements.

**Project Title** Major Building Complex

**Project Expected Completion Date** 5/20/12

Selected DFCS Measures for Implementation

Tier of Feasibility	DFCS Measures	Applicable Safety Incidents	Potential Impediments to Implementation	Potential Solutions to the Impediments	New Potential Solutions to
2B	Around parking areas, ramps, and other elevated traffic surfaces, increase the height of the perimeter wall above the traffic surface to prevent driving off the traffic surface prior to placement of permanent wheelstops, curbs, and guardrails.	[Accident: 200021988]: At approximately 12:34 a.m. on July 11, 2000, Employee #1 was operating a 1997 Caterpillar rubber-wheeled integrated tool carrier equipped with a multi-purpose bucket, a vehicle similar to a front-end loader. He was working near the bottom of a ramp that led to where excavated soil was being stockpiled. Employee #1 was driving to the right of the ramp to dump a load when his right front wheel went up the ramp and the vehicle overturned on its side. He suffered minor injuries and was taken to the hospital, where he was treated for multiple lacerations and released. Employee #1 was not wearing a seat belt at the time of the accident, and later stated that he had not been trained to wear one. He did state that he had been trained to keep his bucket low when traveling with a full load.	Increased Cost; Exposure to liability	Revised contract language; Revised insurance policy; Investigate avenues of potential cost savings on other project features	
1B	Avoid locating electrical rooms under pipes carrying liquids that could pose a shock hazard.	[Accident: 000743799]: An employee was using a miller roughneck 2e constant-current AC welding generator (serial no. JK727114) to perform an arc welding operation. The employee, who was not wearing gloves, was standing on wet ground that was lined with steel reinforcing rods. The 27-year-old employee was found lying on his back by coworkers. The electrode holder, which contained a new welding rod with an unused factory tip was found under dripping water near his body. The dead employee was last seen welding reinforcement grid joints for a concrete wall for a new swimming pool. The employee had been electrocuted, as evidenced by visible burns on the front of his right shoulder (3 inches in diameter) and on his chest near the top of his left breast bone (1 inch in diameter). He also had a puncture wound on the inside of his left hand, between his thumb and his first finger.	Absence of Designer Interest and Motivation	Identify alternative design measure to address the associated safety hazards	
2B	Orient the project to allow for the construction of temporary roads, fire lanes, and approach roads during construction.	[Accident: 202446530]: At approximately 2:30 p.m. on July 13, 2007, Employee #1, a construction foreman, was driving a 2003 Chevy, single cab, long bed, four-wheel drive pickup truck along an uphill roadway leading to a construction site. A scraper operator, unaware of Employee #1's pickup, backed his scraper down the roadway away from the entrance to the site to permit a water truck operator enough clearance to pass the scraper and apply water on the lot. Employee #1, who was in the scraper's blind spot, could not maneuver his vehicle out of the way of the backing scraper in time. The scraper backed up and over the front driver's side of the pickup truck. Employee #1's left hand and wrist sustained serious injuries, and he was air-lifted to Loma Linda University Medical Center.	Increased Cost; Decreased project quality and diminished design creativity; Designers' lack of safety expertise	Engage outside safety experts to review designs; Utilize designers with formal safety training; Investigate avenues of potential cost savings on other project features; Identify alternative design features to address the associated safety hazards	

Page 1 of 3

**Figure 75:** DFCS-TIPS Application Operation – Printing Selected DFCS Measures and User/Project Data

11. From the 'Project Interface' page, the user clicks on the "Save and Close" button. This takes the user to the 'Interface' as seen in *Figure 76* which now includes the organization name and project title as entered for the project. The selected DFCS measures are saved along with the user and project data. To access this saved information, the user can select the project and click on the "Edit Existing Project" button. This would take the user to the 'Project Interface' page with all the data that was entered, just as seen in *Figure 69*. To delete the saved information, the user selects the project and clicks on the "Delete Existing Project" button. This will prompt the user to confirm whether he actually wishes to delete the information for the project. If he confirms, it is deleted.

The screenshot displays the DFCS-TIPS application interface. At the top, the title "DFCS-TIPS" is centered, with the subtitle "DFCS-TIPS Design For Construction Safety - Tool for Implementation on Projects and Systems" below it. The interface is divided into several sections. On the left, there is a button "Add New Project" and a section titled "Select Project and Click Edit" which contains a table with two columns: "OrganizationName" and "ProjectTitle". The first row of the table is highlighted and contains the values "A+E Firm" and "Major Building Complex". Below the table are two buttons: "Edit Existing Project" and "Delete Existing Project". On the right side, there are three buttons: "Add New DFCS Measures", "Edit or Delete Entered DFCS Measures", and "Add or Edit Potential Solutions to the Impediments of DFCS Measures". At the bottom right, there is a "Close DFCS-TIPS" button. The top of the interface has two tabs: "Why Design for Construction (DFCS) Safety?" and "Using the DFCS-TIPS Application".

OrganizationName	ProjectTitle
A+E Firm	Major Building Complex

**Figure 76:** DFCS-TIPS Application Operation – Accessing Saved Data from the Interface

12. The user distributes the recommendation or specification document for DFCS implementation on the project. During project design, several of the DFCS measures were implemented on the project based on their feasibility. And during project construction, there was a near miss incident. From the investigation of the near miss incident, it was discovered that a 'new' DFCS measure would have served in preventing the near miss incident and could thus serve in preventing future occurrences but with more severe outcomes. The user now opens the DFCS-TIPS application to incorporate the new DFCS information. Thus, from the 'Interface' page, the user clicks on the "Add New DFCS Measures" button. This takes the

user to the 'New DFCS Measure' page. The user then enters the 'new' DFCS measure and accompanying details which include the categories in which to place the measure. This is as seen in *Figure 77*. Once the information is entered, the user then clicks on the "Save DFCS Measure and Details in Database" button. This returns the user to the 'Interface' page as seen in *Figure 76*.

The screenshot shows the 'DFCS-TIPS' application window. The title bar reads 'DFCS-TIPS Design For Construction Safety - Tool for Implementation on Projects and Systems'. The main content area is a form with the following fields:

<b>DFCS Measure:</b>	When designing beam-to-column connections with more than one beam connecting to the column, us
<b>Applicable Safety Incident:</b>	There was the case of a near-miss involving a collapsed beam. This could have been prevented with implementation of the DFCS measure.
<b>Potential Impediments to Implementation:</b>	Increased Cost
<b>Potential Solutions to the Impediments:</b>	The connections could be bolted and not welded.
<b>AEC Design Profession:</b>	Civil / Structural Engineer
<b>Project Features:</b>	Member Connections
<b>Stage of Design Phase:</b>	Design Development

At the bottom left is a 'Back' button. At the bottom right is a button labeled 'Save DFCS Measure and Details in Database'.

**Figure 77:** DFCS-TIPS Application Operation – Adding New DFCS Measures and Details

13. As project construction progressed, another near miss incident occurred. The earlier entered 'new' DFCS measure was again identified as being capable of preventing the near miss incident. The user opens the DFCS-TIPS application to incorporate this information. From the 'Interface' page, the user clicks on the "Edit or Delete Entered DFCS Measures" button. This takes the user to the 'Edit Entered DFCS Measures Page'. The user then adds details to the 'Applicable Safety Incident' segment of the 'new' DFCS measure. This is as seen in *Figure 78*. The user then clicks the "Save DFCS Measure and Details in Database" button. This returns the user to the 'Interface'.

<h2 style="text-align: center;">DFCS-TIPS</h2> <p style="text-align: center;">DFCS-TIPS Design For Construction Safety - Tool for Implementation on Projects and Systems</p>	
DFCS Measure:	-When designing beam-to-column connections with more than one beam connecting to the column, u
Applicable Safety Incident:	There was the case of a near-miss involving a collapsed beam. This could have been prevented with implementation of the DFCS measure. Another near-miss incident occurred a week later which also could have been prevented through this DFCS measure.
Potential Impediments to Implementation:	Increased Cost
Potential Solutions to the Impediments:	The connections could be bolted and not welded.
AEC Design Profession:	Civil / Structural Engineer
Project Features:	Member Connections
Stage of Design Phase:	Design Development
<input type="button" value="←"/> <input type="button" value="→"/>	
<div style="display: flex; justify-content: space-between; align-items: center;"> <input type="button" value="Back"/> <input type="button" value="Delete Entered Measure"/> <input type="button" value="Save DFCS Measure and Details in Database"/> </div>	

**Figure 78:** DFCS-TIPS Application Operation – Editing Entered DFCS Measures and Details

14. As project construction progressed, the user made an observation. He saw an approach that was utilized by the construction workers to decrease a certain safety risk. This identified a potential solution to a certain DFCS measure he had seen in the DFCS-TIPS application. The user opens the application to incorporate this information. From the 'Interface' page, the user clicks on the "Add or Edit Potential Solutions to the Impediments of DFCS Measures" button. This takes the user to the 'Solutions Input' page. The user then selects the criteria for the particular DFCS measure as seen in *Figure 79*. Once done, the user clicks on the "Provide Applicable DFCS Measures" button. This takes the user to the 'Solutions Output' page. On this page, the user selects the DFCS measure to which the potential solution applies. This is as seen in *Figure 80*. The user then clicks on the "Complete Selection" button. This takes the user to the 'Solutions Entry' page. On this page, the user enters the potential solution in the 'Enter New Potential Solution to the Impediments' segment of the page. This is as seen in *Figure 81*. Once done, the user clicks on the "Save Potential Solutions to Impediments" button. This returns the user to the 'Solutions Input' page and since he does not have anything else to add at the moment, the user clicks on the "Back" button to return to the 'Interface' as seen in *Figure 76*. Once done using the DFCS-TIPS application, the user then clicks the "Close DFCS-TIPS" button on the 'Interface' to accordingly close the application. All the entered information remains saved in the DFCS-TIPS database until deleted by the user.

## DFCS-TIPS

DFCS-TIPS Design For Construction Safety - Tool for Implementation on Projects and Systems

**AEC Design Profession:**

Select AEC Design Professional

<input checked="" type="checkbox"/>	Architect
<input type="checkbox"/>	Civil / Structural Engineer
<input type="checkbox"/>	Mechanical Engineer
<input type="checkbox"/>	Electrical Engineer
<input type="checkbox"/>	Plumbing Engineer

Record: 1 of 5    No Filter    Search

**Stage of Design Phase:**

Select Stage Of Design Phase

<input type="checkbox"/>	Preliminary Design
<input type="checkbox"/>	Design Development
<input type="checkbox"/>	Construction Documents

Record: 1 of 3    No Filter    Search

**Project Features:**

Select Project Feature

<input type="checkbox"/>	Building Materials
<input type="checkbox"/>	Egress
<input type="checkbox"/>	Finishing
<input type="checkbox"/>	Floor Openings
<input type="checkbox"/>	Multi-level Project
<input type="checkbox"/>	Permanent Ladders
<input type="checkbox"/>	Project / Site Orientation
<input checked="" type="checkbox"/>	Roof
<input type="checkbox"/>	Stairways / Ramps
<input type="checkbox"/>	Walkways
<input type="checkbox"/>	Windows

Record: 8 of 11    No Filter    Search

Back

Provide Applicable DFCS Measures

**Figure 79:** DFCS-TIPS Application Operation – Selecting Input Criteria to Add Solutions to Impediments

## DFCS-TIPS

DFCS-TIPS Design For Construction Safety - Tool for Implementation on Projects and Systems

Select	Tier	DFCS Measures	Applicable Safety Incidents	Potential Impediments to Implementation	Potential Solutions to the Impediments	New Potential Solutions to the Impediments
<input checked="" type="checkbox"/>	1B	Design in a means of attaching a railing of safety lines for roofing operations to ensure fall protection for workers.	[Accident: 200841591]: On June 21, 2007, Employee #1, an iron worker, was walking backward on a roof while positioning an angle iron in preparation for making connections. He accidentally walked off the flat, leading edge of the roof and fell approximately 20 ft, striking a heavy angle iron. Employee #1 suffered severe head trauma and multiple fractures. He was wearing a full body harness with lanyard, but there were no attachment points to which he could tie off or anchor himself.	Designers' lack of safety expertise	Engage outside safety experts to review designs; Utilize designers with formal safety training	N/A
<input type="checkbox"/>	3A	Eliminate tripping hazards around roof openings.	[Accident: 201962402]: At approximately 2:30 p.m. on November 30, 2009, Employee #1 was performing roofing work for by D & E Roofing, LLC when he accidentally tripped or slipped and fell 17 ft 6 in. to the concrete floor. Employee #1 fell through an uncovered roof hatch opening.			N/A

Record: 5 of 11    No Filter    Search

Back

Select All

Deselect All

Complete Selection

**Figure 80:** DFCS-TIPS Application Operation – Selecting DFCS Measures to Add Solutions to Impediments

The screenshot displays the DFCS-TIPS application interface. At the top, a header box contains the title "DFCS-TIPS" and the subtitle "DFCS-TIPS Design For Construction Safety - Tool for Implementation on Projects and Systems". Below this, the main workspace is divided into several sections. On the left, a vertical list of labels includes "DFCS Measure:", "Potential Impediments to Implementation:", "Potential Solutions to the Impediments:", and "Enter New Potential Solution to the Impediments:". To the right of these labels are corresponding text input fields. The first field, under "DFCS Measure:", contains the text "Design in a means of attaching a railing of safety lines for roofing operations to ensure fall protection". The second field, under "Potential Impediments to Implementation:", contains "Designers' lack of safety expertise". The third field, under "Potential Solutions to the Impediments:", contains "Engage outside safety experts to review designs; Utilize designers with formal safety training". The fourth field, under "Enter New Potential Solution to the Impediments:", contains "Specify belaying bolts in the roof design". At the bottom of the main workspace, there are two navigation buttons: a left arrow and a right arrow. Below the main workspace, there is a footer bar with a "Back" button on the left and a "Save Potential Solution to Impediments" button on the right.

**Figure 81:** DFCS-TIPS Application Operation – Entering Solutions to the Impediments of DFCS Measures

This research included the testing, evaluation, and refinement of the DFCS-TIPS application's capabilities and features. This involved using manual DFCS implementation and tool-based implementation with the DFCS Toolbox as benchmarks. Ultimately, through the research tasks, the DFCS-TIPS application was validated as a viable tool to assist designers in making safety considerations in the project design phase. It was also validated as not possessing the inadequacies of existing tools that limit their effectiveness in the current construction and contractual environment of the United States.

### 4.3 Research Discussion

This section discusses certain critical issues related to DFCS as observed from this research and its collected data.

#### 4.3.1 DFCS and Construction Sequence

DFCS suggestions or measures that prescribe means, methods, techniques, sequences or procedures for the contractor will infringe on clauses in the model contracts used by design professionals in the United States and thus expose them to liability in the event of a related safety incident. For architects, this is indicated in Section 3.3.1 of the AIA A201 contract document while for engineers, this is indicated in Section 6.01.H of the EJCDC E-500 contract document. Thus,

DFCS suggestions that prescribe means, methods, techniques, sequences or procedures for the contractor were excluded through this research as they are essentially construction suggestions for worker safety and not design-phase DFCS measures. The complete list of design suggestions in this category is provided in *Appendix B1*. Three examples of such excluded suggestions are provided:

- In multi-story buildings, schedule the exterior wall structure and/or finish to go up with the framework or soon thereafter to serve as integral fall protection.
- Schedule permanent handrails to be erected along with the structural steel as one assembly to ensure worker safety as soon as the steel components are installed.
- Schedule the permanent electrical system to be installed early in the construction phase and available for use by the constructor.

Excluding such DFCS suggestions was found not to have addressed a key shortcoming of the DFCS concept. This is the fact that the effectiveness of DFCS depends on the construction sequence. Where the permanent project features intended for construction worker safety are not constructed till the end of the construction phase, there will be a minimal to negligible impact on construction safety. Thus, until the features are constructed, the construction workers must utilize appropriate safety strategies and protective measures to avoid the related hazards. This appears to be the reason why certain DFCS suggestions specified that not only should one design certain safety features, one should also schedule their construction to actually make them effective. Over 20 of such DFCS suggestions were identified. Six examples are provided:

- Design and schedule new parking areas to be constructed as early as possible to provide a formal, safe location for workers to store materials and equipment.
- Design and schedule the layout of stairway and ladder landings to be constructed as part of the foundation system of the structure.
- Design and schedule the project to minimize the amount of time excavations are open to reduce the potential of cave-ins.
- Design and schedule handrails, guardrails, and stair-rails to be erected as part of the structural steel erection to ensure worker safety as soon as the steel components are installed.
- Design and schedule lighting systems to be erected with the structural framing.
- Design and schedule ventilating systems to be in place in areas where coatings will be applied prior to applying the coatings to help remove toxins from the air.

As the design professional should not indicate the scheduling and sequencing for constructing the DFCS features so as to avoid liability exposure, such design suggestions were excluded. It must be noted that in design-build firms or projects

where the design professionals and contractor are considered the same entity with regards to liability for worker safety, such DFCS suggestions can be more easily implemented. However, this project delivery method is far less utilized than the traditional design-bid-build method and still needs to better diffuse in the AEC industry (Toole and Gambatese, 2007).

The exclusion of the DFCS suggestions, which specify designing and scheduling certain safety features, still did not address the shortcoming that some DFCS measures rely on the scheduling of their construction to be effective. This is as several research participants indicated that certain design-phase DFCS measures depended on the sequencing of their construction. Six examples of the DFCS measures they identified to fit this description are provided:

- To reduce the chance of falls, consider stairs in lieu of a permanent ladder when the ladder will be used frequently to move material and equipment.
- Protect exterior walkways and platforms from the weather (which can make them slippery) by providing a covering, extending the roof line, or locating them on the sheltered side of the structure.
- Provide a non-slip surface treatment on ramps to help prevent slipping and falling.
- Provide permanent guardrails around floor openings.
- In the design of permanent ladders, provide fixed ladder cages, wells, or other safety devices where the length of climb is less than 24 feet but the top of the ladder is at a distance greater than 24 feet above lower levels.
- Design the covers over sumps, outlet boxes, drains, etc. to be flush with the finished floor to eliminate these features as tripping hazards.

A research participant also stated “Dangers to contractors are most prevalent during construction before the designed permanent elements that you have inquired about are put in place”. What needs to be understood is, in many cases, it is not effective for the contractor to delay constructing or installing certain features till the very end of the construction phase. Hence, a significant number of design-phase DFCS measures would likely be in place to have a notable impact on construction worker safety. This gives rise to a future recommendation for research. Researchers could evaluate those DFCS suggestions, which specify designing and scheduling, to identify whether the scheduling aspect can be eliminated and the suggestions revised such that it is more effective and efficient to construct them at the earlier as opposed to the later construction stages.

#### **4.3.2 DFCS, Occupant Safety, and Maintenance Worker Safety**

In this research, DFCS suggestions that do not pertain to the safety of construction workers were excluded. Toole and Gambatese (2008) define DFCS as a process in which engineers and architects explicitly consider the safety of construction workers during the design process. Therefore, design suggestions that only pertain to maintenance workers, inspection workers, and/or project

users and occupants were excluded. The complete list of design suggestions in this category are provided in *Appendix B4*. Four examples of such suggestions are provided:

- Provide sewers with adequate access-ways to allow for ease of inspection and maintenance operations.
- Design open drainage pipes for storm sewers to allow for easy access for the removal of debris.
- To contain hazardous and flammable materials, isolate from adjoining areas the storage areas for combustible and toxic materials, such as paper, explosives, tires, celluloid, excelsior, petroleum, plastics, etc.
- Ensure that sewer lines are suitable for the maximum temperature service conditions.

The exclusion of such measures was because they had no value to DFCS. This is not to imply that DFCS measures that not only enhance construction worker safety but occupant and/or maintenance worker safety are not feasible for implementation. As a reason for the viability of DFCS is the possibility of improving safety for other project phases beyond that of construction, they are actually most feasible for implementation. By contractual agreement and industry practice, designers are clearly liable for occupant safety. It is their responsibility and it is also mandatory by building code provisions. It is also designers' responsibility to consider maintenance worker safety. This is particularly since the occupants and maintenance workers are one and the same in many instances. In other cases, there are areas of access that only maintenance workers utilize. Even for such areas, it is considered good practice for the designer to design for safety. For these reasons, design professionals are more likely to be willing to implement those DFCS measures that also enhance occupant and maintenance worker safety. This is alluded to by several research participants. One of such stated "Our focus is on occupant safety. Construction workers use these things before occupant safety is established. Perhaps if they can be mixed then it could be considered for implementation".

Research participants also indicated they found certain DFCS measures to be more applicable to occupant and operations safety. As one stated, "Some of the DFCS measures seem more applicable to operations safety instead of construction safety". Six examples of the DFCS measures they identified to be more applicable to occupant safety are provided:

- Protect exterior walkways and platforms from the weather (which can make them slippery) by providing a covering, extending the roof line, or locating them on the sheltered side of the structure.
- Design doors to swing open in the direction of exit travel.
- Provide adequate fire protection on all structural framing to protect the members from fire damage.
- Ensure that the interrupting rating is adequate to protect all equipment.

- Minimize flanges in piping under high pressure, or which contains explosive or lethal gases.
- Avoid making direct cross connections between drinking water or utility systems and plant or process streams.

It is quite true that certain DFCS measures will have minimal impact on safety in the construction phase and a more prolonged and extended impact on safety in later project phases. This is because the construction phase is typically far shorter than the operations/occupancy phase. Nevertheless, this does not affect the viability of the DFCS measures since design professionals bear liability for occupant safety. Such measures only increase the set of beneficiaries to include construction workers particularly when they are installed early enough in the construction phase to make a notable impact on worker safety.

Certain design-phase DFCS measures actually specified being in the interest of maintenance safety and not only construction safety. These measures were not excluded as they were relevant to DFCS. Four examples of such design-phase DFCS measures are provided:

- Design appropriate and permanent fall protection systems for roofs to be used for construction and maintenance purposes. Consider permanent anchorage points, lifeline attachments, and/or holes in perimeter for guardrail attachment.
- Provide permanent catwalks or work platforms for ceiling installation and maintenance on tall, long span structures.
- Provide permanent electrical outlets on the roof to allow for easy tie-in during construction and future roof maintenance.
- When designing tanks, design appropriate tank anchor points on the interior of the tank for construction and maintenance purposes.

Research participants still indicated they found other design-phase DFCS measures to be more applicable to maintenance worker safety. As one research participant stated, "When it comes to DFCS, a lot of the measures bridge the gap between maintenance worker safety and construction worker safety". Six examples of such DFCS measures are provided:

- Provide at least two means of egress on large maintenance platforms or walkways to ensure a safe exit for workers during emergencies.
- Design parapets to be 42 inches tall. A parapet of this height will provide immediate guardrail protection and eliminate the need to construct a guardrail during construction or future roof maintenance.
- In the design of permanent ladders and ladder cages, keep the inside of the cage clear of projections to ensure safe movement on the ladder.
- Design the finished floor around mechanical equipment to be at one level (no steps, blockouts, slab depressions, etc.) to reduce tripping hazards.

- Locate electrical circuit breaker boxes in sight of the equipment which they affect to ensure easy access and minimize confusion.
- Where high light fixtures are incorporated into a structure, design the possibility of the entire light fixture to be lowered for safe repair and installation of new bulbs.

Just as in the case of the design-phase DFCS measures identified as being more in the interest of occupant safety, those identified as more applicable to maintenance safety are more likely to have a prolonged safety impact on the operations/maintenance phases. In the case of MEP engineers, construction safety issues are especially closely tied in to maintenance and occupant safety (Gambatese et al, 1997). A significant number of the design-phase DFCS measures addressed safety risks from operating the equipment. A reason why such design measures are still considered applicable to construction worker safety is because, in most instances, the operations/maintenance phase begins before the construction phase concludes. It is quite rare for projects to begin operation when the project is 100 percent complete. Evidence of the close tie-in between construction and maintenance safety are the responses received from the research participants that are MEP engineers. They generally exhibited the most concern for safety and also the most safety knowledge.

DFCS measures or modifications that not only improve construction workersafety but occupant and maintenance worker safety are more likely to be implemented by AEC design professionals and more likely to be accommodated by the project owners as well. A research participant indicated that in his experience, he had not witnessed owners' rejection of maintenance safety features despite the cost and other implications. On the other hand, another research participant stated that he constantly encountered owners that were reluctant to implement any safety measures unless mandatory by regulations and building code provisions. This indicates that DFCS may have value if it is tied into occupant and maintenance worker safety through code. This does not mean making DFCS measures prescriptive or performance-based code requirements, as this would require new legislation and regulations, for which there is no certainty of achieving. Instead, it means linking the DFCS measures to related building code provisions. This could involve developing or revising DFCS measures to meet certain performance-based building code provisions and requirements. This is a new dimension, identified through this research, towards increasing DFCS implementation on capital projects.

#### **4.3.3 DFCS and Code Requirements**

The main purpose of building codes is to protect public health, safety and general welfare as they relate to the construction and occupancy of buildings and structures (ERDC, 2001). As implied, the primary application of building codes is the regulation of proposed or new construction. Typically, building code requirements apply to existing buildings only when the building is undergoing

reconstruction, rehabilitation, or alterations, or when the nature of the building occupancy has been changed (ERDC, 2001).

Essentially, building codes and standards represent the technical codification of a community's decisions on the quality of its built environment and how it should satisfy human safety needs, the need to protect the environment as an investment, and other needs as relevant or necessary for that setting (ERDC, 2001).

Public sector code enforcement officials aim to provide a comprehensive regulatory document to guide decisions within the built environment through the use of model building codes. And, a regulatory community adopts a model building code into law to establish minimum acceptable standards necessary to protect the health, safety, and welfare of its constituents (ERDC, 2001).

There are three model code organizations in the United States that promote building codes for adoption (ERDC, 2001). These are provided.

- The National Building Code: This was published by Building Officials Code Administrators (BOCA) International. It is typically used throughout the northeast and central states.
- The Uniform Building Code: This was published by the International Conference of Building Officials (ICBO). It is typically used throughout the western states.
- The Standard Building Code: This was published by Southern Building Code Congress (SBCCI) International. It is typically used throughout the southeastern United States.

There are two model code organizations that are a congregation of the different code bodies aimed at unifying practices (ERDC, 2001). These are provided.

- The International Code Council (ICC): This was established as a nonprofit organization dedicated to developing a single set of comprehensive and coordinated national codes. The International Building Code (IBC) is a model building code developed by the ICC.
- The Council of American Building Officials (CABO): This is a national organization of building code officials which, through a national consensus process, developed, adopted and promulgated the one and two-family dwelling code.

There are also specialized code organizations or trade associations that publish model building codes.

- The National Fire Protection Association (NFPA): This is a trade association that creates and maintains private, copyrighted, standards and codes for usage and adoption by local governments. This includes publications from model building codes to the many on equipment utilized by firefighters. Such model codes published by the NFPA include the National Fire Alarm Code and the National Electrical Code (NEC).

Codes are intended for general communal good and typically contain the necessary requirements to provide for the safety of the occupants of buildings and their neighbors (ERDC, 2001). They mostly provide prescriptive solutions and require strict execution of the precise terms in the code requirements. Prescriptive-based building codes are expected to provide some significant benefits. These include:

- Compliance is simple as the specifications are clearly provided.
- Since the compliance criteria are visible and readily measurable, enforcement is simple.
- The criteria for product to support in meeting the requirements are simple.

As compliance and enforcement are clearly defined and easily regulated, prescriptive standards have mostly been the code of choice by both development and regulatory communities (ERDC, 2001). But, as in the case of most prescriptive-based regulations, they do not focus on the performance of the prescribed assemblies towards preventing the undesired outcome. This does not offer the opportunity to develop creative and perhaps more effective solutions than those prescribed. As one research participant stated, “Design must not be sublimated to the regulation of life safety, and prescriptive codes often severely limit good design solutions. A performance-based code that allows design to accommodate life safety on a case by case basis is the best to do both”. Additionally, several research participants indicated they found code requirements to be very restrictive. Some also indicated they found meeting code to be an undesired requirement.

In this research, DFCS suggestions that are currently required by building codes were excluded. This primarily included those that suggested adherence. There were two main reasons. Firstly, DFCS suggestions that are already mandatory by building codes most likely exclusively pertained to occupant safety, which is already the primary safety concern of design professionals. Secondly, the fact that they are mandatory made their value in this research limited. Where building codes already require certain DFCS suggestions, there is little need for encouraging their implementation. After all, their non-implementation exposes the design professionals involved to liability and fines in the event of a related safety incident, and even to facility closure based on building inspection alone. Therefore, such suggestions were excluded if indicated as such. As the DFCS suggestions were not evaluated against building codes, only those that specified adhering to building codes were excluded. The complete list of design suggestions in this category is provided in *Appendix B7*. Four examples are provided:

- Ensure that the building height and area per floor meet all local building code requirements for the type of construction used.
- Design piping system components to meet all national, state, and local building code requirements and address the existing construction conditions to ensure worker safety.

- Ensure that tanks and vessels meet all local, state, and federal design code requirements.
- Ensure that control valve specifications meet the piping specifications for body rating, body material (corrosion and hazardous services), and flange type.

Despite the elimination of such DFCS suggestions, research participants identified several DFCS measures to be situated in code requirements. As one stated, “Many of the DFCS measures are code requirements and have to be implemented during design”. 54 DFCS measures were identified by the research participants as code requirements. Ten examples of such DFCS measures are provided:

- Use consistent tread and riser dimensions throughout the stairway run and the project.
- In the design of permanent ladders and ladder wells, keep the inside of the ladder wells clear of projections that could hamper safe movement on the ladder.
- Design doors to swing open in the direction of exit travel.
- Design structural member depths to allow adequate head room clearance around stairs, platforms, valves, and all areas of egress.
- In the design of stairs/railings, design handrails and the top rails of stair-rail systems to withstand at least 200 lbs. applied within 2 in. of the top edge in any downward or outward direction, at any point along the top edge.
- To reduce fall hazards, locate rooftop mechanical/HVAC equipment away from the edge of the structure.
- Provide ventilation systems around fueled equipment operating indoors to maintain the air quality.
- Ensure that the interrupting rating is adequate to protect all equipment.
- Provide grounding circuits to all 480 volt lighting fixtures.
- Design adequate protection against over-pressure for all piping components.

Asides from the DFCS measures identified to be situated in code requirements, research participants identified 3 measures as likely constituting code violations. These are provided:

- In the design of stairs, provide a minimum 2 ft. - 6 in. X 2 ft. - 6 in. landing area.
- Instead of regular swinging doors, use sliding or bi-fold doors.
- Avoid using spiral stairways. If spiral stairways are used, provide a handrail to prevent stepping on areas where the tread width is less than 6 inches.

The CII researchers indicated not retrieving DFCS suggestions from model building codes (Gambatese et al, 1997) yet several were identified as being situated in code. For this reason, the 212 DFCS measures identified and validated as being situated in the design-phase were evaluated to identify those that were already situated in building codes. Based on availability and access, the International Building Code (IBC) of 2006, the National Electrical Code (NEC) of 2008, the current mechanical code (MC) of New York City, and the current safety standards of the State of Michigan were utilized in the process. The findings are provided in *Table 83*.

<b>AEC Design Profession</b>		<b>Number of Design-phase DFCS Measures</b>	<b>Number of Design-phase DFCS Measures in Building Codes</b>	<b>Percentage of Design-phase DFCS Measures in Building Codes</b>
Architects		91	39	42.9%
Civil/Structural Engineers		50	9	18.0%
M/E/P Engineers		71	38	53.5%
	<i>Mechanical</i>	17	11	64.7%
	<i>Electrical</i>	20	14	70.0%
	<i>Plumbing</i>	34	13	38.2%
<b>TOTAL</b>		<b>212</b>	<b>86</b>	<b>40.6%</b>

**Table 83:** Number of Design-phase DFCS Measures in Building Codes

The sources, used as the building codes, were selected to provide an indication of the number of design-phase DFCS measures situated in code requirements. However, it must be noted that the findings depend and this is due to the nature of building codes. Despite significant efforts, building codes are not yet organized. Different elements are interconnected and code provisions are neither uniform nor static. This is as they are constantly being updated. They also differ by states and municipalities (ERDC, 2001).

A recurrent theme was encountered during this research. The AEC design professionals generally wanted to know how DFCS implementation could assist them in meeting code requirements. This presented an opportunity. The opportunity involves linking DFCS to building code compliance to serve towards increasing its implementation in the AEC industry. This is as DFCS is not mandatory. This however does not mean making DFCS measures prescriptive or performance-based code requirements. Design professionals would likely be very opposed. Several research participants indicated they only intend to meet minimal code requirements and have no intention of exceeding code. DFCS would thus likely be an unwanted addition to their concerns. As one research participant stated, "If DFCS is enforced as code, you hamper the designer ability and give more liability". This would however only be the case if it is made a prescriptive-based requirement. As DFCS is still an emerging area, this would be detrimental. This is since there is need for identification of new DFCS strategies and collection of actual DFCS implementation information. As for making it

performance-based code, this would not be detrimental as it would allow for the design professional to reach creative solutions to address the identified hazards. Hence, this could be an effective approach for improving the poor safety record of the construction industry. After all, some project participants could oppose the implementation of DFCS measures unless required by code. On another hand, some research participants indicated that DFCS measures could prove useful particularly in cases where there are no code requirements to prevent certain safety hazards. Conclusively, including DFCS and its design-phase measures as code requirements would require new legislation and regulations, for which there is no certainty of achieving. On this basis, three alternative avenues for linking DFCS to building code compliance were identified through this research.

Firstly, DFCS measures could be developed or revised to meet certain performance-based building code provisions and requirements. Secondly, this is through the development of a tool that integrates building codes which are intended for occupant safety and maintenance worker safety with DFCS measures which are intended for construction worker safety. As some research participants noted, there was unavailability of tools to aid in adherence to building codes. One research participant indicated that the closest tool to code software was COMcheck but it is not for the design phase. Also, when DFCS tools were tested in this research through interviews of AEC design professionals, their responses and commentary indicated they wanted to know how the tools could aid in adherence to building codes. Several research participants also indicated that if DFCS software is integrated with code, it would prove very useful to the industry and market. On this basis and as DFCS is not mandatory, it was determined that DFCS tools would more likely be used if they can aid in adhering to building codes. The DFCS tools could provide design-phase DFCS measures with related building code provisions alongside. They could also provide the DFCS measures developed to meet certain performance-based building code provisions as well as links to the sourced code document.

But, there are reasons for the current unavailability of effective software to aid in the building code compliance process. The field of building code provisions is quite intractable. Besides the fact that code provisions are constantly updated and not uniform, many are inadvertently replicated as they are written differently. For this reason, code writing is a contributing issue. A study by Demir et al (2010) indicated that the users of engineering codes and standards are yet to benefit from the advanced processing and reasoning capabilities of web technologies and information systems partially due to the difficulty of finding appropriate syntaxes to represent the standards. These syntaxes are required to be easily understood and able to be processed by a computer, and also need to be testable and maintainable by standards writing organizations. Recent research developments are attempting to address the underlying issues with regards to vocabulary and code logic. Research by Demir et al (2010) is intended to eventually develop a tool for code writing to address overlaps. This and other research are ultimately to serve towards enabling the development of effective tools to aid the users of codes in identifying applicable code provisions and

complying with them. With this achieved, code compliance tools could be integrated with DFCS tools to produce a composite project safety tool.

The third avenue for linking DFCS to building code compliance is in the DFCS implementation process. Most middle to large-sized AEC design firms employ quality control supervisors. The supervisor evaluates project designs to assure of occupant safety and to ensure of compliance with building codes and other requirements including ADA design standards. Essentially, the supervisor addresses safety for the project designers just the way the safety officer addresses safety for the contractor. Some supervisors are known for being very effective and efficient in identifying safety issues. This makes the quality control supervisor a good candidate as the designated staff charged with ensuring DFCS implementation. This could be a solution to several DFCS impediments. With regards to exposure to liability, the supervisor would likely have limited concern as his/her duties typically involve evaluating safety issues situated in the design phase. As he is familiar with toeing this line, he already knows not to prescribe means, methods, or sequences for the contractor. As a matter of fact, he is mostly the staff that omits or modifies design specifications to ensure they don't expose the design firm or professionals to liability. Hence, he would know better than to implement or specify DFCS measures not situated in the project design phase. Furthermore, where the supervisor is charged with DFCS implementation, it allows the AEC design professionals to concentrate on their main design priorities and decreases the possibility that their concern about exposure to liability may limit their designs. Furthermore, their lack of safety expertise would be significantly diminished as an impediment. The quality control supervisor usually views the major design elements as constraints and then works around them to achieve code requirements. Hence, the issue of diminished project quality would likely be a minimal impediment. Additionally, quality control supervisors usually strive to ensure adherence with the least modifications to the design and with minimal cost and schedule implications. If they maintain this approach, both issues would constitute only minute impediments. And lastly, absence of designer interest and motivation would become a non-factor as the staff charged with assuring safety is utilized to assure of safety though for construction workers in this instance. Hence, the inclusion of DFCS implementation in the responsibilities of the quality control supervisor at the AEC design firm may prove most effective.

Linking DFCS implementation to building code compliance was identified as a viable and perhaps more effective dimension towards improving and increasing DFCS implementation. A significant number of design-phase DFCS measures were identified as being situated in code. It is very likely that some of the DFCS measures were included in code between when they were developed in earlier CII research and when this research was executed. This is as code has been updated multiple times during the period. It must also be noted that this study was not to validate the relevance of DFCS to current practices. This study was instead aimed at minimizing the impediments to DFCS implementation which limited its diffusion for well over a decade.

#### 4.3.4 New DFCS Measures

Though the development of additional DFCS measures was not within the scope of this research, several were yielded. From the surveys of AEC design professionals, two were yielded from the same research participant. He provided them as alternate approaches to addressing the same safety hazard as this DFCS measure: “Avoid steel beams of common depth connecting into the column web at the same location”. The ‘new’ DFCS measures are provided:

- When designing beam-to-column connections with more than one beam connecting to the column, use a four-bolt connection on one side and a three bolt connection on the other side.
- Use seated connections for beam-to-column connections particularly where there are multiple beams connecting to the column.

From the interviews of AEC design professionals, four were yielded. These were mostly volunteered by the research participants as measures to serve in addressing certain safety risks. They are provided:

- Install safety-designed permanent ladders early in the construction phase.
- Utilize safety harnesses that can withstand 5000lbs in any direction and that have a 1000lb shock absorber.
- Use bridging members for roof trusses.
- Use magnetic tape on utility lines to enable easy detection.

The software testing interviews of AEC design professionals included a manual DFCS implementation segment. In this segment of the interview, the research participants suggested different design measures that could be utilized in improving the safety of construction workers on a hypothetical building project. These are provided:

- Eliminate the spiral staircase particularly if the building is high occupancy.
- Provide guardrail.
- Provide rails for stairs.
- Ensure stair widths are appropriate.
- Ensure there are adequate means to get smoke out of building.
- Increase stairway access to the top floor.
- Make the stairs shorter.
- Make clearer paths to exits.
- Adjust some of the doors. Doors are pinch points that may be unnecessary.
- Fire stairs should be shifted more closely to the points of egress.
- Fire doors should not be present at the spiral stairs.
- Sprinklers should be appropriately placed throughout the building.
- Make the door swing outward in the direction of exit.

- Eliminate circular stairs.
- Use the most efficient size members so they are of the least weight.
- Accessibility to the project site must be designed and detailed adequately.
- Design the layout to allow for field splices.
- Specify different products such as metal deck with anti-slip surfaces. The material selection could be adjusted based on the time of year of construction.
- Use panelized construction to lift up and fix rather than sending worker up to heights.
- Allow for extensive use of prefabricated items.
- Avoid cantilevers.
- Prescribe the spaces between columns to be adequate, at least 15 feet apart.
- The points and means of egress should be increased to meet code requirements.
- Par IBC, there should be clear unobstructed directions of exit.
- There should be more exits.
- The exits should be lit with emergency power.
- The doors should swing out in the direction of egress for electrical rooms.
- The elevator should have redundant light sources.
- Water service should be grounded within 6 inches.
- Place disclaimer to call for direction before you dig the ground.
- Emergency exit doors should also swing out.
- Use wall mounted alarm devices to ensure visibility.
- There should be enough building openings to ensure there is adequate smoke evacuation.
- The sprinklers should be placed to ensure adequate reach.
- Elevator machine room should be appropriately located.
- Electrical rooms should be located close to main service entrances.
- Keep live electrical elements protected and underground.
- Keep the transformer 10 feet or more from the building. Terminate inside the building.
- No exposed wires and utilities.
- Keep electrical separate from other utilities.
- Follow code (NEC) Arc 100 worker safety clearance. Layout main electrical clearances to meet these requirements.
- Assess the amperes or voltage. If high, use double the clearance and 2 points of exit in the electrical room.
- Voltage will be 480V for this building so an indoor transformer will be needed to be located in well-situated electrical rooms.
- Work to get the accurate fire ratings then consider if the building will have a sprinkler system.
- Layout the flashing and specification and height to follow the ADA guidelines for mounting devices.
- Design appropriate clearances for electric panels.

- Apply emergency lighting, egress lighting and exit signs. These can be powered by batteries. The owner would be responsible to check them. These are all part of public safety requirements.
- Layout the building to ensure a crane could get into the site and fit rooftop mechanical units on the roof.
- Check for pathways to ensure they are adequate to get things in and out.
- Check for switchgear access and removal.
- Have permanent scaffolding or lifting capabilities where lighting will go into high ceiling. In new construction, one might not have to say it.

In the research tasks, none of the listed design suggestions were evaluated. Some were roughly identical. Some were broad and had more specific requirements in DFCS measures or code provisions. None were assessed to identify if they met the criteria for DFCS. Hence, they were integrated and categorized.

1. These design suggestions were among those yielded through CII's research. Hence, they were already utilized in this research and some of them were eventually categorized as design-phase DFCS measures.
  - Eliminate the spiral staircase particularly if the building is high occupancy. Eliminate circular stairs.
  - Avoid cantilevers.
  - Provide guardrail.
  - Use the most efficient size members so they are of the least weight.
  - Accessibility to the project site must be designed and detailed adequately.
  - Provide rails for stairs.
  - Allow for extensive use of prefabricated items.
  - Make the door swing outward in the direction of exit.
  - Use panelized construction to lift up and fix rather than sending worker up to heights.
  - Design appropriate clearances for electric panels.
  - Check for pathways to ensure they are adequate to get things in and out.
  - Place disclaimer to call for direction before you dig the ground.
2. These design suggestions were specific to the building plan used in the manual DFCS implementation of the software testing interviews.
  - Make the stairs shorter.
  - Adjust some of the doors. Doors are pinch points that may be unnecessary.
  - Increase stairway access to the top floor.
  - Make clearer paths to exits.
  - Fire stairs should be shifted more closely to the points of egress.
  - Fire doors should not be present at the spiral stairs.

- There should be more exits.
  - Voltage will be 480V for this building so an indoor transformer will be needed to be located in well-situated electrical rooms.
3. These design suggestions are situated in the construction phase and are therefore not design-phase DFCS measures.
- Install safety-designed permanent ladders early in the construction phase.
  - Utilize safety harnesses that can withstand 5000lbs in any direction and that have a 1000lb shock absorber.
4. These design suggestions specify adherence to code requirements and most likely pertain to occupant safety.
- Per IBC, there should be a clear unobstructed direction of exit.
  - Ensure stair widths are appropriate.
  - Follow code (NEC) Arc 100 worker safety clearance. Layout main electrical clearances to meet these requirements.
  - Layout the flashing and specification and height to follow the ADA guidelines for mounting devices.
  - The points and means of egress should be increased to meet code requirements.
  - Work to get the accurate fire ratings then consider if the building will have a sprinkler system.
  - Apply emergency lighting, egress lighting and exit signs. These can be powered by batteries. The owner would be responsible to check them. These are all part of public safety requirements.
5. These design suggestions were considered to be situated in the project design phase and were also not identified in earlier DFCS research.
- When designing beam-to-column connections with more than one beam connecting to the column, use a four-bolt connection on one side and a three bolt connection on the other side.
  - Use seated connections for beam-to-column connections particularly where there are multiple beams connecting to the column.
  - Use bridging members for roof trusses.
  - Use magnetic tape on utility lines to enable easy detection.
  - Have permanent scaffolding or lifting capabilities where lighting will go into high ceiling. In new construction, one might not have to say it.
  - Design the layout to allow for field splices.
  - Layout the building to ensure a crane could get into the site and fit rooftop mechanical units on the roof.
  - Elevator machine room should be appropriately located.
  - Electrical rooms should be located close to main service entrances.

- Specify different products such as metal deck with anti-slip surfaces. Material selection could also be adjusted based on the time of year of construction.
- Prescribe the spaces between columns to be adequate, at least 15 feet apart.
- Check for switchgear access and removal.
- Emergency exit doors should also swing out.
- Keep the transformer 10 feet or more from the building. Terminate inside the building.
- The doors should swing out in the direction of egress for electrical rooms.
- Sprinklers should be appropriately placed throughout the building. The sprinklers should be placed to ensure adequate reach.
- Assess the amperes or voltage. If high, there should be double the clearance and 2 points of exit in the electrical room.
- Ensure there are adequate means to get smoke out of building. There should be enough building openings to ensure there is adequate smoke evacuation.
- The exits should be lit with emergency power.
- Keep live electrical elements protected and underground. No exposed wires and utilities.
- Use wall mounted alarm devices to ensure visibility.
- Keep electrical separate from other utilities.
- The elevator should have redundant light sources.
- Water service should be grounded within 6 inches.

There was a need to further categorize those design suggestions identified as being situated in the project design phase. This was to identify those that are already situated in building codes. Such design suggestions do not need to be encouraged for implementation as they are already mandatory. Based on availability and access, the IBC of 2006, the NEC of 2008, and the current mechanical code of New York City were utilized in the process. Those design suggestions identified as being in code requirements are provided.

- Elevator machine room should be appropriately located.
- Emergency exit doors should also swing out.
- Keep the transformer 10 feet or more from the building. Terminate inside the building.
- The doors should swing out in the direction of egress for electrical rooms.
- Sprinklers should be appropriately placed throughout the building. The sprinklers should be placed to ensure adequate reach.
- The exits should be lit with emergency power.
- The elevator should have redundant light sources.
- Use wall mounted alarm devices to ensure visibility.
- Keep live electrical elements protected and underground. No exposed wires and utilities.

The remaining design suggestions are those that could be considered design-phase DFCS measures and be included in future DFCS research towards characterizing and determining their feasibility. The 15 measures are classified by the applicable design professions.

- Architects
  - Layout the building to ensure a crane could get into the site and fit rooftop mechanical units on the roof.
  - Ensure there are adequate means to get smoke out of building. There should be enough building openings to ensure there is adequate smoke evacuation.
- Civil/Structural Engineers
  - When designing beam-to-column connections with more than one beam connecting to the column, use a four-bolt connection on one side and a three bolt connection on the other side.
  - Use seated connections for beam-to-column connections particularly where there are multiple beams connecting to the column.
  - Use bridging members for roof trusses.
  - Prescribe the spaces between columns to be adequate, at least 15 feet apart.
  - Specify different products such as metal deck with anti-slip surfaces. Material selection could also be adjusted based on the time of year of construction.
  - Design the layout to allow for field splices.
- MEP Engineers – Mechanical Engineers
  - Use magnetic tape on utility lines to enable easy detection.
- MEP Engineers – Electrical Engineers
  - Assess the amperes or voltage. If high, there should be double the clearance and 2 points of exit in the electrical room.
  - Have permanent scaffolding or lifting capabilities where lighting will go into high ceiling. In new construction, one might not have to say it.
  - Keep electrical separate from other utilities.
  - Check for switchgear access and removal.
  - Electrical rooms should be located close to main service entrances.
- MEP Engineers – Plumbing Engineers
  - Water service should be grounded within 6 inches.

## **5.0 Contributions**

This research is aimed at aiding, improving and increasing DFCS implementation on projects so as to enhance the safety of construction workers. Towards this, the research achieved a number of contributions in minimizing the impediments to DFCS.

### **5.1 Characterization of DFCS Suggestions**

This research was successful in characterizing the design suggestions for construction worker safety yielded from earlier research. Earlier research seemed to have focused on amassing information on DFCS and potential approaches that could be utilized in its implementation. The design suggestions were however not subjected to assessment to determine whether they met the criteria for DFCS. These criteria were specified in the definitions of DFCS. As such, some of the suggestions were not within the control of the design professionals to implement and pertained to the responsibilities of other project participants. Without characterizing the design suggestions to identify those situated in project design, pertaining to permanent project features, and do not infringe on contractor responsibilities, the user of the suggestions is essentially utilizing a guideline that could provide increased exposure to liability. Additionally, a design professional is both more familiar with and more likely to implement DFCS suggestions that are applicable to his/her design discipline. Based on these reasons, the design suggestions for construction worker safety were characterized, identifying and validating those that are design-phase DFCS measures. Hence, the measures yielded were those that could more feasibly be implemented in the current United States construction and contractual environment. The characterization also identified design suggestions that were better described as construction suggestions for worker safety as they are applicable to the construction phase. The DFCS measures were further characterized identifying those applicable to the different design disciplines and also identifying those applicable to the different stages of the design phase.

This research brought focus to individual DFCS measures and their feasibility for implementation as opposed to for the DFCS concept as a whole. In doing so, the impediments to implementing individual DFCS measures were identified where applicable. Earlier research identified the most critical impediments to DFCS to include designers' concern about increased liability, increased cost, and designers' lack of safety expertise. Others include concerns about schedule problems, diminished design creativity, and designers' lack of interest. By characterizing the DFCS measures in terms of which impediments apply to them, the issues that should be surmounted by AEC design professionals to enhance the feasibility of their implementation are provided.

Research by Behm (2006) yielded the number of construction safety incidents that could have been prevented through implementation of 73 selected design suggestions. This research expanded on the model to yield preventable construction injury incidents for all the design-phase DFCS measures. This further characterized the DFCS measures by providing illustrative cases for their implementation. This research also characterized DFCS measures by identifying those that required revision and then, revised them. This was done to make the design-phase DFCS measures more viable for implementation and for improving construction safety.

The characterization of design suggestions yielded a more fine-tuned and detailed body of knowledge that could be utilized in DFCS implementation. This was important as the research participants mostly indicated they neither had adequate construction safety expertise nor significant experience in implementing DFCS. This further validated designers' lack of safety expertise as an impediment to DFCS. Additionally, research participants indicated the characterizations of the DFCS measures as being very helpful in the DFCS implementation process.

This research also developed a computer application, named DFCS-TIPS, to encapsulate the research findings and to serve as a vehicle for utilizing the research data to enhance DFCS implementation. The application was developed to be without the inadequacies of existing DFCS tools. In doing so, the DFCS measures were further characterized to enable certain functionalities to meet the application requirements for effectiveness and usability. To avoid 'dead-end' scenarios, potential solutions to the DFCS impediments as identified from earlier research were indicated in all cases where the impediments were identified for the different DFCS measures. Another characterization is the 'tier of feasibility'. This was to allow a user to identify those design-phase DFCS measures validated to have no identified impediments and those with some identified impediments. It would also allow users to identify measures based on confidence in their level of effectiveness as determined through this research. The DFCS-TIPS application was tested in the research through interviews of AEC design professionals. Through their responses, a set of features were identified for more advanced and effective software to enhance the DFCS implementation process.

The 'tier of feasibility' characterization also serves to define the research results as not all DFCS measures were subjected to as many research tasks or yielded certain results through the research tasks. Hence, it identifies the DFCS measures that should be prioritized for further characterization based on the approaches and outcomes of this research. A number of 'new' design suggestions for construction worker safety were provided by research participants. These were also characterized to identify those that are situated in the project design phase and meet the criteria for DFCS. These 'new' design-phase DFCS measures are a contribution that could be subjected to further characterization in future research.

Ultimately, this research produced deliverables that decrease the need for designers' safety expertise, avoid increased exposure to liability, and potentially increase designer interest in DFCS. The research also identified where the remaining impediments are applicable. These include increased cost, schedule problems and time constraints, and diminished design creativity and decreased project quality. Hence, the contributions of this research serve in minimizing DFCS impediments, and as a result, could potentially increase the implementation of DFCS on capital projects towards the improvement of construction worker safety.

## **5.2 Addressed Several DFCS Research Gaps**

This research, through its deliverables, serves in fulfilling some of the CPWR recommendations for DFCS research, and also serves in addressing some of the NIOSH NORA DFCS information gaps, that are presented in *Section 1.2.1*. These are both aimed at enhancing DFCS and its implementation.

The CPWR recommendations fulfilled through this research include the accumulation of demonstrable evidence on the effectiveness of DFCS, and this comprises of the investigation of fatal and non-fatal injuries with a special focus on the role of the project design, and also the evaluation of the feasibility of implementing individual DFCS measures. Another fulfilled CPWR recommendation is the development of case studies on the negative consequences of ignoring worker safety in building designs. These were accomplished through the identification of design-phase DFCS measures and their preventable safety incidents. Lastly, this research fulfills the recommendation, for the evaluation of project delivery methods along with design and construction contracts, in developing a design tool to assist designers in addressing safety.

Meanwhile, the NIOSH NORA research gaps addressed through this research include the creation of a repository of existing programs, checklists, and best practices for DFCS which are adaptable according to type of construction. Another is the collection of case studies to effectively demonstrate the DFCS concept and strategies. Another NIOSH NORA research gap addressed through the research is the development of design specifications that allow designers to incorporate DFCS concepts without exposing themselves to inappropriate liability. This is part of the NIOSH NORA broader goal of evaluating, clarifying and addressing the most prevalent obstacles to acceptance and implementation of DFCS. The remaining research gap addressed through this research is the development of tools such as educational documents, checklists, databases and interactive software to enable designers to perform DFCS. The main goal of NIOSH NORA with regards to DFCS is to increase its use so as to prevent or reduce safety and health hazards in construction.

### **5.3 New Dimension for Increasing DFCS Implementation**

This research determined that DFCS measures or modifications that not only improve construction worker safety but occupant and maintenance worker safety are more likely to be implemented by AEC design professionals and more likely to be accommodated by the project owners as well. This determination was made based on the responses of the research participants. This led to the identification of a new dimension for increasing and improving DFCS implementation, through linking DFCS to building code compliance. This is through three potential approaches.

Firstly, DFCS measures could be developed or revised to meet certain performance-based building code provisions and requirements. Secondly, this is through the development of software that integrates building codes which are intended for occupant safety and maintenance worker safety with DFCS measures which are intended for construction worker safety. As some research participants noted, there is unavailability of effective software to aid in adherence to building codes. Several research participants also indicated that if DFCS software is integrated with code, it would prove very useful to the industry and market. On this basis and as DFCS is not mandatory, it was determined that DFCS software would more likely be used if they can aid in adhering to building codes. After all, no research participant indicated familiarity with using any existing DFCS software. The composite DFCS and code software could provide design-phase DFCS measures with related building code provisions alongside. It could also provide the DFCS measures developed to meet certain performance-based building code provisions as well as links to the sourced code documents.

The third approach for linking DFCS to building code compliance is in the DFCS implementation process. Most middle to large-sized AEC design firms employ quality control supervisors. The supervisor evaluates project designs to assure of occupant safety and to ensure of compliance with building codes and other requirements including ADA design standards. Some supervisors are known for being very effective and efficient in identifying safety issues. This makes the quality control supervisor a good candidate as the designated staff charged with DFCS implementation. This could be a solution to several DFCS impediments. It would also allay designer concerns that impact both their willingness and effectiveness in DFCS implementation. Hence, the inclusion of DFCS implementation in the responsibilities of the quality control supervisor at the AEC design firm may prove a very effective strategy.

Though not necessarily a new dimension, this research further emphasized that the design-build project delivery method offers more opportunity and fewer barriers for DFCS implementation. This is due to the fact that liability for worker safety would apply to both the contractor and the design professional. And this is typically whether or not they are employees of the same company as their contractual relationship to the owner is linked. A research participant indicated

extreme willingness to design for construction worker safety and provided the reason as being that he was mostly involved in design-build projects. He stated that he thus possessed the ability to make DFCS specifications with less opposition. The research participant also indicated that he maintained very cordial relationships with the contractor and construction workers involved on his projects. And, as he had been involved with the construction workers on several projects, he indicated it was to be expected that he would be concerned for their safety. A study by Gambatese and Hinze (1999) had commented that this could be the case when it came to DFCS implementation by design-build firms or on design-build projects. Even in such a scenario, linking DFCS to building code compliance could prove very effective in increasing and improving DFCS implementation.

## 6.0 Research Timeline

The timeline of the research is provided in *Table 84*.

RESEARCH TIMELINE																		
	Research Tasks	Timeline																
		Year	2011										2012					
			Month	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1.	Indexing and Categorization of Design Suggestions from CII's DFCS Toolbox																	
2.	Surveys of AEC Design Professionals (Development + Execution)																	
3.	Identification of Applicable Safety Incidents from OSHA Database																	
4.	Interviews of AEC Design Professionals (Development + Execution)																	
5.	Development of Relational Database Application																	
6.	Testing Interviews and Improvement of Relational Database Application																	
7.	Documentation, Submission and Presentation of Research Work and Dissertation																	

**Table 84:** Research Timeline

## **7.0 Summary, Limitations and Recommendations for Future Research**

### **7.1 Summary**

With more than \$800 Billion in new construction annually, the construction industry is one of the largest industries in the United States employing up to 7.2 million wage and salary jobs, and 1.8 million self-employed and unpaid family workers (BLS, 2010). A complimentary industry to that of construction is the Architectural, Engineering, and Related Services industry which provides the design services typically required to execute construction work. This industry employs roughly 1.4 million people (BLS, 2010).

The construction industry is notorious for having one of the worst safety records among all industries in the private sector accounting for up to 18% of work-related deaths and 15% of all worker compensation cases with approximately 1,000 construction workers killed annually in the United States (Bentil, 1990; Behm, 2005; and BLS, 2000-2009). The reasons for the poor safety record stem from the nature of construction work which includes many inherently hazardous conditions and tasks (NIOSH, 2009). Such include site conditions and geographical factors along with factors determined by the project scope. Other reasons are due to the nature of the construction workforce and organizations. These include such issues as seasonal employment, high turnover, and also training and cultural factors.

Major construction site safety hazards include falls of individuals and materials, strike by equipment, electrical shocks, transport accidents, excavation collapses, exposure to hazardous substances, fires and explosions, and overturning or collapse of site structure (BLS, 2010). The common root causes of these safety hazards include human error, strenuous work, unsafe practices, poor supervision and drug and alcohol use (Toole, 2002; Huang, 2003; and CII, 2003). Macro-level factors affecting construction safety were also identified and these include size of construction firm, type of contractual agreement between the owner and contractor, type of project delivery method, management and owner commitment to safety, and also number of firms involved in a project.

In addressing safety on a construction or capital project, CII (2003) encouraged a number of best practice measures that include management participation in accident investigation, safety staffing, safety planning, safety training and education, worker participation and involvement, recognition and rewards, subcontractor management, accident reporting and investigation, and drug and alcohol testing. There are also a number of protective measures identified to prevent site safety hazards or to reduce injury in the event of their occurrence. These include the use of personal protective equipment, safety harnessing systems, guardrail systems, housekeeping, and also signs, signals and barricades (Davies and Tomasin, 1996; and Reese and Eidson, 1999). Another

approach for improving construction safety is the monitoring, investigation, and analysis of near misses. Research by CII (2003) found companies that tracked near misses to have better safety performance. The study also found that injury rates were lower for companies that recorded more near misses. Though the documentation and investigation of near misses is not required by law as in the case of accident reporting and investigation for recordable injuries, addressing the root causes of near misses could serve to prevent the incidents from reoccurring but with more tragic results (ENR, 2009). This then could serve towards strengthening the safety management plans of projects and companies.

Additionally, a number of safety initiatives and programs were also identified. These include project safety assessment, design for construction safety, best value bid approach, collaborative project procurement, fire protection programs, site safety monitoring, facility management and maintenance safety programs, and also, demolition safety planning (Reese and Eidson, 1999; Hislop, 1999; Anumba, 1999; and Scott et al, 2006). Technological developments have also been contrived towards making specific construction activities safer and also towards improving the effectiveness of certain safety strategies. These include material, automated construction, site surveillance, site planning and other technologies.

Safety regulations were also discussed as the means through which governments address worker safety. In the United States, the Occupational Safety and Health Administration (OSHA) of the Department of Labor is the official conductor of safety regulatory oversight in all sectors and industries. Safety and health requirements for the construction industry are situated in Part 1926 of OSHA's regulatory standards, and include 26 subparts addressing a significant number of issues and activities ranging from fall protection to excavations, ladders and steel erection among many others.

Earlier research developed a number of models for addressing construction safety. The models differ in purpose, function, and format. They also show different factors, features, and issues that can impact construction site safety. Examples of these include the Accident Causation model, the Accident Root Causes Tracing model, the Constraint-Response model, Marcum and Veltri's Analytic model, the Modified Loss Causation model, Reason's Accident Trajectory model, the Safety Equilibrium model, the Task Demand-Capability model, and the Two-Factor model. Among all the presented models of construction safety, only three consider issues that potentially arise from the pre-construction project phases. These include the Constraint-Response model, Reason's Accident Trajectory model, and the Two-Factor model.

The different safety strategies and programs apply to different phases in a capital project. There are typically seven project phases which include concept and feasibility studies, design and engineering, procurement, construction, start-up and commissioning, operation and utilization, and disposal and decommissioning. Based on information from earlier literature, I developed the

safety delivery lifecycle to indicate the applicable project phases for each of the strategies. The project lifecycle was considered from the owner's perspective and as applicable to design-bid-build projects.

Strategies applicable to the earlier project phases were determined to more likely have a significant impact in improving construction worker safety. This is for three main reasons. Firstly, the ability to influence safety declines as a project advances through its phases (Stephenson, 1991; and Symberski, 1997). Safety risk is therefore best mitigated in the early phases of a capital project. Secondly, the early identification and elimination of potential safety hazards is a more cost-effective approach to addressing construction worker safety. This is because it is less costly to combat risks at source than to contain problems when they occur at a later phase (Anumba, 1999). Lastly, implementing safety strategies in the early project phases can positively influence the implementation of strategies applicable to later phases.

The strategies applicable to the pre-construction project phases include project safety assessment, design for construction safety (DFCS), best value bid approach, and collaborative project procurement approaches. Among the strategies, DFCS currently has the most potential to make an immediate contribution in decreasing construction site safety incidents as it has the ability to function effectively in the current construction environment without requiring any major changes in procedure or contractual structure.

DFCS, also known as "Construction Hazard Prevention through Design (CHPtD)", is defined as the consideration of construction site safety in the design of a project (Behm, 2005). It was also defined as a process in which engineers and architects explicitly consider the safety of construction workers during the design process (Toole and Gambatese, 2008). DFCS entails addressing construction worker safety in the design of permanent project features (Gambatese et al, 2005). DFCS addresses safety by minimizing the number of safety decisions that have to be made by contractors and construction workers on the work site. By eliminating a hazard at the design phase, a decision will no longer have to be made on site, with regards to preventing or minimizing the hazard. This results in fewer opportunities for poor safety decisions made on site, leading to accidents (Mroszczyk, 2006). Eliminating the hazard is recognized as a far more effective way to improve safety than reducing the hazard risk or providing safety devices, warning systems and personal protective equipment to workers (Manuel, 1997; and Gambatese et al, 2005).

Gambatese et al (2005) identify project characteristics or issues that DFCS implementation could potentially impact along with those that could potentially impact DFCS implementation. Designer knowledge of the concept, designer acceptance of the concept, design education and training, designer motivation to implement the concept, ease of implementation of the concept, availability of implementation tools and resources, competing design/project objectives, and design criteria/physical characteristics are the factors identified to impact DFCS

implementation. Meanwhile, construction worker safety, other construction characteristics, completed facility characteristics, and design firm liability/profitability, are the factors identified to be either impacted or have implications through DFCS implementation.

A number of research cases have been made for implementing DFCS as a safety strategy. For example, Weinstein et al (2005) conducted an analysis of a full-scale DFCS initiative during the design and construction of a \$1.5 billion semiconductor fabrication and research facility in the Pacific Northwest of the United States. In the project, DFCS was found to have been successful in eliminating or mitigating significant safety and health hazards during construction. Another study by Behm (2005) investigated 224 construction fatality investigation reports and determined that the associated risk that contributed to 42% of the incidents would have either been reduced or eliminated had the DFCS concept been utilized. A successive study by Gambatese et al (2008) validated 71% of the reviewed cases.

Worker safety consideration has traditionally not been part of the project designer's role (Gambatese et al, 2005). The contractor is generally recognized as the project participant responsible for construction worker safety (Hinze and Wiegand, 1992; Gambatese, 1998; and Mroszczyk, 2006). As the primary party that executes construction, the contractor is responsible for ensuring the safety of its workers. This is also indicated in OSHA regulations and model contract language. However, as the project design dictates not only how a project will appear but how the project and its components will be assembled, designers can have influence on the safety of the project's construction (Gambatese and Hinze, 1999). The role of designers in construction safety has also been recognized by OSHA as some subparts and paragraphs of the regulatory standards require or suggest the involvement of a professional engineer (Toole and Gambatese, 2002). In the United Kingdom, designers and all project participants have been mandated outright to participate in construction worker safety related matters through the Construction, Design and Management (CDM) regulations of 1995.

A study by Toole (2005) identified five tasks through which designers could increase their safety roles. These include reviewing for safety, creating design documents for safety, procuring for safety, reviewing submittals for safety, and inspecting site operations for safety. While all these tasks can meaningfully contribute to construction worker safety, not all are feasible for implementation due to a number of barriers that include increased exposure to liability and increased conflict with budget, duration, functionality and aesthetics (Toole, 2005). These barriers have also collectively limited designer's motivation and interest in construction safety. An additional barrier is their lack of safety expertise which could limit the effectiveness of their role in construction safety.

Among all the barriers, fear of liability exposure is the most significant (Hinze and Wiegand, 1992). To avoid this barrier, designers' role in construction safety must

not infringe on contractors' responsibilities. Designers must therefore not attempt to manage worker and site safety during construction and should only focus on minimizing or eliminating safety hazards through their designs. Additionally, their expertise should address the safety aspects of permanent structures and not the temporary structures used during construction. DFCS is essentially an active safety hazard risk mitigation strategy for designers and a passive one for contractors. These guidelines underlie the DFCS concept and its implementation process. Toole and Gambatese (2008) identify five future trajectories for DFCS which include increased prefabrication, increased use of less hazardous materials and systems, increased application of construction engineering, increased spatial investigation and consideration, and increased collaboration and integration.

The process of implementing DFCS involves conducting constructability reviews in the project design phase (Gambatese et al, 2005). Constructability review involves the incorporation of construction knowledge in the design of a project (Gambatese, 2000). Decreased cost, decreased schedule and improved quality constitute the primary objectives of constructability analysis and review (Gambatese et al, 2007). Improved safety is considered an added benefit. Decreased schedule means there is less period of risk exposure for the construction workers to get injured. Improved quality means less need for rework which also means a lesser period of risk exposure for the construction workers. Additionally, ensuring the ability to complete the project using standard construction methods, materials and techniques means the workers are more likely to have both the training and experience to execute the tasks with less safety risk. When it comes to the safety constructability review process or DFCS implementation, the key feature is the input of site safety knowledge into design decisions (Toole et al, 2006). As the review stages advance, the degree of detail of the design measures for safety are to increase. During the reviews, the design professional weighs the merits of implementing the design measures based on project characteristics, constraints and features, and then decides which to implement (Gambatese, 2000). Upon completing DFCS implementation, the design documents will not look different from typical drawings and specifications but will however reflect an inherently safer design that minimizes or eliminates risks of certain construction hazards (Toole et al, 2006).

With regards to the site safety knowledge input, few design professionals possess the expertise necessary to effectively perform DFCS (Gambatese et al, 2005; and Toole, 2005). Towards this, researchers have developed guidelines and tools to aid the DFCS implementation process. An example is a computer application, the CII's DFCS Toolbox, with over 400 design suggestions for safety incorporated in it (Gambatese et al, 1997). Despite the presence of guidelines and tools for DFCS, many design professionals have remained reluctant or unwilling to implement DFCS. Research by Gambatese et al (2005) investigated this matter and through face-to-face surveys of AEC design professionals, identified a number of impediments to DFCS implementation. The impediments

mainly stem from designer perceptions and concerns on the outcomes of implementation. The most critical impediments include designers' concern about increased liability, increased cost, and designers' lack of safety expertise. Others include concerns about schedule problems and time constraints, decreased project quality and diminished design creativity, and designers' lack of interest and motivation.

Earlier research proposed solutions through which the impediments to DFCS implementation could be addressed. These include revising model contract language and insurance policies, provision of formal DFCS training to undergraduates and professionals, the provision of incentives, and the provision of additional DFCS guidelines and tools (Gambatese et al, 1997; Gambatese et al, 2005; and Toole, 2005). These solutions would involve conducting further research on DFCS and collecting data on actual cases of DFCS implementation, and documenting the details and outcomes. This is also echoed in the Center to Protect Workers' Rights (CPWR) recommendations for DFCS research and also the National Institute for Occupational Safety and Health (NIOSH) National Research Agenda (NORA) DFCS information gaps.

This research considered a different paradigm towards increasing DFCS implementation. The new paradigm considers that several guidelines and tools have already been provided to enable and aid DFCS implementation but are however incomplete, inaccurate and/or inadequate to serve their intended purpose. This is particularly since many of the guidelines and tools have been available for over a decade but, are still experiencing limited use with the diffusion of DFCS relatively minimal in the United States (Toole and Gambatese, 2008). To better enable DFCS implementation, the available tools could be fine-tuned through research. They could be improved to address or avoid the impediments to DFCS implementation. On this basis and with consideration given to feasibility, I decided on a number of research deliverables.

1. DFCS measures applicable to the design phase of a capital project.
2. Impediments to successful implementation of DFCS measures that apply in the CPDP (Capital Project Delivery Process) design phase.
3. Revised DFCS measures based on 1 and 2.
4. Preventable construction site hazard incidents for 1 and 3.
5. Computer tool/application to aid the implementation of design phase DFCS measures through use of 1, 2, 3 and 4.

The DFCS measures applicable to the design phase of a capital project were to be determined from the extensive list of 430 design suggestions accumulated by the Construction Industry Institute (CII) in their DFCS Toolbox application. None of the design suggestions were discarded based on cost, schedule, relative risk reduction, or any other design or construction performance criteria (Gambatese et al, 1997). As a result, many of the suggestions are not applicable to the project design phase and would therefore expose the design professional to additional

liability, and are thus infeasible for implementation. The design suggestions were to be individually analyzed to identify those applicable to design professionals and to the project design phase. They were also to be assessed to identify those that address or avoid the impediments to DFCS implementation. As hundreds of design suggestions were yet to be individually evaluated, the development of additional DFCS measures was not within the scope of this research.

The identification of impediments to successful implementation of DFCS measures, that are applicable to the project design phase, serves to achieve three functions. Firstly, it provides a means for evaluating the DFCS measures for feasibility of implementation. As earlier stated, none were discarded based on any criteria (Gambatese et al, 1997). Several studies identified impediments to implementing DFCS. However, only a limited number considered individual DFCS measures (Gambatese et al, 2005; and Behm, 2006). Secondly, this deliverable presents the issues that must be surmounted to enhance the feasibility of implementing individual design-phase DFCS measures, thus providing a basis for yielding specific potential solutions to the impediments. Thirdly, this deliverable provides a basis for revising the DFCS measures to better enable their implementation. The yielded impediments to be avoided or addressed are essentially to serve as a specification for making the DFCS measures more feasible for implementation.

The revising of design-phase DFCS measures based on their impediments to implementation is to serve in making the measures more viable for implementation and for improving construction safety. This is as some of the design suggestions from the CII study, which are applicable to the project design phase, may be poorly specified, inaccurate and/or incomplete. Some DFCS measures could be revised to be more specific and applicable to the particular project feature they address. Others meanwhile, could be revised to avoid perceived impediments to their implementation or to provide their individual basis for implementation.

Preventable construction hazard incidents were to be identified for each design-phase DFCS measure to serve as illustrative cases for the implementation of the measures. For this, OSHA's publicly accessible database was to be used. OSHA, as the authority charged with safety regulatory oversight, collects and compiles data on occupational safety hazards. For a majority of DFCS measures, potential benefits of their implementation have neither been determined nor provided. Behm (2005), Behm (2006), and Gambatese et al (2008) conducted research in this direction by attempting to link certain injury incidents with the DFCS concept.

A new computer tool was to be developed to provide design-phase DFCS measures, their potential impediments, and their preventable safety incidents based on project characteristics. The need for such a tool was determined from a comparative analysis of existing DFCS computer applications. The analysis determined that a more effective DFCS tool is one that could function effectively

in the current contractual environment of the United States AEC industry without providing a means for increased exposure to liability. The design-phase DFCS measures were to include both those that were revised and those that were not revised. The tool was thus to incorporate the other research deliverables. The product of using the tool is to be a guideline that includes selected DFCS measures that are applicable to the features of the project on which DFCS is being implemented. Based on the type of data to be incorporated in the application and also its desired functionality, it was to be a desktop relational database application. It was to be developed and refined in the interest of effectiveness and usability in enhancing or assisting in DFCS implementation.

A number of elicitation methods were reviewed and evaluated as potential approaches for data collection and research towards producing the deliverables. These methods include observation, interviewing, document review, historical analysis, narrative inquiry, focus groups, questionnaires and surveys, and computer and internet technologies among others. Marshall and Rossman (2006) identified a number of criteria a researcher should consider in determining the data collection methods to use in his/her research. These criteria include practicality, efficiency, ethicality, cost-effectiveness, provision of adequate information, and feasibility. Marshall and Rossman (2006) also state that a researcher should carefully examine the methods based on questions guiding his/her study. Each of the data collection methods were evaluated, scored and ranked by the criteria, and questionnaires and surveys, interviews, literature review, and computer and internet technologies were selected for use in the research. Also, in producing the deliverables, the development of the relational database application is another task that is part of the research method. Surveys, interviews, and relational database applications were discussed with regards to their technique, potentials, design and implementation.

Validation is a process that evaluates the correctness or credibility of a description, conclusion, explanation, interpretation, or other sort of account (Maxwell, 2005). Validity is generally acknowledged to be a key issue in research design (Maxwell, 2005). Approaches for validity testing include intensive long-term involvement, intervention, respondent validation, rich data, triangulation, comparison, searching for negative cases, and quasi-statistics (Maxwell, 2005). For reasons of applicability and feasibility, triangulation was selected as the approach for validating this research. Triangulation involves collecting information from a variety of methods and sources to reduce the risk that conclusions will reflect only the systematic biases or limitations of a specific source or method (Maxwell, 2005). Both methodological and data triangulation were to be used in this research.

For the reason of feasibility with regards to scope and time, and also based on the selected data collection and research methods, along with the selected validation approach, I determined the listed research tasks and their placement. The tasks were executed towards yielding the research deliverables.

1. Indexing and Categorization of Design Suggestions from CII's DFCS Toolbox
2. Surveys of AEC Design Professionals (Development + Execution)
3. Identification of Applicable Safety Incidents from OSHA Database
4. Interviews of AEC Design Professionals (Development + Execution)
5. Development of Relational Database Application
6. Testing Interviews and Improvement of Relational Database Application

The objective of indexing and categorizing the design suggestions from CII's DFCS Toolbox was to identify DFCS measures applicable to the design phase of a capital project. As earlier stated, none of the design suggestions were discarded based on any design or construction performance criteria (Gambatese et al, 1997). The design suggestions pertain to different AEC design disciplines and were each assessed to identify those applicable to designers and the project design phase. The criteria for DFCS, as specified in its definitions, were utilized in the indexing and categorization process. At the completion of this research task, the total number of DFCS suggestions that were identified as being situated in the project design-phase was 317 out of the 430 suggestions. 134 were applicable to architects while 74 were applicable to civil/structural engineers and 109 were applicable to MEP engineers. Among those applicable to MEP engineers, 25 were applicable to mechanical engineers, 33 to electrical engineers, and 51 to plumbing engineers.

The surveys of AEC design professionals were used for three main purposes. Firstly, they were used in validating the product of the first research task, DFCS measures applicable to the project design phase. Secondly, the surveys were used in obtaining the impediments to successful implementation of these DFCS measures. Lastly, the surveys were intended to obtain revisions or the basis for revising the DFCS measures in the interest of improving their use and enhancing their effectiveness. A sample size of 644 AEC design professionals was required to complete this research task. Out of the 644 total email recipients, 90 responded that they were willing to complete the survey. And out of these, 67 completed the surveys. This corresponded to an overall survey response rate of 10.4%. Out of the 317 DFCS measures included in the surveys, 234 were validated as being situated in the project design phase. 33 were identified as possibly being situated in the project design phase. The remaining design suggestions were indicated as not being situated in the project design phase. With regards to the second objective, obtaining the impediments to implementing the DFCS measures, this was also achieved where applicable. Expectedly, for some DFCS measures, impediments were identified while for others, they were not. With regards to the third objective, obtaining revisions or the basis for revising the DFCS measures to enhance their effectiveness, the information necessary to revise only 2 DFCS measures out of the 317 DFCS measures was yielded, representing an extremely low output. The potential reasons for this were discussed. Additionally, logical sequencing was used to address illogical sets of responses, and also, to control the research scope. Conclusively, the

objectives of the survey were achieved as identified design-phase DFCS measures were validated, and their impediments and revisions yielded where applicable.

The objective of identifying applicable safety incidents from the OSHA Database was to document the potential benefits of implementing the design-phase DFCS measures. The hazard incidents are to serve as illustrative cases to justify implementation of the measures. Using the project features to which each of the DFCS measures pertain, the OSHA database was searched for hazard incidences that could justifiably have been avoided through the measures. Preventable safety incidents were identified for all the DFCS measures considered applicable to the project design phase. However, not all the identified incidents were fully and directly preventable through their respective DFCS measures. Where no safety incident was found to be directly preventable through certain DFCS measures, those found to be most applicable were identified for the DFCS measures. It must be noted that in all instances, the DFCS measures were to have at least the potential of decreasing the risk of the identified safety incidents from the OSHA database.

The interviews of AEC design professionals were to be primarily used in the validation of products from the earlier research tasks. Firstly, the interviews were used in validating and yielding impediments to successful implementation of 127 design-phase DFCS measures. These were measures that were earlier validated to be applicable to the project design phase, indicated to improve construction safety, and indicated to not have impediments significant enough to prevent their implementation. The DFCS measures were selected and utilized in the interest of research feasibility. This issue was thoroughly discussed. Secondly, the interviews were used to validate the applicable safety incidents, identified from the OSHA database, as preventable through the DFCS measures. Lastly, they were used in obtaining revisions to the DFCS measures where applicable.

A sample size of 223 AEC design professionals was required to complete this research task. Out of the 223 total email recipients, 41 responded that they were willing to be interviewed. And out of these, 24 were interviewed. This corresponded to an overall interview participation rate of 10.8%. With regards to the first objective, the validation and yielding of the impediments to successful implementation of the DFCS measures, this was accomplished. Some of the impediments were data as well as methodologically validated through the interview responses. With regards to the second objective, the validation of applicable safety incidents identified from the OSHA database, this was also achieved. Several safety incidents were identified as being preventable by their respective DFCS measures. Several others were identified as possibly being preventable while others were indicated to not be preventable by their respective DFCS measures. Where such responses were provided, most interviewees indicated that the DFCS measures would not have prevented their respective safety incidents as the workers were the cause due to their unsafe practices.

Among the safety incidents that were not considered validated, a significant majority were identified as being related. Lastly, with regards to the third objective, obtaining revisions to the DFCS measures where applicable, this was also achieved. The basis for revising 13 DFCS measures was yielded. The design-phase DFCS measures were accordingly revised.

The objective of developing the relational database application is to assist designers in making safety considerations in the project design phase. The beneficiaries of the software application primarily include design professionals; architects, civil/structural engineers and mechanical/electrical/plumbing engineers. Other project participants could also utilize the software. The earlier research tasks yielded a structured collection of data on DFCS measures. The application is intended to enable users to retrieve this data and essentially enable use of the research results. Hence, the application is a vehicle to encapsulate and utilize the research findings. Relational database applications can be developed using such existing software as Microsoft Access, Visual FoxPro, Oracle, Siebel and MySQL among others. For reasons of capability and familiarity, Microsoft Access was to be used in developing the desktop application while Microsoft Visual Basic was to be used for developing its user interface. User requirements, system requirements and software design specifications, were determined and defined for the application, and a prototype was developed and its features discussed.

The relational database application was named DFCS-TIPS, an abbreviation for Design for Construction Safety - Tool for Implementation on Projects and Systems. The DFCS-TIPS application was developed to have the functionality to provide design-phase DFCS measures, their preventable safety incidents, their potential impediments, potential solutions to their impediments, and their tier of feasibility, based on project characteristics, design profession, and the stage of the design phase. The application also allows for the addition of new DFCS measures, their preventable safety incidents, their potential impediments, and potential solutions to their impediments. This enables the adaptability of the software application to the user and enables the incorporation of new knowledge particularly given that DFCS is still an emerging area. The user can also define the AEC design profession, project feature, and the stage of the design phase applicable to the newly entered DFCS measures. And, even for the DFCS measures included in the DFCS-TIPS application, the user can enter potential solutions to their impediments. On this basis, the DFCS-TIPS application was successfully developed to meet the pre-defined user requirements, software design specifications and system requirements.

The objective of the software testing interviews of AEC design professionals was to validate the relational database application, DFCS-TIPS, as a viable tool that can assist designers in making safety considerations in the project design phase. This was to be achieved through the testing of the application by AEC design professionals and through collecting their critique and commentary on its

functionality and usability. Based on the information collected through the interviews, the DFCS-TIPS application was to be improved. Towards validating the viability of the DFCS-TIPS application, its use in DFCS implementation was compared against manual DFCS implementation in the interviews. Additionally, as the DFCS-TIPS application was developed to be without the inadequacies of existing tools to better aid or enhance the DFCS implementation process, there was need for a DFCS tool to compare the DFCS-TIPS application against and the logical selection was the CII's DFCS Toolbox. As the only tool that provided DFCS measures, it had the least inadequacies. To facilitate the testing interviews, a hypothetical DFCS implementation project was provided and utilized with set parameters.

A sample size of 9 AEC design professionals was required to complete this research task. Out of the 9 email recipients, 7 interviewees were yielded. This represented an interview participation rate of 77.8%. Out of the 7 interviewees, 5 had previously been utilized for input in this research through the earlier surveys and interviews. The interviews were successful in comparing the DFCS-TIPS application to the DFCS Toolbox in terms of effectiveness and usability. They were also effective in comparing DFCS implementation using the software against manual DFCS implementation. The interviews were also successful in identifying potential improvements to the DFCS-TIPS application. Those improvements determined to be feasible were implemented. Most pertained to the interface and functionalities of the application. Ultimately, based on the interview results and interpretation, the DFCS-TIPS application was validated as a viable tool that can assist designers in making safety considerations in the project design phase. It was also validated as not possessing the inadequacies of existing DFCS tools that limit their effectiveness in the current environment of the U.S. AEC industry.

Upon completion of the research tasks, the research deliverables were yielded. Firstly, the research identified and validated 212 DFCS measures as being situated in the project design phase, after logical sequencing and the elimination of redundancies. This research was also successful in yielding the impediments to the design-phase DFCS measures, where applicable, as not all the DFCS measures were indicated to have impediments. Increased cost was identified as the most prevalent impediment to the DFCS measures. This was followed by decreased project quality, and then exposure to liability. Revisions of 13 design-phase DFCS measures were also successfully yielded through this research. This was as a significant majority of the DFCS measures were not identified to require revision. The research was also successful in yielding preventable construction hazard incidents for all the design-phase DFCS measures. 73.2% of the safety incidents that were subjected to validation through the research tasks were validated as being preventable by their respective design-phase DFCS measures. And, when all the yielded safety incidents are considered whether subjected to validation or not, 43.9% were validated as being preventable by their respective DFCS measures. Lastly, the research was successful in developing the computer application to effectively assist in DFCS implementation.

A number of recurring issues were observed from the research data and its interpretation. This also included the responses of the research participants, which were fully documented, categorized based on topics addressed, and discussed. The results emphasized a key shortcoming of the DFCS concept. This is the effectiveness of DFCS depends on the construction sequence. Where the permanent project features intended for construction worker safety are not constructed till the end of the construction phase, there will be a minimal to negligible impact on construction safety. However, it must be noted that in many cases, it is not effective for the contractor to delay constructing or installing certain features till the very end of the construction phase. Hence, a significant number of design-phase DFCS measures would likely be in place to have a notable impact on construction worker safety.

From the responses of research participants, it was determined that DFCS measures or modifications that not only improve construction worker safety but occupant and maintenance worker safety are more likely to be implemented by AEC design professionals and more likely to be accommodated by the project owners as well. On this basis, a new dimension was identified through this research, towards increasing and improving DFCS implementation. This is through linking DFCS to building code compliance. This could be achieved through three potential approaches. Firstly, DFCS measures could be developed or revised to meet certain performance-based building code provisions and requirements. Secondly, this is through the development of software that integrates building codes with DFCS measures. Based on the commentary of research participants, there is unavailability of effective software to aid in adherence to building codes. And several research participants also indicated that if DFCS software is integrated with code, it would prove very useful to the industry and market. On this basis and as DFCS is not mandatory, it was determined that DFCS software would more likely be used if it can aid in adhering to building codes. The third approach for linking DFCS to building code compliance is in the DFCS implementation process. This is through the inclusion of DFCS implementation in the responsibilities of quality control supervisors at AEC design firms. It must be noted that linking DFCS to building code compliance does not necessarily mean converting DFCS measures to prescriptive or performance-based code requirements, as this would require new legislation and regulations, for which there is no certainty of achieving.

Also, this research further emphasized that the design-build project delivery method offers more opportunity and fewer barriers for DFCS implementation. This is due to the fact that liability for worker safety would apply to both the contractor and the design professional. And this is typically whether or not they are employees of the same company as their contractual relationship to the project owner is linked. Additionally, the development of new DFCS measures was not within the scope of this research. However, research participants provided several design suggestions for construction worker safety. These were

categorized to identify those that are design-phase DFCS measures. 15 of the design suggestions fit the criteria and could thus be utilized and further characterized in future DFCS research.

This research achieved a number of contributions. Firstly, the research characterized the design suggestions for construction worker safety yielded from earlier research. This characterization defined those situated in the design phase, those applicable to the different design disciplines, and also those applicable to the different stages of the design phase. This research also brought focus to individual DFCS measures and their feasibility for implementation, as opposed to for the DFCS concept as a whole. In doing so, the impediments to implementing individual DFCS measures were identified where applicable, and illustrative cases for their implementation were yielded. The characterization of design suggestions essentially produced a more fine-tuned and detailed body of knowledge that could be utilized in DFCS implementation. Secondly, this research, through its deliverables, serves in fulfilling some of the CPWR recommendations for DFCS research, and serves in addressing some of the NIOSH NORA DFCS information gaps, which are both aimed at enhancing DFCS and its implementation. Thirdly, this research identified a new dimension for increasing and improving DFCS implementation, through linking DFCS to building code compliance, and potential approaches for doing so. These contributions are collectively intended to enhance and increase DFCS implementation on projects. This is the avenue through which this research intends to improve construction safety.

There are a number of motivating factors for improving construction safety through DFCS. Firstly, professional, ethical and moral obligations require the safety of others be protected. It is thus every AEC design professional's responsibility to preserve and protect human life including that of construction workers (Toole et al, 2006). This is as indicated in the design professionals' respective code of ethics. Secondly, the improvement of safety could potentially benefit every project stakeholder and participant by minimizing or eliminating the costs associated with injuries to construction workers. These continually escalating costs include injury and fatality compensation, OSHA fines, litigation and legal costs, and also, the cost of insurance programs (Jaselskis et al, 1996; Gambatese et al, 1997; and Toole et al, 2006). Thirdly, all project participants may also benefit in that reducing the number of construction accidents and injuries could avoid disruption to work and avert delays in project completion, and as a result, improve productivity (Huang, 2003). Additionally, poor safety performance and its resulting consequences such as court cases and lawsuits expose all project participants to bad publicity which could have such adverse impacts as preventing job awards or causing even more lawsuits from prior projects (Huang, 2003). These reasons collectively highlight the importance of improving construction worker safety and towards this goal, this research emphasized and enhanced DFCS as a strategy for reducing or eliminating construction hazard risks on capital projects.

## **7.2 Research Limitations**

This research has a number of limitations arising from its design. These were largely due to the outcomes of the research tasks and were mostly identified in hindsight. The outcome of the first research task, the indexing and categorization of DFCS suggestions, was 317 design suggestions identified to be situated in the project design phase. This was more than twice the number initially anticipated. These were utilized in the next research task for validation and to elicit data. Stemming from this outcome, the surveys of AEC design professionals proved to be much less effective than anticipated. This was from two angles. Firstly, the low response rate significantly extended the period of time required to complete the research task. Secondly, the responses were not as detailed as would have been preferred. The surveys ultimately provided the minimum detail required. As they were self-reported, they did not allow for clarification or confirmation of entries. It is fathomable that it would have proved more effective to utilize interviews for the second research task instead of the surveys. It might have taken less time, and provided more valid results that could have been less subject to the respondents' constraints. The surveys were initially selected to allow for validation through methodological triangulation. They were also selected as they seemed appropriate for the specific and targeted information that was sought.

Due to the large number of DFCS measures for which data was to be collected and/or validated, it became infeasible for all to be utilized in the interviews of AEC design professionals. Hence, the DFCS measures were categorized and those in a specified tier were selected for utilization. These were measures that were earlier validated to be applicable to the project design phase, indicated to improve construction safety, and indicated to not have impediments significant enough to prevent their implementation. As a result of this, not all DFCS measures were subjected to equal numbers and types of research tasks. This also meant that a significant percentage of the research deliverables were not subjected to validation. Thus, the impediments to implementing certain design-phase DFCS measures were not subjected to validation. And, the same applied to many of the applicable safety incidents, and to the revisions of the DFCS measures. This constituted the main research limitation.

Another limitation is that, the research results were based on participants' perceptions with regards to different aspects of DFCS implementation. The perceptions and responses of the participants could be subject to change over time. However, given the impediments to DFCS were mostly situated in designer concerns, this was considered an appropriate research approach. And short of monitoring and evaluating full-scale implementation of DFCS on actual projects, it proved effective in yielding useful data for this research.

### **7.3 Recommendations for Future Research**

As DFCS is still an emerging practice in the United States, there is significant opportunity for research. There are several recommendations for future research stemming from the scope and deliverables of this research.

In the identification of DFCS measures applicable to the project design phase, a number of design suggestions for construction safety were found to not meet the criteria for DFCS but have the potential of being revised to do so. Examples of such design suggestions are those that require both design and scheduling. Two are provided:

- Design and schedule the layout of stairway and ladder landings to be constructed as part of the foundation system of the structure.
- Design and schedule the project to minimize the amount of time excavations are open to reduce the potential of cave-ins.

Where the scheduling aspect is eliminated, the design aspect may or may not be sufficient to eliminate or minimize certain construction hazards. This is since where the permanent project features intended for construction worker safety are not constructed till the end of the construction phase, there will be a minimal to negligible impact on construction safety. Future research can identify such design suggestions and where possible, revise them to be applicable to the project design phase while still being effective in eliminating or minimizing certain construction hazard risks. Also, future research can revise the suggestions such that it is more effective and efficient to construct them at the earlier as opposed to the later construction stages.

Additionally, all the DFCS suggestions, yielded from the CII's research and utilized in this research, could be subjected to further validation using alternate approaches. This research utilized either only two sources of data or two elicitation methods in validating the design suggestions identified as being situated in the project design phase. Future research could utilize focus groups to validate with more sources of data. This would significantly increase the validity of the results. The 'new' DFCS suggestions, yielded through this research, could also be included. The focus groups should include AEC design professionals and other individuals that are relevant to the DFCS implementation process. The focus groups could also be used to identify and validate impediments to implementing the individual DFCS measures and their potential solutions. They may also serve to revise the DFCS measures where applicable. Additionally, for the DFCS measures which applicable safety incidents were not validated as being preventable, the focus group may provide near miss safety incidents that could be preventable by implementing the DFCS measures. As the monitoring and analysis of near misses is neither mandatory nor recorded in a single comprehensive source, the focus group participants may prove useful as a source of near miss incidents.

While the use of focus groups is inherently more convenient for the researcher, it has other shortcomings (Marshall and Rossman, 2006). Firstly, logistical problems may arise as the groups can vary a great deal and can also be hard to assemble. Secondly, the interviewer often has less control over a group interview. Additionally, time can be lost while irrelevant issues are discussed. Lastly, power dynamics may limit the participation of some members in the focus groups. These were the reasons why I decided not to use focus groups as a data collection method in this research. And even in the case of the recommended future research, multiple meetings of the focus groups would likely be needed to accomplish the objectives. This is due to the large number of DFCS suggestions that would need to be evaluated. Additionally, lengthy deliberation on a single DFCS suggestion could be unavoidable.

There were also a number of potential improvements identified for the relational database application, DFCS-TIPS, which was developed through this research. These include the development and use of diagrams, drawings, pictorials and videos to clarify all its included design-phase DFCS measures. Another potential enhancement is the incorporation of the software application with Building Information Modeling (BIM) to make it more effective, more interactive and easier to use. In addition to this, the application could include the capability for the DFCS measures to be selected and automatically applied to the design drawings and construction documents. The application could also be developed to be a market-ready and organization level tool. Capabilities that could be incorporated towards this include control of access and editing, through the use of passwords and other identification features. Additionally, future research could build on the software content including the DFCS measures and their corresponding details. All these potential improvements were determined to be infeasible to effect in this research.

Another potential improvement considered to be infeasible was the integration of building code provisions and requirements with the DFCS measures in the DFCS-TIPS application to create a composite 'project safety' tool which could also link the user to the appropriate code documents. Based on the commentary of research participants, there is unavailability of effective software to aid in adherence to building codes, and it was determined that DFCS software would more likely be used if it can aid in adhering to building codes, particularly since DFCS implementation is not mandatory. The software could also have code updating capabilities. In this research, linking DFCS to building code compliance was identified as a new dimension towards increasing and improving DFCS implementation. This would require research work. DFCS measures could be developed or revised to meet certain performance-based building code provisions and requirements. Future research could also investigate the issues associated with including DFCS implementation in the responsibilities of quality control supervisors who are typically charged with ensuring building code compliance of project designs at AEC design firms.

This research emphasized that the design-build project delivery method offers more opportunity and fewer barriers for DFCS implementation. However, this method of project delivery is far less utilized than the traditional design-bid-build method and still needs to better diffuse in the AEC industry (Toole and Gambatese, 2007). Future research could investigate the factors that currently limit the diffusion of the design-build method despite its advantages. Research could also identify issues that would impact DFCS implementation on such project types and where applicable, propose solutions towards addressing them.

The responses of the research participants indicated that DFCS measures or modifications that not only improve construction worker safety but occupant and maintenance worker safety are more likely to be implemented by AEC design professionals and more likely to be accommodated by the project owners as well. Future research could evaluate this finding by eliciting data from project designers and owners. Research could also serve to determine if this only applies when it comes to building code requirements.

The primary objectives of constructability analysis and review include decreased cost, decreased schedule, and improved quality. Improved safety is typically an added benefit. Future research could evaluate the extent to which safety is achieved based on the nature and number of constructability reviews. Future research could also investigate the implications of including improved safety as a primary objective in the process, through DFCS. These would collectively serve to better characterize the safety constructability process and provide a means for enhancing its effectiveness in minimizing and eliminating construction site hazards from the project design phase.

There are several other opportunities for future research. This is as indicated in the CPWR recommendations for DFCS research and NIOSH NORA DFCS information gaps presented in *Section 1.2.1*. Those not addressed or fulfilled through this research are recommended for future research. Such research will serve to further characterize and promote DFCS, and also develop methods and determine incentives for DFCS while addressing its obstacles. It would also serve to further characterize the design-phase DFCS measures based on their implementation. This is through the documentation and evaluation of cases, where the DFCS measures were implemented, indicating the full benefit and cost implications of their implementation. This could serve to determine whether their identified impediments are accurate and the extent to which they apply. And, this could also yield effective solutions to address or minimize the impediments to their implementation.

## 8.0 Administrative Requirements and Compliance

There were certain administrative requirements to be met by this PhD research. These include that of the School of Architecture and that of the university.

The School of Architecture has requirements for the form, submission and presentation of the dissertation. The parts required in the written form of the dissertation have been included in this document.

Carnegie Mellon University requires that all research involving the use of human research subjects or participants be reviewed and approved by the Institutional Review Board (IRB) before the research can be initiated. The IRB functions according to the guidelines of the United States Office of Human Research Protection (OHRP) and other federal regulatory agencies to assure that appropriate steps are taken to protect the rights and welfare of humans participating in the research. This research included surveys and interviews of AEC design professionals in industry and academia. The research protocol therefore had to be approved by the IRB. The IRB also required the completion of an on-line education program through the Collaborative Institutional Training Initiative (CITI).

Accordingly, the education program was completed and all the required documents were submitted. And before I proceeded with the human subjects' research, I received approval from the IRB. The approval document is provided in *Appendix K*.

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## Appendix

### **Appendix A:**        **Pictorials of Sample DFCS Suggestions from CII's DFCS Toolbox**

#### DFCS Suggestions pertaining to the Design of Skylights

- Design domed, rather than flat, skylights with shatterproof glass or add strengthening wires
- Place skylights on a raised curb (10-12 inches)
- Locate skylights on flat areas of the roof and away from the roof edges

The photograph and pictorial below show the three suggestions after implementation in project construction. They are intended to minimize or eliminate the risk of workers falling through skylights.

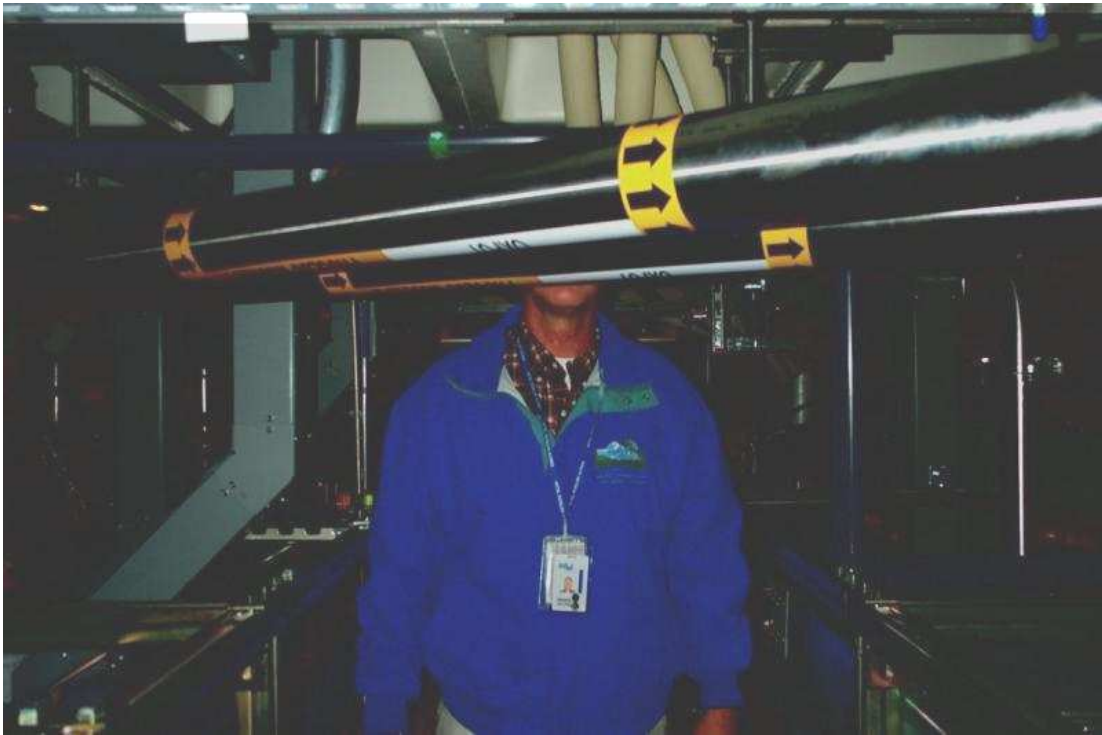


(Source: Toole, 2009)

### DFCS Suggestion pertaining to Pipe Head Knockers

- Route piping to avoid head knockers (6 ft. - 6 in. minimum above grade) and tripping hazards

The photograph below shows 'unsafe' routing of pipes that could lead to head injuries. This DFCS suggestion is intended to minimize the risk of such injuries due to this hazard.

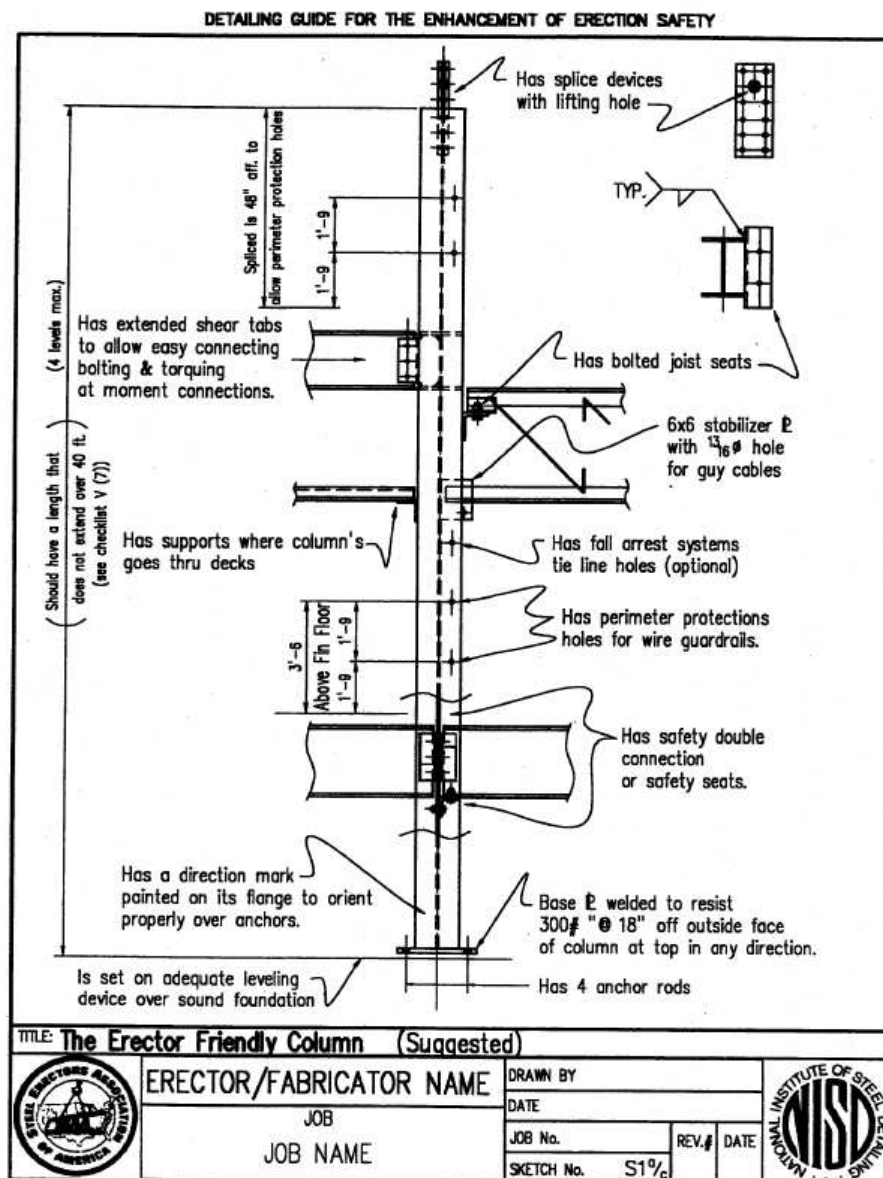


(Source: Toole, 2009)

## DFCS Suggestions pertaining to Column Design and Splice Locations

- Design columns with holes in the web at approximately 21 and 42 inches above the floor level to provide built-in safe support locations for lifelines and guardrails
- Column splice connections which are located at or just below the floor level can present safety hazards for construction workers. Locate column splices and connections at reasonable heights above floor

The diagram below is a detailing guide for implementing these two DFCS suggestions in the project design phase. This is to provide a means for fall protection and minimize the risk of trip and/or fall hazards.



(Source: Toole, 2009)

## **Appendix B:        Design Suggestions from the CII DFCS Toolbox Not Situated in the Project Design Phase**

### **Appendix B1:**        Design suggestions that prescribe means, methods, techniques, sequences or procedures for the contractor

#### ADMINISTRATIVE: LAYOUT

##### Underground and Site Utilities

- Provide a work sequence for safe tie-ins to existing utilities such as the mechanical and HVAC systems.

##### Jobsite Hazards

- Schedule the permanent electrical system to be installed early in the construction phase and available for use by the constructor.
- Schedule permanent telephone lines to be installed early in the construction phase, especially in remote buildings, process areas, and on the site perimeter and when possible, bury these lines to minimize overhead encumbrances.
- Schedule permanent lighting systems to be installed early in the construction phase and available for use by the constructor.
- If possible, where existing electrical lines need to be in service during construction, consider scheduling the voltage or current to be decreased before construction begins.

##### Structural

- During demolition operations, schedule fire walls and fire doors to be kept in place as long as possible.

#### ADMINISTRATIVE: PLANNING

##### General Scheduling

- Allow limited or no work to be performed on Friday or Saturday nights.
- Impose a ceiling on the number of workers on site or in a particular area.
- Minimize the amount of night work.
- Provide or require the constructor to submit a construction sequence for complicated or unique designs, as these may introduce hazards that warrant special attention.

##### Site Activities

- Schedule sidewalks, slabs, and roadways around elevated work areas to be constructed as early as possible to serve as solid footing for scaffolding and ladders.
- If possible, where existing electrical lines need to be in service during construction, consider scheduling the voltage or current to be decreased before construction begins.
- Provide a work sequence for safe tie-ins to existing utilities.
- Require hand excavation around existing underground utilities.
- Schedule an underground firewater system to be constructed at the beginning of the project to have early firefighting capabilities.
- Schedule permanent lighting systems to be installed early in the construction phase and available for use by the constructor.
- Schedule permanent telephone lines to be installed early in the construction phase, especially in remote buildings, process areas, and on the site perimeter and when possible, bury these lines to minimize overhead encumbrances.
- Schedule the permanent electrical system to be installed early in the construction phase and available for use by the constructor.
- Consider alternative methods for pouring concrete when specifying concrete pours below or next to overhead power lines, such as the use of a pumping truck.

#### Timing and Sequencing

- During demolition operations, schedule fire walls and fire doors to be kept in place as long as possible.
- For multi-story buildings, schedule a firewater protection system to be installed and in use as early as possible during construction.
- In multi-story buildings, schedule the exterior wall structure and/or finish to go up with the framework or soon thereafter to serve as integral fall protection.
- On renovation projects, maintain existing automatic sprinkler systems in operation as long as possible in the construction phase.
- Provide a schedule for removing concrete forms and shores to avoid premature removal of structural supports.

#### Facility Components

- Design and schedule ventilating systems to be in place in areas where coatings will be applied prior to applying the coatings to help remove toxins from the air.
- Limit the lift height of concrete pours to minimize the load on formwork and the risk of collapse of fresh concrete during pouring operations.
- Limit the heights of steel erection work without fall protection.
- Provide a procedure for placing and holding initial loads on post-tensioned concrete. This procedure should include the safe positioning of workers.
- Schedule a permanent stairway to be constructed at the beginning, or as close as possible to the start of construction, to reduce the hazards of using temporary stairs and ladders.
- Schedule air conditioning, heating, and ventilating systems to be available for use by the constructor at close-in to enhance project safety.
- Schedule fire walls and fire doors to be constructed or placed early in the construction phase.
- Schedule materials, piping, and equipment to be painted and/or insulated prior to erection or installation to reduce worker exposures.
- Schedule permanent emergency exit and egress signs to be erected early in construction.
- Schedule permanent handrails to be erected along with the structural steel as one assembly to ensure worker safety as soon as the steel components are installed.

#### Minimizing Hazards Through Scheduling

- Account for incompatible activities in the schedule, e.g. no welding during painting operations.

### ADMINISTRATIVE: DESIGN

#### Sitework

- Require hand excavation around existing underground utilities.
- Schedule sidewalks, slabs, and roadways around elevated work areas to be constructed as early as possible to serve as solid footing for scaffolding and ladders.

#### Safe Work Procedures

- Limit the lift height of concrete pours to minimize the load on formwork and the risk of collapse of fresh concrete during pouring operations.
- Provide a procedure for placing and holding initial loads on post-tensioned concrete members. This procedure should include the safe positioning of workers.
- Limit the heights of steel erection work without fall protection.
- Specify the use of testing devices which are embedded in concrete members in order to test the strength of the concrete before form removal.

- Schedule a permanent stairway to be constructed at the beginning, or as close as possible to the start of construction, to reduce the hazards of using temporary stairs and ladders.
- Schedule permanent handrails to be erected along with the structural steel as one assembly to ensure worker safety as soon as the steel components are installed.
- Design and schedule ventilating systems to be in place in areas where coatings will be applied prior to applying the coatings to help remove toxins from the air.
- Schedule materials, piping, and equipment to be painted and/or insulated prior to erection or installation to reduce worker exposures.
- Pre-fabricate building components in the shop or on the ground and erect them as one assembly to reduce work performed at elevation.
- Erect permanent lighting systems along with the structural framing as one assembly to reduce work performed at elevation.
- In multi-story buildings, schedule the exterior wall structure and/or finish to go up with the framework or soon thereafter to serve as integral fall protection.
- When designing an atrium in a building, design permanent guardrails, anchor points, or other such fall protection mechanisms so they are sequenced early into the schedule to allow use by construction workers.

#### SITework: LAYOUT

##### General Considerations

- Minimize the amount of night work.
- Provide adequate illumination on projects during work at night.

##### Overhead Power Lines

- Disconnect the power lines before construction begins.
- Bury overhead power lines below grade before construction begins.
- Re-route the power lines around the project site before construction begins.

##### Underground Work

- Require hand excavation when near existing underground utilities.

##### Site Terrain

- Require rock fences to be erected on embankments early in the construction phase to smother any falling rocks.
- For projects adjacent to open rock slopes, require rock fences to be erected, or regularly spaced benches to be cut into the slopes, early in the construction phase.

##### Transportation on Site

- Allow for at least two formal, controlled intersections at access points to the site.
- Require at least two formal, controlled intersections at access points to the site.
- Limit long hauls on steep grades.
- Design and schedule traffic and emergency signs for early erection.
- Design and schedule new parking areas to be constructed as early as possible to provide a formal, safe location for workers to store materials and equipment.
- Avoid road work and maintenance during peak traffic volume periods of the day.

#### SITework: ROADS/PAVING

##### Site Considerations

- Provide adequate illumination on projects during work at night.

#### Scheduling Work

- Avoid performing road work on Friday and Saturday nights because of added roadway risks.
- Minimize the amount of night work.
- Avoid road work and maintenance during peak traffic volume periods of the day.

#### Terrain and Road Layout

- Limit long hauls on steep grades.

#### Parking Areas

- Design and schedule new parking areas to be constructed as early as possible to provide a formal, safe location for workers to store materials and equipment.

#### Public Access and Control

- During road work, slow down the ongoing traffic as much as possible by closing down adjacent lanes, posting flagpeople to control traffic, or running lead cars to guide the adjacent traffic.
- Design and schedule traffic and emergency signs for early erection.
- During highway construction activities, posted speed limits should be reduced and strictly enforced to increase the safety of highway workers.
- During road work, when the work zone of the trucks conflicts with the work zone of the flaggers, establish an alternate layout of the work zone, such as closing additional lanes of the highway.

### SITWORK: EARTHWORK

#### General Information

- Minimize the amount of night work.
- Provide adequate illumination on projects during work at night.

#### Haul Roads

- Limit long hauls on steep grades.
- During road work, slow down the ongoing traffic as much as possible by closing down adjacent lanes, posting flaggers to control traffic, or running lead cars to guide the adjacent traffic.

#### Topography

- For projects adjacent to open rock slopes, require rock fences to be erected, or regularly spaced benches to be cut into the slopes, early in the construction phase.
- Require rock fences to be erected on embankments early in the construction phase to smother any falling rocks.

#### Excavation Work

- Require hand excavation when near existing underground utilities.

### FOUNDATIONS

#### Excavations

- Design and schedule the project to minimize the amount of time excavations are open to reduce the potential of cave-ins.

#### Rebar

- Run continuous reinforcing steel through all floor openings in elevated slabs and place sheathing over the reinforcing steel. The rebar can then be cut after work on elevated slab is complete.
- Align post-tensioning cables such that if failure of a jack, cable, or fitting occurs during tensioning, the cable is not directed towards an active work area.

#### Concrete Slabs

- Design and schedule the layout of stairway and ladder landings to be constructed as part of the foundation system of the structure.
- Consider alternative methods for pouring concrete when specifying concrete pours below or next to overhead power lines, such as the use of a pumping truck.
- Design and schedule slabs-on-grade, sidewalks, roadways, and other flatwork around elevated structures to be constructed as early as possible and available for use as a stable base for scaffolding and ladders.

#### Concrete Floor Surfaces

- When design features such as ventilation systems, trash chutes, chimneys, elevators, skylights, etc. cause floor openings to occur during construction, provide a warning in the plans and specifications for construction, and design in permanent guardrail systems and sequence them early in the construction process for use by all contractors.

### ROOFING

#### Roof Fall Protection

- Design and schedule the installation of eye-bolts or other connections used for window maintenance so that they can be constructed as early as possible and used during construction for fall protection.
- When designing an atrium in a building, design permanent guardrails, anchor points, or other such fall protection mechanisms so they are sequenced early into the schedule to allow use by construction workers.

#### Added Features

- When design features such as ventilation systems, trash chutes, chimneys, elevators, skylights, etc. cause floor openings to occur during construction, provide a warning in the plans and specifications for construction, and design in permanent guardrail systems and sequence them early in the construction process for use by all contractors.

### STRUCTURAL: STEEL

#### Steel Erection

- Align or locate post-tensioning cables such that if failure of a jack, cable, or fitting occurs during tensioning, the cable is not directed towards an active work area.

#### Connections

- Eliminate field welding of steel with a galvanized coating.
- Ensure that the welding procedures specified are compatible with the materials being welded.

### FINISHES: GENERAL

#### Ceilings and Catwalks

- Design and schedule lighting systems to be erected with the structural framing.

#### Signs

- Design and schedule traffic and emergency signs for erection early in the construction phase.

#### Miscellaneous Issues

- Design and schedule materials and equipment to be painted and/or insulated prior to erection or placement to reduce worker exposures to work at elevation.

## FINISHES: STAIRS/RAILINGS

### Stairs

- Design and schedule permanent stairways to be built as soon as possible in the construction phase and used by the construction workers, to reduce the hazards of using temporary stairs and ladders.

### Rails

- Design and schedule handrails, guardrails, and stairrails to be erected as part of the structural steel erection to ensure worker safety as soon as the steel components are installed.

## DOORS & WINDOWS

### Doors

- Design and schedule doors to be installed late in the construction phase.
- Design and schedule new fire doors to be hung as early as possible in the construction phase. In demolition projects, keep existing fire doors in place as long as possible.

## MECHANICAL & HVAC

### Procedures and Safeguards

- Design and schedule safe tie-ins to existing utilities such as the mechanical and HVAC systems.

### Space Around Equipment

- When design features such as ventilation systems, trash chutes, chimneys, elevators, skylights, etc. cause floor openings to occur during construction, provide a warning in the plans and specifications for construction, and design in permanent guardrail systems and sequence them early in the construction process for use by all contractors.

### Equipment Characteristics

- Design and schedule equipment to be painted and/or insulated prior to erection or installation to reduce worker exposures at elevation.

### Ventilation

- Design and schedule ventilation and illumination in stair shafts to be operable early so fresh air and lighting are available during construction.
- Design and schedule new air conditioning and ventilating systems to be in use as early as possible in the construction phase to enhance project safety.
- Schedule new ventilating systems to be in use in areas in which painting or other coatings will be applied, prior to their application to help remove toxins from the air.

## ELECTRICAL

### Light Fixtures

- Design and schedule lighting systems to be provided in enclosed stair shafts as early as possible in the construction phase to ensure adequate lighting.
- In structures with tall stories, design and schedule the lighting systems to be erected with the structural steel to maintain a safe construction work sequence.

### Telephone Lines

- Schedule telephone lines to be installed and in-use early in the construction phase, especially in remote buildings, process areas, and on the site perimeter, and when possible, bury these lines to minimize overhead encumbrances.

#### Site Electric

- Design and schedule the electrical system to be constructed early and allow the constructor to tie into it for use during construction, to reduce the need for electric generators and temporary power on site.
- Specify hand excavation when near existing underground lines.
- Place a brightly-colored warning tape along underground lines approximately 12 inches above the lines.
- Disconnect the power lines, or decrease the voltage, before construction begins.
- Bury the power lines below grade, or re-route the lines around the project site, before construction begins.
- Design and schedule safe tie-ins to existing utilities.

#### INDUSTRIAL PIPING

##### Connections

- Design and schedule safe tie-ins to existing utilities and ensure that the tie-in is appropriate for the piping contents and system.

##### Pipe Systems

- To reduce fall hazards design and schedule piping materials to be painted and/or insulated prior to erection or installation.

##### Buried Lines

- Require hand excavation when near existing underground utilities.
- Protect existing and operational underground lines from crushing by use of sleeves or slabs, or by providing guard posts to prevent travel over them.
- Provide over-sized pipe sleeves around existing underground lines under railroad tracks and highways to avoid damage to the tracks or roadbed in case of a leak.
- Place a brightly-colored warning tape along underground lines approximately 12 inches above the lines.

##### Work Sequence

- For taller buildings, design and schedule the fire water system to be installed early in the construction phase to be available for fire protection.
- Design and schedule an underground fire water system to be constructed throughout the project site before construction begins.

#### TANKS & VESSELS

##### Access

- Provide for a door to be installed in floating roofs for large vessels. Design and schedule the door to be installed prior to erection of the roof.

##### General Considerations

- Fabricate tank roofs at grade and lift them into place as one assembly to reduce fall hazards.

## **Appendix B2:**     Design suggestions that pertain to temporary construction or project features

### ADMINISTRATIVE: PLANNING

#### Site Activities

- Schedule the project to minimize the amount of time that excavations are open to reduce the potential of cave-ins.

### SITEWORK: ROADS/PAVING

#### Road and Paving Design

- Use durable thermoplastic markings or buttons rather than shorter-lived paint for pavement markings.

### FINISHES: GENERAL

#### Signs

- Ensure proper position and location of warning signs to clearly alert workers of hazards.
- Ensure that proper warning signs, controls, and alarms are standardized throughout the project to alert workers about hazards.
- Ensure that hazardous areas are identified, classified, and provided with adequate boundaries that are clearly marked.
- Provide appropriate signs, lights, alarms, etc. to ensure safety near dangerous equipment areas.
- Provide warning signs that clearly describe the allowable floor loading in elevated areas.

#### Miscellaneous Issues

- Provide clear signage for emergency showers and eye-wash basins in areas where personnel might come in contact with highly toxic or poisonous materials.

### MECHANICAL & HVAC

#### Procedures and Safeguards

- Provide appropriate signs, lights, alarms, etc. as necessary to ensure safety near exposed equipment.

## **Appendix B3: Design suggestions that pertain to other contractor responsibilities**

### **ADMINISTRATIVE: LAYOUT**

#### **Traffic Control**

- Require public traffic to be detoured around the project site.
- Require ongoing public traffic to be slowed down as much as possible by using flagcars, flaggers, or by closing adjacent traffic lanes.

#### **Underground Safety**

- Use red concrete to encase newly-installed underground utility lines to mark their location.

#### **Materials and Material Storage**

- Require unused or unsecured materials to be stored in designated areas only, and not in areas of construction activity.
- To preserve the structural integrity of existing reinforced concrete members, require the constructor to locate and mark existing reinforcing steel prior to cutting into the concrete.
- Ensure that specified materials of construction are appropriate for the flammability hazards which may be encountered on the work site.

#### **Housekeeping**

- Require regularly scheduled site housekeeping to ensure a neat, clean and safe work area.

#### **Underground and Site Utilities**

- Require the constructor to pothole for underground utilities before excavation operations.

#### **Jobsite Hazards**

- Confirm that the constructor knows of the potential hazards of all construction materials, and their proper storage and disposal.
- On renovation projects, maintain existing automatic sprinkler systems in operation as long as possible in the construction phase.

#### **Safety Plans**

- Require the submittal of a fire control plan, or that the fire department be contacted to discuss plans for fire protection services during construction. Consider a fire watch system.
- Require the submittal of a job-site safety survey and plan, and an emergency action plan.
- Require the submittal of an erosion control plan.
- Provide for evacuation drills, egress routes, and expedite installation, testing, and turnover of fire systems.
- Require a pre-construction safety meeting between all workers on the site, and require a jobsite safety survey and plan to be submitted before construction begins.
- Where job site access is limited, consideration should be given to alternating work schedules for short-term interruption of work tasks to allow additional clearance for crane set-up and use.

#### **Public Safety**

- Minimize construction visitation and public access through or adjacent to the project site, as these can result in distractions that can create hazards for workers.
- Contact the local police department to set up police officer patrols during road construction and maintenance work.

## ADMINISTRATIVE: PLANNING

### General Scheduling

- Consider involving OSHA in planning safety measures prior to starting construction, or prior to performing complicated or unique construction efforts.
- Prior to the start of the project, erect informational signs near the project site and announce to the media about the construction work and schedule.
- Require a pre-construction meeting between the general contractor and all subcontractors to discuss safety issues, as the failure to plan can compromise safety.
- Require a pre-construction safety meeting between all workers on the site, and require a jobsite safety survey and plan to be submitted before construction begins.
- Require the submittal of a fire control plan, or that the fire department be contacted to discuss plans for fire protection services during construction. Consider a fire watch system.
- To prevent accidents resulting from tired construction workers, do not allow schedules which require workers to work extensive overtime.
- To prevent accidents resulting from tired construction workers, do not allow schedules which require workers to work extensive overtime.
- When designing plans that will result in construction work being performed in an operational facility, communicate/coordinate the construction activities and plans with existing manufacturing operations.

### Site Activities

- Avoid road work during peak traffic volume times of the day.
- Require regularly scheduled site housekeeping to ensure a neat, clean work area.

### Timing and Sequencing

- Prohibit the manual placement of metal decking or forms if wind speeds exceed 25 mph.
- Require concrete test results to be verified before form stripping and removal of shoring, as structural collapse might occur if forms are stripped prematurely.

### Facility Components

- Before demolishing and renovating any roof structure which is damaged, ensure that an engineering survey is performed by a competent person to determine the condition of the roof, trusses, purlins, and the structure itself to evaluate the possibility of the structure and its components failing during the work, and to evaluate how fall protection devices will be incorporated into a damaged structure.

## ADMINISTRATIVE: DESIGN

### General Safety Planning

- Provide or require the constructor to submit a construction sequence for complicated or unique designs, as these may introduce hazards that warrant special attention.
- Require the submittal of a fire control plan, or that the fire department be contacted to discuss plans for fire protection services during construction.
- Consider a fire watch system.
- Require the submittal of a job-site safety survey and plan, and an emergency action plan.
- Require a pre-construction meeting between the general contractor and all subcontractors to discuss safety issues.
- Consider involving OSHA in planning safety measures prior to starting construction, or prior to performing complicated or unique construction efforts.

### Sitework

- Require the submittal of an erosion control plan.

#### Safe Work Procedures

- Require concrete test results to be verified before form stripping and removal of shoring, as structural collapse might occur if forms are stripped prematurely.

#### Hazardous Materials

- Ensure that specified materials of construction are appropriate for the flammability hazards which may be encountered on the work site.
- Avoid using creosote or other toxic substances to treat timber piles, railroad ties, or other ground contact members.

### SITWORK: LAYOUT

#### General Considerations

- Prior to the start of the project, erect informational signs near the project and announce to the media about the construction project.
- Employ police officers to patrol around the project site to help with traffic control.

#### Underground Work

- Allow adequate clearance for shoring, forms, equipment, and workers to perform below-grade work to provide a safe working space.
- Provide road access into large, deep excavations such as wastewater treatment ponds and underground garages.

#### Public Access and Transportation

- Detour public traffic around the project site.
- Minimize construction visitation and public access through and adjacent to the construction site.

#### Transportation on Site

- Allow adequate room for constructor parking, temporary buildings, shops, material storage areas, and unobstructed access to and from the project site.
- Allow for pedestrian traffic to be isolated from construction vehicular traffic.
- Locate project control points away from areas of high construction and public traffic.
- Allow room for temporary roadways to be constructed for use by emergency vehicles.
- Maintain site distances on the project site and haul roads.

### SITWORK: ROADS/PAVING

#### Site Considerations

- Locate project control points away from areas of high construction and public traffic.

#### Terrain and Road Layout

- Design the slope, width, height, turning radius, and surface treatment of traffic surfaces with consideration of the anticipated size, weight, and maneuverability of the construction equipment.
- Design periodic turnouts into long straight roadways. This allows trucks to turn around, minimizes reverse motion, and allows for passing of other vehicles.
- Provide road access into large, deep excavations such as wastewater treatment ponds and underground garages.
- Provide structural support at the edge of roadways to keep heavy construction equipment from crushing the edge and overturning.
- Prepare, or require submittal of, an erosion control plan.

#### Utilities

- Ensure that all open sewer embankments are designed for adequate stability under anticipated worksite conditions.

- Require the constructor to locate, or pothole, existing underground utilities before excavation operations begin (utilize the “call before you dig” number, call 811).

#### Road and Paving Design

- For traffic facility components, increase the specification standards to lengthen the project maintenance life cycle.
- Require at least two formal, controlled intersections at access points to the site.
- Design the slope, width, height, turning radius, and surface treatment of traffic surfaces with consideration of the anticipated size, weight, and maneuverability of the construction equipment.
- Maintain site distances on the project site and haul roads.

#### Public Access and Control

- Prior to the start of the project, erect informational signs near the project and announce to the media about the construction project.
- Allow room for temporary roadways to be constructed for use by emergency vehicles.
- Detour public traffic around the project site.
- Minimize construction visitation and public access through and adjacent to the construction site.
- Employ police officers to patrol around the project site to help with traffic control.

### SITWORK: EARTHWORK

#### General Information

- Prior to the start of the project, erect informational signs near the project and announce to the media about the construction project.
- Prepare, or require the submittal of, an erosion control plan.

#### Access to the Site and Public Traffic

- Require at least two formal, controlled intersections at access points to the site.
- Minimize construction visitation and public access through and adjacent to the construction site.
- Detour public traffic around the project site.

#### Haul Roads

- Maintain site distances on the project site and haul roads.

#### Excavation Work

- Provide road access into large, deep excavations such as wastewater treatment ponds and underground garages.
- Provide a seal slab or walls in excavations where the soil is saturated or likely to flood the excavation before backfilling.

#### Sewer Lines and Drainage

- Cover open drainage routes in high foot traffic areas to prevent tripping hazards.
- Ensure that all open sewer embankments are designed for adequate stability under anticipated worksite conditions.
- Require the constructor to locate, or pothole, existing underground utilities before excavation operations begin.

### FOUNDATIONS

#### Excavations

- Allow adequate clearance for shoring, forms, and workers within the excavation to provide a safe working space.

#### Concrete Slabs

- Prohibit the manual placement of metal decking or forms if wind speeds exceed 25 mph.

### ROOFING

#### Added Features

- Before demolishing and renovating any roof structure which is damaged, ensure that an engineering survey is performed by a competent person to determine the condition of the roof, trusses, purlins, and the structure itself to evaluate the possibility of the structure and its components failing during the work, and to evaluate how fall protection devices will be incorporated into a damaged structure.

### STRUCTURAL: STEEL

#### Steel Erection

- Minimize the amount of overhead work to reduce fall and other hazards.
- Discontinue steel erection when wind forces exceed 25 mph.

#### Building Design

- Avoid access to areas near hoist or crane electrification points and in the path of travel.

### STRUCTURAL: CONCRETE

#### Post-tensioning cables and rebar

- Align or locate post-tensioning cables such that if failure of a jack, cable, or fitting occurs during tensioning, the cable is not directed towards an active work area.

#### Formwork

- Prohibit forming work by hand if wind speed exceeds 30 mph.

#### Fall Protection

- Avoid connection points for lifeline and guardrail attachment which are welded or connected to columns by the Constructor but can break off, and also protrude into working areas.

#### Mechanical Equipment

- Avoid access to areas near hoist or crane electrification points and in the path of travel.

### STRUCTURAL: MASONRY

#### Building Design Issues

- Avoid access to areas near hoist or crane electrification points and in the path of travel.

#### Safe Work Procedures

- To reduce worker exposure to falls, use pre-fabricated panels for work over water, railways, roads, etc.

### STRUCTURAL: TIMBER / WOOD

#### Mechanical and Electrical

- Avoid access to areas near hoist or crane electrification points and in the path of travel.
- Minimize the amount of overhead work to reduce fall and other hazards.

## FINISHES: GENERAL

### Signs

- Design signs with rounded or blunt corners, free of sharp edges, burrs, splinters, and other sharp projections. Orient fasteners so that they do not constitute a safety hazard.

### Miscellaneous Issues

- Minimize the amount of overhead work to reduce fall, ergonomic, and other hazards.
- Use smaller, lightweight materials and equipment for elevated work to make it easier and safer to handle.
- Provide recessed handles and other cabinet, cupboard, and locker hardware which do not project into work areas and passageways.

## FINISHES: STAIRS/RAILINGS

### Stairs

- Consider using prefabricated stairways which can be erected as one assembly to reduce worker exposure to falls.

### Rails

- Avoid attaching equipment or other objects to the top rails.

### Landings

- Coordinate the layout of exterior stair landings with the foundation design to provide a smooth, clear landing area free of tripping hazards.
- Avoid stair landings constructed separate from the stairs.

## FINISHES: LADDERS

### Ladder Landing

- Provide a minimum 2 ft. - 6 in. X 2 ft. - 6 in. landing area at the top and bottom of ladders. Coordinate the layout of the landings with the structure design to eliminate tripping hazards.

## DOORS & WINDOWS

### Doors

- Clearly mark interior glass doors to prevent workers from mistakenly trying to walk through the doors when closed.

### Windows

- Clearly mark interior glass windows to prevent workers from mistakenly trying to walk through the windows.

## MECHANICAL & HVAC

### Controls

- Provide clearly marked and identified emergency controls and displays.

### Overhead Equipment

- Specify the material hoist or crane loading capacity to be clearly stenciled onto the hoist or crane beams or rails.
- Minimize the amount of overhead work to reduce fall and other hazards.
- Locate lifting eyes, hoist, or crane above the equipment to aid in the installation and maintenance of the equipment.

#### Equipment Characteristics

- Require systems, components, and welds to be tested to ensure they meet minimum requirements (hydrostatic, radiographic, ultrasonic, magnaflux, weldsectioning, dye penetrant, halogen mass spectrometer, etc.).

### ELECTRICAL

#### Circuits and Grounding

- Ensure that all electrical circuits are sufficiently identified throughout their length.

#### Routing Circuits

- Minimize the amount of overhead work to reduce fall and other hazards.
- Avoid access to areas near hoist and crane electrification components.

#### Electrical/Instrumentation System

- Specify that all electrical and instrumentation wiring is to be color coded to comply with N.E.C. design requirements so workers can reliably identify the purpose of the wiring.

#### Site Electric

- Locate underground lines in areas easily accessible for excavation. Allow sufficient area around the excavations for stockpiling the soil.
- Require the constructor to locate, or pothole, for underground lines before work begins.
- Encase new underground lines in concrete which is colored red.
- Avoid locating power lines adjacent to constructor material storage areas.

#### System Considerations

- Require systems, components, and welds to be tested to ensure they meet minimum requirements (hydrostatic, radiographic, ultrasonic, magnaflux, weld sectioning, dye penetrant, halogen mass spectrometer, etc.).

### INDUSTRIAL PIPING

#### Pipe Identification

- Check that foreign piping components are compatible with other piping system components.
- Color code the pipes to easily identify their contents.

#### Connections

- Avoid interior welds in large pipes and tanks, and ensure that welding conditions are appropriate for the type of pipe material, e.g. alloy piping systems requiring PWHT/preheat.
- Require performance testing of the piping system, components, and welds using such tests as hydrostatic, radiographic, ultrasonic, magnaflux, weld sectioning, dye penetrant, etc.
- Use bolted rather than welded connections when working around existing flammable structures.

#### Pipe Systems

- Minimize downtime periods of existing automatic sprinkler systems to optimize their useful service during construction.
- Require a stress analysis to be performed on applicable systems.

#### Control Pressure

- Provide a tag or other positive i.d. of the appropriate pressure, temperature, etc. on all valves.

#### Fall Protection

- Provide fall restraint cables along the length of overhead piping runs. This will help ensure that workers do not tie off to inappropriate elements (e.g. sprinkler pipes).

#### Buried Lines

- Locate underground lines in areas easily accessible for excavation. Allow sufficient area around the excavations for stockpiling and transporting the soil.
- Encase newly-installed underground lines in red concrete for ease of detection.

### TANKS & VESSELS

#### Access

- Coordinate the layout of tank stair landings with the tank foundation design to prevent tripping hazards.

#### Welds and Confined Spaces

- Avoid interior welds in tanks. Provide ventilation in the tank if interior welds are required.
- Provide at least two access ports for tanks and vessels to aid in access/egress and ventilation.
- Complete interior welds on tank walls before erecting the roof.
- Specify the need for a permit-required confined space program when utilizing flammable materials inside tanks.

#### General Considerations

- Protect underground tanks and vessels against crushing by superimposed loads with the use of sleeves, concrete slabs, or by providing guard posts to prevent travel over them.

## **Appendix B4:**      Design suggestions that do not pertain to the safety of construction workers

### SITework: ROADS/PAVING

#### Utilities

- Provide sewers with adequate accessways to allow for ease of inspection and maintenance operations.
- Ensure that sewer lines are suitable for the maximum temperature service conditions.
- Provide adequate clearance between process/sanitary sewers and any adjacent or crossing potable water lines.

### SITework: EARTHWORK

#### Sewer Lines and Drainage

- Design open drainage pipes for storm sewers to allow for easy access for the removal of debris.
- Ensure that all accessways and manholes are provided with venting or non-venting lids appropriate for the service and traffic location.
- Provide sewers with adequate accessways to allow for ease of inspection and maintenance operations.
- Ensure that sewer lines are suitable for the maximum temperature service conditions.
- Provide adequate clearance between process/sanitary sewers and any adjacent or crossing potable water lines.

### FOUNDATIONS

#### Health Concerns

- In locations where radon is prevalent, design coarse granular fill and drain pipe(s) under the slab such that the arrangement allows radon to be diverted to the ambient air rather than through the slab and into the structure.

### STRUCTURAL: STEEL

#### Health Concerns

- To contain hazardous and flammable materials, isolate from adjoining areas the storage areas for combustible and toxic materials, such as paper, explosives, tires, celluloid, excelsior, petroleum, plastics, etc.

### STRUCTURAL: CONCRETE

#### Design Features

- To contain hazardous and flammable materials, isolate from adjoining areas the storage areas for combustible and toxic materials, such as paper, explosives, tires, celluloid, excelsior, petroleum, plastics, etc.

### STRUCTURAL: MASONRY

#### Building Design Issues

- To contain hazardous and flammable materials, isolate from adjoining areas the storage areas for combustible and toxic materials, such as paper, explosives, tires, celluloid, excelsior, petroleum, plastics, etc.

## STRUCTURAL: TIMBER / WOOD

### Design Considerations

- To contain hazardous and flammable materials, isolate from adjoining areas the storage areas for combustible and toxic materials, such as paper, explosives, tires, celluloid, excelsior, petroleum, plastics, etc.

## ELECTRICAL

### Safety Modifications

- Specify rubberized floor mats around electrical components (such as breakers) with holes that allow for water drainage. This can prevent worker electrocution.

## TANKS & VESSELS

### General Considerations

- Provide vents and overflow or relief devices to avoid over-pressurization, and to avoid creating sufficient vacuum to cause the tank to collapse.
- Provide dikes around storage tanks which contain hazardous substances. Use a slab rather than an HDPE liner for the leak detection (LD) system on the bottom of large storage tanks.

## **Appendix B5:**      Design suggestions that pertain to designer responsibilities and processes that are not part of project design

### ADMINISTRATIVE: LAYOUT

#### Materials and Material Storage

- Schedule the release of engineering drawings such that sufficient time is allowed for materials to be purchased, delivered, and installed.
- Find areas for contractor material storage that is at least fifty feet from any powerlines.
- Provide the constructor with a list and the location of toxic substances and other hazardous materials which may be located on the site, as these pose an obvious hazard for workers.

#### Underground and Site Utilities

- Indicate on the contract drawings the locations of shut-off valves and switches for existing utilities. Provide the contractor access to these locations to help ensure the safety of workers, especially during emergency situations.
- Indicate on the contract drawings the locations of existing underground utilities and mark a clear zone around the utilities. This is essential when excavation operations take place.

#### Jobsite Hazards

- Provide the constructor with original erection drawings of the existing structure on renovation projects.
- Include the name, address, and telephone number of local utility companies on the drawings.
- Note on the drawings the source of information and level of certainty on the location of underground utilities.
- For projects that occur on or near steep slopes, provide warnings and information about the site conditions in the construction documents.

#### Safety Plans

- Specify testing procedures for complicated designs or specialized mechanical, electrical, or piping systems, to avoid faulty assumptions being made by the constructor.
- Increase the project maintenance life cycle by increasing or upgrading the project specification standards, resulting in less exposure of workers to traffic.

#### Structural

- Note on the contract drawings the locations of existing vertical load bearing walls. Also, provide information on the load-bearing capacity of these walls.
- Indicate on the contract drawings the locations where shoring of the existing structure is required during construction. Also indicate the load that must be supported per shore.
- Review the condition and integrity of the existing structure and indicate any known hazards or deficiencies on the contract drawings.
- Provide the constructor with floor and roof design loads for use in determining material stockpile locations and heavy equipment maneuverability.

### ADMINISTRATIVE: PLANNING

#### General Scheduling

- Investigate the hazards associated with the specified construction materials and alert the constructor of the necessary safety precautions.
- Schedule the release of engineering drawings such that sufficient time is allowed for materials to be purchased, delivered, and installed.

- When estimating the length of time for completion of individual work stages and the overall project, take into account the safety and health requirements of the construction workers.

#### Site Activities

- Research the history of the project site and alert the constructor of the type and location of any hazardous and toxic substances existing on the site.

#### Minimizing Hazards Through Scheduling

- Design and schedule different projects that occur at the same location to be performed simultaneously.
- To minimize exposure to hazards, design and schedule projects which occur at the same location to be completed simultaneously.

### ADMINISTRATIVE: DESIGN

#### General Safety Planning

- Increase the project maintenance life cycle by increasing or upgrading the project specification standards.
- Conduct constructability reviews early in the design phase, and include constructor and maintenance personnel in the reviews to assist in identifying hazards.
- In estimating the durations for the completion of work stages and the overall project, take into account the time required to ensure worker safety and health.

#### Sitework

- Research the history of the project site and alert the constructor of the type and location of any hazardous and toxic substances existing on the site.

#### Safe Work Procedures

- Specify testing procedures for complicated designs or specialized mechanical, electrical, or piping systems, to avoid faulty assumptions being made by the constructor.
- Provide the constructor with floor and roof design loads for use in determining material stockpile locations and heavy equipment maneuverability.

#### Hazardous Materials

- Ensure that all materials meet the expected environmental and work site conditions relative to their flammability and toxicity.
- Investigate the hazards associated with the specified construction materials and alert the constructor of the necessary safety precautions.

### SITework: LAYOUT

#### General Considerations

- For traffic facility components, increase the specification standards to lengthen the project maintenance life cycle.

#### Overhead Power Lines

- Clearly mark the power lines with warning flags, tape, paint, chalk, etc., and note their location on the contract drawings.
- Locate areas for contractor material storage that is at least fifty feet from any powerlines.

#### Site Terrain

- For projects that occur on or near steep slopes, provide warnings and information about the site conditions in the construction documents.

## FOUNDATIONS

### Concrete Slabs

- Note on the contract drawings the existing and new floor design loads to aid the constructor in determining material stockpile locations and heavy equipment maneuverability.

## MECHANICAL & HVAC

### Controls

- Indicate on the contract drawings the location of equipment shut-off valves and switches for existing utilities. Provide the constructor access to these locations for emergency situations.

## ELECTRICAL

### Controls

- Indicate on the contract drawings the location of existing equipment and electrical shut-off switches. Allow the constructor access to these locations for emergency situations.

### Safety Modifications

- Include the name, address, and telephone number of the local electrical power supply company on the contract drawings for quick reference in emergency situations.

### Routing Circuits

- Provide warnings throughout the plans and specifications when electrical systems create floor openings.

### Site Electric

- Note on the contract drawings the level of certainty and source of information on the location of existing underground power lines.
- Mark on the contract drawings a clear zone around existing underground power lines. This is essential when excavation operations take place.
- Clearly mark the power lines with warning flags, and note their location on the drawings.

## INDUSTRIAL PIPING

### Pipe Identification

- Show the pipe content flow direction on the contract drawings so that the first valve upstream of an emergency can be easily located.

### Racks

- Specify the use of hose racks for all areas requiring hoses.

### Control Pressure

- Locate piping lines which are under very high pressure or contain explosive or lethal gases on the outside of buildings or in areas properly ventilated and guarded.

### Safe Procedures

- Provide adequate safety measures in the event of possible equipment failure.
- Indicate on the contract drawings the location of shut-off valves and switches for existing systems. Provide and provide access by the constructor to the locations.

### Control Valves

- Check safety relief valves against the piping process to determine if the valves are required to be A.S.M.E. code stamped.

#### Buried Lines

- Note on the contract drawings the level of certainty and source of information on the location and size of existing underground lines.
- On the contract drawings, mark a clear zone around existing underground lines. This is essential when excavation operations take place.

## **Appendix B6:**      Design suggestions that are currently mandatory by OSHA standards

### SITEWORK: LAYOUT

#### Overhead Power Lines

- Maintain a minimum clearance between the project and overhead power lines as outlined in Section 1926.950 of the Code of Federal Regulations.

#### Work Spaces

- Allow for a large, unobstructed, open area (limited access zone) below elevated masonry work to minimize the risk of workers being struck by falling objects. See Section 1926.750 of the Code of Federal Regulations.

### FOUNDATIONS

#### Soil Conditions

- Design the foundation for the soil variations within the site. Consider the soil classifications outlined in Section 1926.650 of the Code of Federal Regulations.

### STRUCTURAL: STEEL

#### Building Design

- Provide a clear, unobstructed, spacious work area around all permanent mechanical equipment to avoid hazards posed by control valves or control panels. See Section 1926.403 of the Code of Federal Regulations.

### STRUCTURAL: CONCRETE

#### Mechanical Equipment

- Provide a clear, unobstructed, spacious work area around all permanent mechanical equipment to avoid hazards posed by control valves or control panels. See Section 1926.403 of the Code of Federal Regulations.

### STRUCTURAL: MASONRY

#### Building Design Issues

- Provide a clear, unobstructed, spacious work area around all permanent mechanical equipment to avoid hazards posed by control valves or control panels. See Section 1926.403 of the Code of Federal Regulations.

#### Safe Work Procedures

- Allow for a large, unobstructed, open area (limited access zone) below elevated masonry work to minimize the risk of workers being struck by falling objects. See Section 1926.750 of the Code of Federal Regulations.

### STRUCTURAL: TIMBER / WOOD

#### Mechanical and Electrical

- Provide a clear, unobstructed, spacious work area around all permanent mechanical equipment to avoid hazards posed by control valves or control panels. See Section 1926.403 of the Code of Federal Regulations.

## MECHANICAL & HVAC

### Placement of Equipment

- Provide a clear, unobstructed, spacious area around all permanent equipment to avoid hazards posed by control valves or control panels. See Section 1926.403 of the Code of Federal Regulations.

### Equipment Characteristics

- Specify mechanical and HVAC equipment which does not produce high noise levels while operating. See Section 1926.52 of the Code of Federal Regulations for acceptable noise levels.

## ELECTRICAL

### Site Electric

- Allow adequate clearance between the power lines and the structure. See Section 1926.950 of the Code of Federal Regulations for minimum clearances.

## **Appendix B7: Design suggestions that are currently required by building codes**

### **ADMINISTRATIVE: LAYOUT**

#### **Materials and Material Storage**

- Avoid specifying materials which contain asbestos or other known hazardous substances.

### **ADMINISTRATIVE: DESIGN**

#### **Hazardous Materials**

- Avoid specifying materials which contain asbestos or other known hazardous substances.

### **STRUCTURAL: STEEL**

#### **Building Design**

- Ensure that the building height and area per floor meet all local building code requirements for the type of construction used.

### **STRUCTURAL: CONCRETE**

#### **Design Features**

- Ensure that the building height and area per floor meet all local building code requirements for the type of construction used.

### **STRUCTURAL: MASONRY**

#### **Building Design Issues**

- Ensure that the building height and area per floor meet all local building code requirements for the type of construction used.

### **STRUCTURAL: TIMBER / WOOD**

#### **Design Considerations**

- Ensure that the building height and area per floor meet all local building code requirements for the type of construction used.

### **INDUSTRIAL PIPING**

#### **Pipe Systems**

- Design piping system components to meet all national, state, and local building code requirements and address the existing construction conditions to ensure worker safety.

#### **Safe Procedures**

- Ensure that control valve specifications meet the piping specifications for body rating, body material (corrosion and hazardous services), and flange type.

### **TANKS & VESSELS**

#### **General Considerations**

- Ensure that tanks and vessels meet all local, state, and federal design code requirements.

**Appendix B8:**      Design suggestions identified by survey respondents as not situated in design

- Group floor openings together to create one larger opening rather than many smaller openings, as these can be more easily guarded.
- When specifying roofing materials which are not suitable for walking, such as corrugated fiberglass panels, ensure they are distinguishable from safe, secure walking surfaces on the roof, or install guardrails around surfaces not suitable for walking.
- Keep all equipment and related hardware on a pad above the finished floor to reduce them as trip hazards.
- Provide a non-slip surface treatment on ramps to help prevent slipping and falling.
- In the design of stairs/railings, design the height of handrails to be between 30 and 37 inches from the upper surface of the handrail to the surface of the tread.
- For access doors through floors, use doors which immediately provide guarded entry around the hole perimeter when the door is opened.
- In the design of permanent ladders, locate the first step/rung between 6 and 12 inches above the bottom landing, and the top step/rung at the level of the top landing.
- Design perimeter walls to rise above the elevated automobile traffic surface level to provide a curb before permanent wheelstops and guardrails are placed.
- Locate skylights on flat areas of the roof.
- In the design of permanent ladders, design vertical bars to be spaced at intervals not more than 9.5 in. apart between centerlines.
- Design circumferential stairways to ascend clockwise.
- In the design of stairs, provide a minimum 2 ft. - 6 in. X 2 ft. - 6 in. landing area.
- Design parapets to be 42 inches tall. A parapet of this height will provide immediate guardrail protection and eliminate the need to construct a guardrail during construction or future roof maintenance.
- Provide drainage for all floor areas, especially around elevated equipment pads, to avoid any slippery water buildup on flooring surfaces.
- Design window sills to be 42 inches minimum above the floor level. Window sills at this height will act as guardrails during construction.
- Keep steps, curbs, blockouts, slab depressions, and other tripping hazards away from window openings, exterior edges, and floor openings.
- Provide door protection such that natural elements (snow, wind, lightning) will not cause unsafe conditions.
- For buildings with mechanical equipment in the top floor, design the roof of the area to have a hatch (e.g., 9 ft. x 9 ft.) for lowering large equipment into the mechanical room.
- In the design of permanent ladders, design horizontal bands to be spaced at intervals not more than 4 ft. apart between centerlines.
- Use wood, concrete, or other nonconductive materials instead of steel for stairways in areas where electrical work will be performed.
- Locate skylights away from the roof edges.
- Keep the finished floor around mechanical and HVAC equipment free of steps, blockouts, and other encumbrances to maintain a safe work area around the equipment.

- Design traffic barriers and guardrails so that there is no need to temporarily or permanently replace or redesign them when new pavement overlays are put down.
- In the design of permanent ladders, provide a minimum perpendicular clearance of 30 inches between the centerline of ladder rungs, cleats, steps, and any obstruction on the climbing side of fixed ladders, but if obstructions are unavoidable, clearance may be reduced to 24 inches provided a deflection device is installed to guide workers around the obstruction.
- In the design of permanent ladders, design the step-across distance between the center of the step/rung and the nearest edge of a landing to be between 7 and 12 inches. Provide a landing platform if more than 12 inches.
- On sloped sites, orient the project layout or grade the site accordingly to minimize the amount of work on steep slopes.
- In the design of permanent ladders and ladder cages, keep the inside of the cage clear of projections to ensure safe movement on the ladder.
- To minimize the risk of falling due to building offsets, minimize the number of offsets, and make the offsets a consistent size and as large as possible.
- Provide ladder cages or wells around ladders which have greater than 15 inches clear width to the nearest permanent object on each side of the centerline of the ladder.
- Design scaffolding tie-off points into exterior walls of buildings for construction purposes.
- In the design of commercial and industrial buildings, consider if sheet metal could be utilized as a walking surface and specify appropriate sheet metal gauge for walking and the appropriate screws for lengthening.
- Design all impoundments or holding ponds with emergency bypass capabilities.
- Avoid requiring trenches in previously backfilled or disturbed soil, or which cross between different types or conditions of soil.
- Limit the height of steel framed structures that have not been laterally braced. Permanent bolting and/or welding should occur as soon as possible.
- Design perimeter beams and beams above floor openings to support lifelines (minimum dead load of 5400 lbs.). Design connection points along the beams for the lifelines. Note on the contract drawings which beams are designed to support lifelines, how many lifelines, and at what locations along the beams.
- Minimize the amount of excavation work and maintain a constant foundation depth throughout the project to better support the excavation wall.
- For precast concrete members, provide inserts or other devices to attach lines or lanyards for fall protection.
- Design holes in the webs of beams located above piping for the attachment of pipe supports and lifelines/lanyards.
- When designing tanks, provide connection points for lifelines at the center of the tank roof.
- On larger masonry blocks, provide cast-in handles or handholds for easy lifting.
- For tower type structures, design a cable-type lifeline system into the structure that allows workers to be hooked onto the structure and allows for their movement up and down the structure.
- Locate new footings away from existing foundations.
- Use small sized rebar for framing members at elevated floor levels.
- Design new utilities under roadways and sidewalks to be placed using trenchless technologies or tunneling instead of trenching.

- Avoid placing machinery breathing equipment, oxygen sensor, refrigerant sensor, or refrigerant/fuel burning equipment in the same space unless a clean air source is provided.
- Minimize the need for special or complicated equipment installation operations.
- Provide ventilation systems in mechanical rooms and confined spaces that control both the temperature and air quality.
- Design all mechanical equipment and HVAC components to address the anticipated corrosive environment and the loading requirements of the construction site.
- When new electrical lines are to be placed below existing concrete surfaces, roads, or other traffic areas, design the lines to be placed using trenchless technologies.
- Isolate all live conductors and equipment from accidental contact.
- Isolate live conductors from accidental contact by overhead placement, secure enclosures, locked panels, etc.
- Avoid routing dangerous fluids over equipment, control boards, aisles, and operator areas to avoid injury in case of a pipe leak.
- Design in connection points on piping sections for lifting operations. Consider designing the connection points such that after pipe installation they can be used to connect the pipe sections.
- Route pipes at least 30 inches above the finished floor level to keep them from becoming trip hazards.
- Provide for thermal expansion of the piping by adding pipe bends, offsets, etc.
- Design overhead piping and supports to hold up a worker.
- Allow for the placement of underground utilities using trenchless technologies rather than the cut and cover method.
- Minimize the amount of overhead piping and piping component work to reduce fall and other hazards.

**Appendix C:        Research Survey Samples**

**Appendix C1:        Pilot Survey [Version for the Architects]**

## **Survey on Design for Construction Safety**

Dear AEC Professional,

Thank you for agreeing to participate in this research study. This is part of a doctoral dissertation in “Design for Construction Safety (DFCS)”. Design-for-Construction Safety (DFCS) is the explicit consideration of construction worker safety in the design of a project. It also involves including worker safety considerations in the constructability review process.

This is a study of design measures for construction safety, to obtain information on their feasibility for implementation. As a professional in the Architecture/Engineering/Construction industry, your answers to the questions will be very helpful in the study.

Your responses, together with others, will be collectively analyzed, interpreted and summarized. Responses will remain confidential. Please complete to your best ability. The survey is expected to take 10 minutes. Please email the completed survey to my address (mbello@andrew.cmu.edu).

If you have any questions or concerns about the survey and/or study, here are my full contact details:

Mustapha A. Bello  
Carnegie Mellon University  
405 Margaret Morrison Carnegie Hall  
Pittsburgh, PA 15213  
Email: mbello@andrew.cmu.edu  
Phone: (412)330-8832

You may also contact my advisor, Prof. Omer Akin, School of Architecture, Carnegie Mellon University, 412 MMCH, Pittsburgh, PA 15213 (Email: oa04@andrew.cmu.edu). Once again, your participation is much appreciated.

Sincerely,  
Mustapha A. Bello  
PhD Candidate  
School of Architecture &  
Department of Civil and Environmental Engineering  
Carnegie Mellon University

**SECTION 1: GENERAL INFORMATION**

Profession: \_\_\_\_\_

Job Title / Position: \_\_\_\_\_

Years of Experience: \_\_\_\_\_

## SECTION 2: DESIGN MEASURES

Below are a number of design measures for construction worker safety. For each of the measures, please answer the questions.

	DFCS Measures	Is this measure applicable to the design phase of a project?  Why or why not?	Can this measure be successfully implemented in the project design phase?  Why or why not?	Do you find a revision could improve this measure to increase its implementation on projects?  If Yes, please provide your revision of the measure
1.	Locate exterior stairways and ramps on the sheltered side of the structure to protect them from rain, snow, and ice to minimize fall hazards.			
2.	In multi-story buildings, design each floor plan to have a smaller area than the story below to prevent objects and workers from falling more than one story.			
3.	Design window sills to be 42 inches minimum above the floor level. Window sills at this height will act as guardrails during construction.			
4.	Design a permanent guardrail that surrounds each skylight.			
5.	On sloped sites, orient the project layout or grade the site accordingly to minimize the amount of work on steep slopes.			
6.	Design scaffolding tie-off points into exterior walls of buildings for construction purposes.			
7.	Design pre-fabricated members to be of one size and shape, or make them easily distinguishable to avoid incorrect placement.			
8.	Design signs to be integral parts of walls and floors using color, tiles, or floor coverings.			

### **SECTION 3: OTHER QUESTIONS**

How long did it take you to complete the survey? \_\_\_\_\_

Would you like your participation in the study to be confidential? \_\_\_\_\_

Do you have any general comments or suggestions? \_\_\_\_\_

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Once again, your participation is much appreciated.

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	<b>DFCS Measures</b>	<b>Is this measure applicable to the design phase of a project?</b>  <b>Why or why not?</b>	<b>Can this measure be successfully implemented in the project design phase?</b>  <b>Why or why not?</b>	<b>Do you find a revision could improve this measure to increase its implementation on projects?</b>  <b>If Yes, please provide your revision of the measure.</b>
1.	Provide the constructor with floor and roof design loads for use in determining material stockpile locations and heavy equipment maneuverability.			
2.	Use a single size, or a minimum number of sizes possible, of bolts, nails, and screws. If more than one size is required, specify sizes which vary greatly and are easily distinguishable.			
3.	Consider alternative steel framing systems which reduce the number of elements and where beams are landed on supports rather than suspended between them.			
4.	In order to allow sufficient walking surface, use a minimum beam width of 6 inches.			
5.	Align or locate post-tensioning cables such that if failure of a jack, cable, or fitting occurs during tensioning, the cable is not directed towards an active work area.			
6.	Design wood piles such that they are below the water table, and do not specify creosote for protection of the piles from environmental deterioration.			
7.	On spread and continuous footings, and mat foundations, design the top layer of reinforcing steel to be spaced at no more than 6 inches on center, each way, to provide a continuous, stable walking surface before the concrete is poured.			
8.	Design special attachments or holes in structural members at elevated work areas to provide permanent, stable connections for supports, lifelines, guardrails, scaffolding or lanyards.			

### **SECTION 3: OTHER QUESTIONS**

How long did it take you to complete the survey? \_\_\_\_\_

Would you like your participation in the study to be confidential? \_\_\_\_\_

Do you have any general comments or suggestions? \_\_\_\_\_

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**Appendix C3:**      Research Web Survey [Sample Version for the Architects]  
(Administered through [www.surveymonkey.com](http://www.surveymonkey.com))

<b>Design for Construction Safety - A3</b>	<a href="#">Exit this survey</a>
<b>Cover Page</b>	

SURVEY ON DESIGN FOR CONSTRUCTION SAFETY

Dear AEC Professional,

Thank you for agreeing to participate in this research study. This survey is part of a doctoral dissertation in "Design for Construction Safety". Design-for-Construction Safety (DFCS) is the explicit consideration of construction worker safety in the design of a project. It also involves including worker safety considerations in the constructability review process.

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PhD Candidate  
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Department of Civil and Environmental Engineering  
Carnegie Mellon University

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## Liability for Worker Safety

## The Issue of Liability for Worker Safety

A study by Gambatese et al (2005) found most designers believe DFCS will increase their liability exposure. Avoiding liability for construction worker safety underlies the paragraphs in most model contracts that explicitly states the design professional as not being responsible for construction site safety methods or programs. Architects in the United States use the American Institute of Architects (AIA) A201 contract document. The issue of architects' involvement in construction safety is addressed in sections 3.3.1, 4.2.2, 4.2.7, 5.3.1, 10.1, 10.2 and 10.6. The most relevant to DFCS is section 3.3.1 which is presented.

3.3.1 The Contractor shall supervise and direct the Work, using the Contractor's best skill and attention. The Contractor shall be solely responsible for and have control over construction means, methods, techniques, sequences and procedures and for coordinating all portions of the Work under the Contract, unless the Contract Documents give other specific instructions concerning these matters. If the Contract Documents give specific instructions concerning construction means, methods, techniques, sequences or procedures, the Contractor shall evaluate the jobsite safety thereof and, except as stated below, shall be fully and solely responsible for the jobsite safety of such means, methods, techniques, sequences or procedures. If the Contractor determines that such means, methods, techniques, sequences or procedures may not be safe, the Contractor shall give timely written notice to the Owner and Architect and shall not proceed with that portion of the Work without further written instructions from the Architect. If the Contractor is then instructed to proceed with the required means, methods, techniques, sequences or procedures without acceptance of changes proposed by the Contractor, the Owner shall be solely responsible for any resulting loss or damage.

One could argue that the model contract precludes architects from making design decisions in the interest of construction worker safety. However, one can also infer that so long as the architect does not prescribe means, methods, techniques, sequences or procedures, the designer can be involved in construction worker safety although the designer is not responsible for site safety. It is thus important that DFCS measures do not interfere with the contractor's means and methods.

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General Information

**\*Profession:**

**Job Title / Position:**

**\*Years of Experience:**

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## Introduction to Design Measures

This section includes six (6) design measures for construction worker safety. For each of the measures, please answer the questions. Single word responses are acceptable.

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## Design Measure 1

MEASURE 1: Avoid the design of elevated exterior structures, equipment, etc. next to roof edges.

**\*Is this measure applicable to the design phase of a project?**

- ☐ Yes  
☐ No  
☐ Other (please specify)

**Why?**

**\*Do you feel this measure can improve construction worker safety?**

- ☐ Yes  
☐ No  
☐ Other (please specify)

**Why?**

**\*Would you implement this measure in your design?**

- ☐ Yes  
☐ No  
☐ Other (please specify)

**Why?**

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## Design Measure 2

MEASURE 2: Provide permanent guardrails around floor openings.

**\*Is this measure applicable to the design phase of a project?**

- ☐ Yes
- ☐ No
- ☐ Other (please specify)

**Why?**

**\*Do you feel this measure can improve construction worker safety?**

- ☐ Yes
- ☐ No
- ☐ Other (please specify)

**Why?**

**\*Would you implement this measure in your design?**

- ☐ Yes
- ☐ No
- ☐ Other (please specify)

**Why?**

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Design Measure 3

MEASURE 3: Eliminate tripping hazards around roof openings.

**\*Is this measure applicable to the design phase of a project?**

- ☐ Yes
- ☐ No
- ☐ Other (please specify)

**Why?**

**\*Do you feel this measure can improve construction worker safety?**

- ☐ Yes
- ☐ No
- ☐ Other (please specify)

**Why?**

**\*Would you implement this measure in your design?**

- ☐ Yes
- ☐ No
- ☐ Other (please specify)

**Why?**

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## Design Measure 4

MEASURE 4: Locate exterior stairways and ramps on the sheltered side of the structure to protect them from rain, snow, and ice to minimize fall hazards.

**\*Is this measure applicable to the design phase of a project?**

- ☐ Yes  
☐ No  
☐ Other (please specify)

**Why?**

**\*Do you feel this measure can improve construction worker safety?**

- ☐ Yes  
☐ No  
☐ Other (please specify)

**Why?**

**\*Would you implement this measure in your design?**

- ☐ Yes  
☐ No  
☐ Other (please specify)

**Why?**

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## Design Measure 5

MEASURE 5: Protect exterior walkways and platforms from the weather (which can make them slippery) by providing a covering, extending the roof line, or locating them on the sheltered side of the structure.

**\*Is this measure applicable to the design phase of a project?**

- ☐ Yes  
☐ No  
☐ Other (please specify)

**Why?**

**\*Do you feel this measure can improve construction worker safety?**

- ☐ Yes  
☐ No  
☐ Other (please specify)

**Why?**

**\*Would you implement this measure in your design?**

- ☐ Yes  
☐ No  
☐ Other (please specify)

**Why?**

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## Design Measure 6

MEASURE 6: Provide permanent catwalks or work platforms for ceiling installation and maintenance on tall, long span structures.

**\*Is this measure applicable to the design phase of a project?**

- ☐ Yes
- ☐ No
- ☐ Other (please specify)

**Why?**

**\*Do you feel this measure can improve construction worker safety?**

- ☐ Yes
- ☐ No
- ☐ Other (please specify)

**Why?**

**\*Would you implement this measure in your design?**

- ☐ Yes
- ☐ No
- ☐ Other (please specify)

**Why?**

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Other Questions

**Do you have any general comments or suggestions on DFCS (Design for Construction Safety) or on the study?**

**\*Would you like your participation in the study to be confidential?**

☐ Yes

☐ No

**\*Would you be willing to further participate in this study?**

☐ Yes

☐ Maybe

☐ No

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## **Appendix D:    Profession and Information of the Survey Respondents**

	<b>Survey Version</b>	<b>Profession</b>	<b>Job Title</b>	<b>Years of Experience</b>
1	<b>A1</b>	Architect	President	36
2		Architecture	Architect and Educator	15
3	<b>A2</b>	Architect		35
4	<b>A3</b>	Architect		11
5	<b>A4</b>	Architect	Project Architect	17
6		Professor of Architecture	Assistant Professor	3
7	<b>A5</b>	Architect	Principal/Owner	30
8	<b>A6</b>	Architecture Education	Architect/Assistant Professor	16
9	<b>A7</b>	Architecture	Architect, Sole Proprietor	16
10	<b>A8</b>	Architect	Principal	23
11	<b>A9</b>	Architect	Project Architect	16
12	<b>A10</b>	Professor / Practicing Architect	Clinical Assistant Professor	6
13	<b>A11</b>	Architecture	Principal	12
14	<b>A12</b>	Architect	Principal	15
15	<b>A13</b>	Architect	Senior Project Architect / Vice-President	29
16	<b>A14</b>	Architect	Principal	32
17	<b>A15</b>	Architect / Professor	Associate Professor, Registered Architect	30
18	<b>A16</b>	Architecture	Registered Architect / Professor	17
19		Architect	Architect and Professor of Architecture	32
20		Architect	Principal / Professor	33
21		Architecture	Principal	13
22	<b>A17</b>	Architect	Associate Professor	10
23	<b>A18</b>	Architect		11
24	<b>A19</b>	Architect	Principal + Owner	20
25	<b>A20</b>	Architect / Educator	Sole practitioner / Assistant Professor	14
26	<b>A21</b>	Architect	Principal	37
27		Architect	Assistant Professor	5
28	<b>A22</b>	Architecture		23
29	<b>A23</b>	Architect	Principal / Designer	37
30	<b>C1</b>	Civil Engineer	Vice President	18
31	<b>C2</b>	Education	Associate Professor	20
32	<b>C3</b>	Structural Engineer	Office Manager / Senior Vice President	28
33	<b>C4</b>	Civil Engineer	Assistant Professor	7
34	<b>C5</b>	Academic	Assistant Professor	6
35	<b>C6</b>	Structural Engineer	Senior Associate	13
36	<b>C7</b>	Academia	Professor	23
37		Professor	Assistant Professor	6

	Survey Version	Profession	Job Title	Years of Experience
38	C8	Structural Engineering	Associate Professor	29
39	C9	Civil Engineering Academia	Assistant Professor	16
40	C10	Education / Research	Assistant Professor	15
41	C11	Former Structural Engineer	Currently Assistant Professor	27
42	C12	Structural Engineering	Senior Engineer	3
43	C13	Structural Engineering	Professor	10
44	M1	Instructor	Associate Professor	27
45	M2	Consulting Engineer - MEP	Vice President	9
46	M3	Mechanical Engineer	Department Director	21
47	M4	Mechanical Engineer	President	20
48	M5	Engineer	Senior Vice President	25
49	E1	Electrical teacher	Instructor	3
50	E2	Electrical Engineering	VP / Principal	25
51		Electrical Engineer	Principal	30
52	E3	Electrical Engineering	Principal Electrical Engineer	20
53		Electrical Engineer	Project Manager	11
54	E4	Electrical Consultant	Principal	37
55	E5	Electrical Engineer	Staff Electrical Engineer, P.E.	10
56		Electrical Engineer	Staff Electrical Engineer, P.E.	10
57	E6	MEP Consulting Engineer	Electrical Engineer	9
58	P1	Engineering designer	Sr. Mechanical Designer	30
59	P2	HVAC Plumbing	Manufacturers Representative	37
60		Mechanical Engineering	Mechanical Designer	35
61	P3	Professor PHVACR	Assistant Professor PHVACR Technology	30
62	P4	Consulting Engineer (Mechanical and Electrical)	Principal	25
63	P5	Engineering	Sr. Plumbing Engineer	32
64	P6	Mechanical Engineering	Senior Engineer	25
65	P7	Mechanical Engineer		14
66	P8	Mechanical Design for Building Systems	Senior Mechanical Engineer	28
67	P9	Mechanical Engineer	Director of MEP Engineering	13

**Appendix E:        Research Interview Guides**

**Appendix E1:        Pilot Interview Guide [For Architect]**

## **Interview on Design for Construction Safety**

Dear AEC Professional,

Thank you for agreeing to participate in this research study. This is part of a doctoral dissertation in “Design for Construction Safety (DFCS)”.

Design-for-Construction Safety (DFCS) is the explicit consideration of construction worker safety in the design of a project. It also involves including worker safety considerations in the constructability review process.

This is a study of design measures for construction safety, to obtain information on their feasibility for implementation. As a professional in the AEC (Architecture/Engineering/Construction) industry, your answers to the questions will be very helpful in the study.

Your responses, together with others, will be collectively analyzed, interpreted and summarized. Responses will remain confidential. The interview is expected to take 30 minutes at the most. This document was prepared to facilitate the interview.

If you have any questions or concerns about the study, here are my full contact details:

Mustapha A. Bello  
Carnegie Mellon University  
405 Margaret Morrison Carnegie Hall  
Pittsburgh, PA 15213  
Email: mbello@andrew.cmu.edu  
Phone: (412)330-8832

You may also contact my advisor, Prof. Omer Akin, School of Architecture, Carnegie Mellon University, 412 MMCH, Pittsburgh, PA 15213 (Email: oa04@andrew.cmu.edu). Once again, your participation is much appreciated.

Sincerely,  
Mustapha A. Bello  
PhD Candidate  
School of Architecture &  
Department and Civil and Environmental Engineering  
Carnegie Mellon University

### *The Issue of Liability for Worker Safety*

A study by Gambatese et al (2005) found most designers believe DFCS will increase their liability exposure. Avoiding liability for construction worker safety underlies the paragraphs in most model contracts that explicitly states the design professional as not being responsible for construction site safety methods or programs. Architects in the United States use the American Institute of Architects (AIA) A201 contract document. The issue of architects' involvement in construction safety is addressed in sections 3.3.1, 4.2.2, 4.2.7, 5.3.1, 10.1, 10.2 and 10.6. The most relevant to DFCS is section 3.3.1 which is presented.

3.3.1 The Contractor shall supervise and direct the Work, using the Contractor's best skill and attention. The Contractor shall be solely responsible for and have control over construction means, methods, techniques, sequences and procedures and for coordinating all portions of the Work under the Contract, unless the Contract Documents give other specific instructions concerning these matters. If the Contract Documents give specific instructions concerning construction means, methods, techniques, sequences or procedures, the Contractor shall evaluate the jobsite safety thereof and, except as stated below, shall be fully and solely responsible for the jobsite safety of such means, methods, techniques, sequences or procedures. If the Contractor determines that such means, methods, techniques, sequences or procedures may not be safe, the Contractor shall give timely written notice to the Owner and Architect and shall not proceed with that portion of the Work without further written instructions from the Architect. If the Contractor is then instructed to proceed with the required means, methods, techniques, sequences or procedures without acceptance of changes proposed by the Contractor, the Owner shall be solely responsible for any resulting loss or damage.

One could argue that the model contract precludes architects from making design decisions in the interest of construction worker safety. However, one can also infer that so long as the architect does not prescribe means, methods, techniques, sequences or procedures, the designer can be involved in construction worker safety although the designer is not responsible for site safety. It is thus important that DFCS measures do not interfere with the contractor's means and methods.

**SECTION 1: GENERAL INFORMATION**

Profession: \_\_\_\_\_

Job Title / Position: \_\_\_\_\_

Years of Experience: \_\_\_\_\_

## SECTION 2: DESIGN MEASURES

Below are a number of design measures for construction worker safety. For each of the measures, please answer the questions.

**Measure 1:** In multi-story buildings, design each floor plan to have a smaller area than the story below to prevent objects and workers from falling more than one story.

Possible impediments to successful implementation of this measure in the project design phase were identified. Do you find these or other impediments to be applicable?

	Possible Impediments to this DFCS Measure	Are these impediments to the DFCS Measure?
1.	Decreased project quality and diminished design creativity	
2.	Schedule problems and time constraints	
3.	Increased cost	
4.		
5.		

Revisions of this DFCS Measure were made towards improving its implementation on projects. Do you find these or other revisions achieve this purpose?

	Possible Revisions to this DFCS Measure	Do these revisions improve the DFCS measure for implementation?
1.	Design the balcony on each floor to overlook the balcony on the immediate lower floor.	
2.	In multi-story buildings, balconies on the immediate lower floor should be designed to extend beyond those of the upper floor.	
3.		
4.		
5.		

The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure.

Accident: 170075329 -- Report ID: 0257250 -- Event Date: 12/16/2003						
Inspection <a href="#">306662263</a>	Open Date 12/17/2003	SIC <a href="#">1521</a>	Establishment Name Constructora I Melendez Inc			
On December 16, 2003, an employee fell from the fourth floor balcony of a residential building and was instantly killed.						
Keywords:			fall, fracture			
End Use Multi-family dwelling	Proj Type Alteration or rehabilitation		Proj Cost \$50,000 to \$250,000	Stories 4	NonBldgHt 26	Fatality X
Inspection <a href="#">1 306662263</a>	Age	Sex	Degree Fatality	Nature Fracture	Occupation Occupation not reported	Construction <b>FallDist:</b> 26 <b>FallHt:</b> 26 <b>Cause:</b> Temporary work (buildings, facilities) <b>FatCause:</b> Fall from/with structure (other than roof)

Is this incident preventable with implementation of this DFCS measure? \_\_\_\_\_

---



---

**Measure 2:** Design a permanent guardrail that surrounds each skylight.

Possible impediments to successful implementation of this measure in the project design phase were identified. Do you find these or other impediments to be applicable?

	<b>Possible Impediments to this DFCS Measure</b>	<b>Are these impediments to the DFCS Measure?</b>
1.	Decreased project quality and diminished design creativity	
2.	Schedule problems and time constraints	
3.	Increased cost	

Revisions of this DFCS Measure were made towards improving its implementation on projects. Do you find these or other revisions achieve this purpose?

	<b>Possible Revisions to this DFCS Measure</b>	<b>Do these revisions improve the DFCS measure for implementation?</b>
1.	Design guardrails of at least 1 meter (3 feet) height to surround skylights.	
2.		
3.		

The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure.

Accident: 200674133 -- Report ID: 0418800 -- Event Date: 01/14/2003						
Inspection	Open Date	SIC	Establishment Name			
<a href="#">306176231</a>	01/14/2003	<a href="#">1522</a>	Aqua-Shield Corp			
On January 14, 2003, a construction employee was working on the sixth story of a building. He was securing a lifeline on a concrete beam when he stepped back and fell through a skylight, approximately 60 feet to the ground. The employee was hospitalized with a concussion and died three days later from his injuries.						
Keywords: construction, building, fall, fall protection, walking backward, skylight, concussion, beam, walking on beam						
End Use	Proj Type		Proj Cost		Stories	NonBldgHt Fatality
Multi-family dwelling	Alteration or rehabilitation		\$500,000 to \$1,000,000		6	X
Inspection	Age	Sex	Degree	Nature	Occupation	Construction
<a href="#">1</a> <a href="#">306176231</a>			Fatality	Concussion	Construction laborers	<b>FallDist:</b> 60 <b>FallHt:</b> 60 <b>Cause:</b> Fencing, installing lights, signs, etc. <b>FatCause:</b> Fall through opening (other than roof)

Is this incident preventable with implementation of this DFCS measure? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

**Measure 3:** Design window sills to be 42 inches minimum above the floor level.  
Window sills at this height will act as guardrails during construction.

Possible impediments to successful implementation of this measure in the project design phase were identified. Do you find these or other impediments to be applicable?

	<b>Possible Impediments to this DFCS Measure</b>	<b>Are these impediments to the DFCS Measure?</b>
1.	Decreased project quality and diminished design creativity	
2.	Schedule problems and time constraints	
3.	Increased cost	

Revisions of this DFCS Measure were made towards improving its implementation on projects. Do you find these or other revisions achieve this purpose?

	<b>Possible Revisions to this DFCS Measure</b>	<b>Do these revisions improve the DFCS measure for implementation?</b>
1.	Design window sills to be 42 inches minimum above the floor level to eliminate the OSHA requirement for temporary guardrails during construction.	
2.		
3.		

The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure.

Accident: 200202745 -- Report ID: 0418200 -- Event Date: 05/24/2006						
Inspection	Open Date	SIC	Establishment Name			
<a href="#">309256444</a>	05/24/2006	<a href="#">1521</a>	Henderson Enterprises, Inc.			
On May 24, 2006, Employee #1, a superintendent, was walking in a room, when he tripped and fell through an unguarded window. The window was located on the second floor of a building. He fell approximately 18 ft upon an adjacent concrete patio and died from traumatic brain injuries that included a fractured skull.						
Keywords: unguarded, building, tripped, lost balance, fall, fracture, skull						
End Use		Proj Type		Proj Cost		Stories NonBldgHt Fatality
Single family or duplex dwelling		New project or new addition		\$500,000 to \$1,000,000		3 X
Inspection	Age	Sex	Degree	Nature	Occupation	Construction
<a href="#">1 309256444</a>			Fatality	Fracture	Occupation not reported	<b>FallDist:</b> 18 <b>FallHt:</b> 18 <b>Cause:</b> Installing windows and doors, glazing <b>FatCause:</b> Fall through opening (other than roof)

Is this incident preventable with implementation of this DFCS measure? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

**Measure 4:** Design skylights with shatterproof glass or add strengthening wires.

Possible impediments to successful implementation of this measure in the project design phase were identified. Do you find these or other impediments to be applicable?

	<b>Possible Impediments to this DFCS Measure</b>	<b>Are these impediments to the DFCS Measure?</b>
1.	Decreased project quality and diminished design creativity	
2.	Schedule problems and time constraints	
3.	Increased cost	

Revisions of this DFCS Measure were made towards improving its implementation on projects. Do you find these or other revisions achieve this purpose?

	<b>Possible Revisions to this DFCS Measure</b>	<b>Do these revisions improve the DFCS measure for implementation?</b>
1.	Design skylights to withstand 230 Kg (500 lbs) of weight without failure.	
2.		
3.		

The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure.

Accident: 200202380 -- Report ID: 0418200 -- Event Date: 10/25/2004						
Inspection	Open Date	SIC	Establishment Name			
<a href="#">307348847</a>	10/26/2004	<a href="#">1542</a>	Tiernan & Patrylo, Inc.			
Employee #1 was moving a large tarp on the roof of an existing building when he stepped on a skylight. The skylight failed under his weight and he fell 17 feet to the concrete floor. He was killed.						
Keywords:	skylight, fall, work surface, roof, fracture, construction					
End Use	Proj Type		Proj Cost	Stories	NonBldgHt	Fatality
Commercial building	Alteration or rehabilitation		\$50,000 to \$250,000	1	17	X
Inspection	Age	Sex	Degree	Nature	Occupation	Construction
<a href="#">1 307348847</a>			Fatality	Fracture	Occupation not reported	<b>FallDist:</b> 16 <b>FallHt:</b> 16 <b>Cause:</b> Exterior masonry <b>FatCause:</b> Fall through opening (other than roof)

Is this incident preventable with implementation of this DFCS measure? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

### **SECTION 3: QUESTIONS PERTAINING STUDY**

Would you like your participation in the study to be confidential? \_\_\_\_\_

Do you have any general comments or suggestions about the interview or study?

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## **Interview on Design for Construction Safety**

Dear AEC Professional,

Thank you for agreeing to participate in this research study. This interview is part of a doctoral dissertation in “Design for Construction Safety”.

Design-for-Construction Safety (DFCS) is the explicit consideration of construction worker safety in the design of a project. It also involves including worker safety considerations in the constructability review process.

This is a study of design measures for construction safety, to obtain information on their feasibility for implementation. As a professional in the AEC (Architecture/Engineering/Construction) industry, your answers to the questions will be very helpful in the study.

Your responses, together with others, will be collectively analyzed, interpreted and summarized. Responses will remain confidential. The interview is expected to take 45 minutes at the most. This document was prepared to facilitate the interview.

If you have any questions or concerns about the study, here are my full contact details:

Mustapha A. Bello  
Carnegie Mellon University  
405 Margaret Morrison Carnegie Hall  
Pittsburgh, PA 15213  
Email: mbello@andrew.cmu.edu  
Phone: (412)330-8832

You may also contact my advisor, Prof. Omer Akin, School of Architecture, Carnegie Mellon University, 412 MMCH, Pittsburgh, PA 15213 (Email: oa04@andrew.cmu.edu). Once again, your participation is much appreciated.

Sincerely,  
Mustapha A. Bello  
PhD Candidate  
School of Architecture &  
Department and Civil and Environmental Engineering  
Carnegie Mellon University

### *The Issue of Liability for Worker Safety*

A study by Gambatese et al (2005) found most designers believe DFCS will increase their liability exposure. Avoiding liability for construction worker safety underlies the paragraphs in most model contracts that explicitly states the design professional as not being responsible for construction site safety methods or programs. Architects in the United States use the American Institute of Architects (AIA) A201 contract document. The issue of architects' involvement in construction safety is addressed in sections 3.3.1, 4.2.2, 4.2.7, 5.3.1, 10.1, 10.2 and 10.6. The most relevant to DFCS is section 3.3.1 which is presented.

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One could argue that the model contract precludes architects from making design decisions in the interest of construction worker safety. However, one can also infer that so long as the architect does not prescribe means, methods, techniques, sequences or procedures, the designer can be involved in construction worker safety although the designer is not responsible for site safety. It is thus important that DFCS measures do not interfere with the contractor's means and methods.

**SECTION 1: GENERAL INFORMATION**

Profession: \_\_\_\_\_

Job Title / Position: \_\_\_\_\_

Years of Experience: \_\_\_\_\_

## SECTION 2: DESIGN MEASURES

Below are a number of design measures for construction worker safety. For each of the measures, please answer the questions.

**Measure 1:** Around parking areas, ramps, and other elevated traffic surfaces, increase the height of the perimeter wall above the traffic surface to prevent driving off the traffic surface prior to placement of permanent wheelstops, curbs, and guardrails.

---

Do you feel this measure can improve construction worker safety? \_\_\_\_\_

Why? \_\_\_\_\_  
\_\_\_\_\_

---

The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure:

[Accident: 200021988]

At approximately 12:34 a.m. on July 11, 2000, Employee #1 was operating a 1997 Caterpillar rubber-wheeled integrated tool carrier equipped with a multi-purpose bucket, a vehicle similar to a front-end loader. He was working near the bottom of a ramp that led to where excavated soil was being stockpiled. Employee #1 was driving to the right of the ramp to dump a load when his right front wheel went up the ramp and the vehicle overturned on its side. He suffered minor injuries and was taken to the hospital, where he was treated for multiple lacerations and released. Employee #1 was not wearing a seat belt at the time of the accident, and later stated that he had not been trained to wear one. He did state that he had been trained to keep his bucket low when traveling with a full load.

Is this incident preventable with implementation of this DFCS measure? \_\_\_\_\_

---

Would you implement this measure in your design? \_\_\_\_\_

Would any of the following factors prevent you from implementing this measure in your design?

Exposure to liability	
Increased cost	
Schedule problems and time constraints	
Decreased project quality and diminished design creativity	
Designers' lack of safety expertise	
Absence of designer interest and motivation	

**Measure 2:** Avoid locating electrical rooms under pipes carrying liquids that could pose a shock hazard.

---

Do you feel this measure can improve construction worker safety? \_\_\_\_\_

Why? \_\_\_\_\_  
\_\_\_\_\_

---

The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure:

[Accident: 000743799]

An employee was using a miller roughneck 2e constant-current AC welding generator (serial no. Jk727114) to perform an arc welding operation. The employee, who was not wearing gloves, was standing on wet ground that was lined with steel reinforcing rods. The 27-year-old employee was found lying on his back by coworkers. The electrode holder, which contained a new welding rod with an unused factory tip was found under dripping water near his body. The dead employee was last seen welding reinforcement grid joints for a concrete wall for a new swimming pool. The employee had been electrocuted, as evidenced by visible burns on the front of his right shoulder (3 inches in diameter) and on his chest near the top of his left breast bone (1 inch in diameter). He also had a puncture wound on the inside of his left hand, between his thumb and his first finger.

Is this incident preventable with implementation of this DFCS measure? \_\_\_\_\_

---

---

Would you implement this measure in your design? \_\_\_\_\_

Would any of the following factors prevent you from implementing this measure in your design?

Exposure to liability	
Increased cost	
Schedule problems and time constraints	
Decreased project quality and diminished design creativity	
Designers' lack of safety expertise	
Absence of designer interest and motivation	

---

**Measure 3:** Design appropriate and permanent fall protection systems for roofs to be used for construction and maintenance purposes. Consider permanent anchorage points, lifeline attachments, and/or holes in perimeter for guardrail attachment.

---

Do you feel this measure can improve construction worker safety? \_\_\_\_\_

Why? \_\_\_\_\_  
\_\_\_\_\_

---

The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure:

[Accident: 200841591]

On June 21, 2007, Employee #1, an iron worker, was walking backward on a roof while positioning an angle iron in preparation for making connections. He accidentally walked off the flat, leading edge of the roof and fell approximately 20 ft, striking a heavy angle iron. Employee #1 suffered severe head trauma and multiple fractures. He was wearing a full body harness with lanyard, but there were no attachment points to which he could tie off or anchor himself.

Is this incident preventable with implementation of this DFCS measure? \_\_\_\_\_

---

---

Would you implement this measure in your design? \_\_\_\_\_

Would any of the following factors prevent you from implementing this measure in your design?

Exposure to liability	
Increased cost	
Schedule problems and time constraints	
Decreased project quality and diminished design creativity	
Designers' lack of safety expertise	
Absence of designer interest and motivation	

---

**Measure 4:** Locate exterior stairways and ramps on the sheltered side of the structure to protect them from rain, snow, and ice to minimize fall hazards.

---

Do you feel this measure can improve construction worker safety? \_\_\_\_\_

Why? \_\_\_\_\_  
\_\_\_\_\_

---

The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure:

[Accident: 200772382]

Employee #1, a carpenter, was clearing snow on the second floor of an apartment building under construction when he lost his footing, slipped and fell to the ground. He was hospitalized with his injuries.

Is this incident preventable with implementation of this DFCS measure? \_\_\_\_\_

---

---

Would you implement this measure in your design? \_\_\_\_\_

Would any of the following factors prevent you from implementing this measure in your design?

Exposure to liability	
Increased cost	
Schedule problems and time constraints	
Decreased project quality and diminished design creativity	
Designers' lack of safety expertise	
Absence of designer interest and motivation	

---

**Measure 5:** Avoid specifying the use of masonry materials or liquids which contain toxic substances. When materials cannot be avoided, the level of toxicity should be clearly noted.

---

Do you feel this measure can improve construction worker safety? \_\_\_\_\_

Why? \_\_\_\_\_  
\_\_\_\_\_

---

The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure:

[Accident: 201507381]

On March 7, 2007, Employee #1 was in a shallow pit (approximately 2 feet deep) where wet cement was being poured and formed into a foundation to support tanks. While working in the wet cement, which was approximately 6 inches deep, his skin was exposed to the wet cement which resulted in severe burns to his feet. Without the knowledge of the site foreman or coworkers, he was wearing leather boots with laces which were not company approved. When coworkers noticed this, they helped Employee #1 leave the wet cement and wash his feet. He reentered the wet cement wearing company-approved, protective foot wear, which included rubber boots sealed with duct tape near the upper middle area of the lower leg. He worked the remainder of the shift in the wet cement and began to experience pain at approximately 3:00 p.m. but continued to work the rest of the shift. Later that evening, he was admitted to the hospital with second- and third-degree burns on his right foot and second degree burns on his left foot.

Is this incident preventable with implementation of this DFCS measure? \_\_\_\_\_

---

Would you implement this measure in your design? \_\_\_\_\_

Would any of the following factors prevent you from implementing this measure in your design?

Exposure to liability	
Increased cost	
Schedule problems and time constraints	
Decreased project quality and diminished design creativity	
Designers' lack of safety expertise	
Absence of designer interest and motivation	

---

**Measure 6:** Provide permanent catwalks or work platforms for ceiling installation and maintenance on tall, long span structures.

---

Do you feel this measure can improve construction worker safety? \_\_\_\_\_

Why? \_\_\_\_\_  
\_\_\_\_\_

---

The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure:

[Accident: 170736862]

Employee #1 was working from a rolling scaffold platform 6 ft above grade, installing a drop ceiling at Gifford Micro Sciences. He was working alone and had no ground helper. Employee #1 was reaching to install a wire in the drop ceiling when the scaffold moved away from the wall and he fell. He landed on the right side of his body and suffered a fracture of his distal radius. The wheels of the scaffold were not locked at the time of the accident. According to Employee #1, this was done so that the scaffold could be easily moved during the installation process.

Is this incident preventable with implementation of this DFCS measure? \_\_\_\_\_

---

---

Would you implement this measure in your design? \_\_\_\_\_

Would any of the following factors prevent you from implementing this measure in your design?

Exposure to liability	
Increased cost	
Schedule problems and time constraints	
Decreased project quality and diminished design creativity	
Designers' lack of safety expertise	
Absence of designer interest and motivation	

---

### **SECTION 3: QUESTIONS PERTAINING STUDY**

Would you like your participation in the study to be confidential? \_\_\_\_\_

Do you have any general comments or suggestions about the interview or study?

---

---

---

## **Interview on Design for Construction Safety**

Dear AEC Professional,

Thank you for agreeing to participate in this research study. This interview is part of a doctoral dissertation in “Design for Construction Safety”.

Design-for-Construction Safety (DFCS) is the explicit consideration of construction worker safety in the design of a project. It also involves including worker safety considerations in the constructability review process.

This is a study of design measures for construction safety, to obtain information on their feasibility for implementation. As a professional in the AEC (Architecture/Engineering/Construction) industry, your answers to the questions will be very helpful in the study.

Your responses, together with others, will be collectively analyzed, interpreted and summarized. Responses will remain confidential. The interview is expected to take 45 minutes at the most. This document was prepared to facilitate the interview.

If you have any questions or concerns about the study, here are my full contact details:

Mustapha A. Bello  
Carnegie Mellon University  
405 Margaret Morrison Carnegie Hall  
Pittsburgh, PA 15213  
Email: mbello@andrew.cmu.edu  
Phone: (412)330-8832

You may also contact my advisor, Prof. Omer Akin, School of Architecture, Carnegie Mellon University, 412 MMCH, Pittsburgh, PA 15213 (Email: oa04@andrew.cmu.edu). Once again, your participation is much appreciated.

Sincerely,  
Mustapha A. Bello  
PhD Candidate  
School of Architecture &  
Department and Civil and Environmental Engineering  
Carnegie Mellon University

### *The Issue of Liability for Worker Safety*

A study by Gambatese et al (2005) found most designers believe DFCS will increase their liability exposure. Avoiding liability for construction worker safety underlies the paragraphs in most model contracts that explicitly states the design professional as not being responsible for construction site safety methods or programs. Engineers in the United States use the Engineers Joint Construction Documents Committee (EJCDC) E-500 contract document. The issue of engineers' involvement in construction safety is addressed in sections 6.01, A.1.05, A.2.02 and D1.01. The most relevant to DFCS is section 6.01.H which is presented.

6.01.H. Engineer shall not at any time supervise, direct, or have control over Contractor's work, nor shall Engineer have authority over or responsibility for the means, methods, techniques, sequences, or procedures of construction selected or used by Contractor, for security or safety at the Site, for safety precautions and programs incident to the Contractor's work in progress, nor for any failure of Contractor to comply with Laws and Regulations applicable to Contractor's furnishing and performing the Work.

One could argue that the model contract precludes engineers from making design decisions in the interest of construction worker safety. However, one can also infer that so long as the engineer does not prescribe means, methods, techniques, sequences or procedures, the engineer can be involved in construction worker safety although the engineer is not responsible for site safety. It is thus important that DFCS measures do not interfere with the contractor's means and methods.

**SECTION 1: GENERAL INFORMATION**

Profession: \_\_\_\_\_

Job Title / Position: \_\_\_\_\_

Years of Experience: \_\_\_\_\_

## SECTION 2: DESIGN MEASURES

Below are a number of design measures for construction worker safety. For each of the measures, please answer the questions.

**Measure 1:** Consider the use of welded wire mesh for slab reinforcing to allow placement of the steel in large sections rather than the placement of many small pieces of reinforcing bars.

---

Do you feel this measure can improve construction worker safety? \_\_\_\_\_

Why? \_\_\_\_\_  
\_\_\_\_\_

---

The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure:

[Accident: 171058340]

At approximately 2:40 p.m. on November 3, 1999, Employee #1, a 19-year-old iron worker and rod buster for JD Steel, and a coworker were at the construction site in Salt Lake City, UT. They had just loaded approximately 300 lb of rebar onto the tray portion of a bottle cart and secured it with #9 wire. The coworker went to an upper level to receive the load and begin work. Employee #1 was moving the cart by himself to position it for a crane lift when it tipped over, resulting in a compound fracture of his lower right leg. The cart was not properly loaded, nor was the load adequately secured.

Is this incident preventable with implementation of this DFCS measure? \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_

---

Would you implement this measure in your design? \_\_\_\_\_

Would any of the following factors prevent you from implementing this measure in your design?

Exposure to liability	
Increased cost	
Schedule problems and time constraints	
Decreased project quality and diminished design creativity	
Designers' lack of safety expertise	
Absence of designer interest and motivation	

**Measure 2:** Design structural member depths to allow adequate head room clearance around stairs, platforms, valves, and all areas of egress.

---

Do you feel this measure can improve construction worker safety? \_\_\_\_\_

Why? \_\_\_\_\_  
\_\_\_\_\_

---

The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure:

[Accident: 170361919]

Employee #1 was climbing onto a catwalk when he stood up under a large steel beam that was 60 1/2 in. above the catwalk and struck his head with enough force to break the suspension in his hard hat. He did not seek medical treatment at the time, but over a year later he began experiencing numbness in his extremities. He was diagnosed with severe stenosis of his neck vertebra and underwent surgery. The steel beam was neither marked nor padded.

Is this incident preventable with implementation of this DFCS measure? \_\_\_\_\_

---

---

Would you implement this measure in your design? \_\_\_\_\_

Would any of the following factors prevent you from implementing this measure in your design?

Exposure to liability	
Increased cost	
Schedule problems and time constraints	
Decreased project quality and diminished design creativity	
Designers' lack of safety expertise	
Absence of designer interest and motivation	

---

**Measure 3:** Provide an initial earthwork bench at the level of the work area to allow sufficient room for construction equipment and materials.

---

Do you feel this measure can improve construction worker safety? \_\_\_\_\_

Why? \_\_\_\_\_  
\_\_\_\_\_

---

The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure:

[Accident: 565069]

Employee #1 was the superintendent of a building construction site. Earth work had just begun on one end and the dirt was excavated and transferred to the other end as fill. Two other contractors had equipment on site performing dirt work by the hour. Employee #1, a qualified operator of heavy equipment, was operating a compactor in a circular clockwise direction coordinating with a small dozer moving the layer of wet dirt around. Employee #1 consistently stayed to the right of the compactor until the last pass when he made a much larger circle and came over behind the dozer. The compactor was at an angle to the edge of the fill dirt and Employee #1 apparently just drove it over the 40 inch high edge of fill dirt. The compactor overturned, crushing Employee #1 to death.

Is this incident preventable with implementation of this DFCS measure? \_\_\_\_\_

---

---

Would you implement this measure in your design? \_\_\_\_\_

Would any of the following factors prevent you from implementing this measure in your design?

Exposure to liability	
Increased cost	
Schedule problems and time constraints	
Decreased project quality and diminished design creativity	
Designers' lack of safety expertise	
Absence of designer interest and motivation	

---

**Measure 4:** Consider the erection process when designing and locating member connections.

---

Do you feel this measure can improve construction worker safety? \_\_\_\_\_

Why? \_\_\_\_\_

---

The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure:

[Accident: 930727]

At approximately 2:40 p.m. on February 25, 1992, Employees #1 and #2, iron workers, were working on the steel erection of section 2a of the airport office building at the Denver International Airport construction site in Denver, CO. The two workers were connecting a steel beam to a steel column on the seventh level of the building. One worker was seated on the beam that was being connected to the column, while the other worker was standing at the base of the column, at the top of a sheer concrete wall. The base of the column was secured to the concrete wall by temporary welds to an embedded steel plate. When the crew had a problem connecting the beam to the structural steel column, a determination was made by the steel erecting crew to pull the top of the column 1 in. to the north to facilitate the connection. The pull was performed by tensioning a cable guy wire, using a come-along, by applying a fork at the column being connected, and by using a sleeper. While one employee was seated on the beam, the temporary welds at the column base fractured. The column collapsed, and Employees #1 and #2 fell to their death.

Is this incident preventable with implementation of this DFCS measure? \_\_\_\_\_

---

Would you implement this measure in your design? \_\_\_\_\_

Would any of the following factors prevent you from implementing this measure in your design?

Exposure to liability	
Increased cost	
Schedule problems and time constraints	
Decreased project quality and diminished design creativity	
Designers' lack of safety expertise	
Absence of designer interest and motivation	

---

**Measure 5:** For elevated floors, use permanent metal formed decking with concrete fill rather than a concrete slab which requires temporary formwork.

---

Do you feel this measure can improve construction worker safety? \_\_\_\_\_

Why? \_\_\_\_\_  
\_\_\_\_\_

---

The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure:

[Accident: 14367064]

After Employees #1 through #6 finished a third floor pour of concrete, the southwest bay formwork collapsed. Employees finishing the edge of the bay fell 50 ft to the ground. The three in the center landed on the second floor among concrete and other materials. The six employees sustained broken bones, concussions, and bruises. An engineering study determined that various components of the formwork structure were underdesigned and overloaded.

Is this incident preventable with implementation of this DFCS measure? \_\_\_\_\_

---

---

Would you implement this measure in your design? \_\_\_\_\_

Would any of the following factors prevent you from implementing this measure in your design?

Exposure to liability	
Increased cost	
Schedule problems and time constraints	
Decreased project quality and diminished design creativity	
Designers' lack of safety expertise	
Absence of designer interest and motivation	

---

**Measure 6:** In order to allow sufficient walking surface, use a minimum beam width of 6 inches.

---

Do you feel this measure can improve construction worker safety? \_\_\_\_\_

Why? \_\_\_\_\_  
\_\_\_\_\_

---

The OSHA database was investigated and this safety incident was identified as applicable to this DFCS measure:

[Accident: 951434]

Employee #1, who was installing plywood decking on the second floor of a single-family home under construction, was headed to the ladder to go down and get more material. He was walking across a 3 in. wide by 9 ft long steel beam when he slipped and fell 11 ft onto a concrete floor. Employee #1 struck his head and was transported to the hospital, where he died at 2:30 p.m. on October 24, 1997.

Is this incident preventable with implementation of this DFCS measure? \_\_\_\_\_

---

---

Would you implement this measure in your design? \_\_\_\_\_

Would any of the following factors prevent you from implementing this measure in your design?

Exposure to liability	
Increased cost	
Schedule problems and time constraints	
Decreased project quality and diminished design creativity	
Designers' lack of safety expertise	
Absence of designer interest and motivation	

---

**SECTION 3: QUESTIONS PERTAINING STUDY**

Would you like your participation in the study to be confidential? \_\_\_\_\_

Do you have any general comments or suggestions about the interview or study?

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## **Appendix F:    Profession and Information of the Interviewees**

	<b>Interview Guide Version</b>	<b>Profession</b>	<b>Job Title</b>	<b>Years of Experience</b>	<b>Mode of Interview</b>	<b>Location of Interview</b>
1	<b>A1</b>	Architect	Principal	26	Face-to-Face	University Campus
2	<b>A2</b>	Architect	Principal	23	Face-to-Face	Interviewee's Office
3	<b>A3</b>	Architect	Principal / President	36	Face-to-Face	Interviewee's Office
4	<b>A4</b>	Architect	Principal	31	Face-to-Face	Interviewee's Office
5	<b>A5</b>	Architect	Principal	35	Remote-Phone	N/A
6	<b>A6</b>	Architect	Associate	22	Remote-Phone	N/A
7	<b>A7</b>	Architect	Principal	36	Remote-Phone	N/A
8	<b>A8</b>	Architect and Engineer	Vice President of Engineering and Marketing	34	Remote-Phone	N/A
9	<b>C1</b>	Academia / Consulting	Assistant Professor / Professional Engineer	13	Face-to-Face	Interviewee's Office
10	<b>C2</b>	Structural Engineering	Vice President, Director of Structural Engineering	25	Remote-Phone	N/A
11		Structural Engineer	President	23	Remote-Phone	N/A
12	<b>C3</b>	Structural Engineer	Principal	25	Remote-Phone	N/A
13	<b>C4</b>	Structural Engineer	Vice President	25	Remote-Phone	N/A
14	<b>C5</b>	Structural Engineer	Principal	12	Remote-Phone	N/A
15	<b>C6</b>	Structural Engineer	Proprietor	32	Remote-Phone	N/A
16	<b>M1</b>	Mechanical Engineer / Architectural Engineer	Professor	23	Remote-Phone	N/A
17	<b>M2</b>	Mechanical Engineer	Principal	36	Face-to-Face	Interviewee's Office
18	<b>E1</b>	Electrical Engineer	President	42	Face-to-Face	Interviewee's Office
19	<b>E2</b>	Electrical Engineer	Vice President, Electrical Engineering	18	Face-to-Face	Interviewee's Office
20		Electrical Engineer	Vice President, Electrical Engineering	26	Remote-Phone	N/A
21	<b>E3</b>	Electrical Engineer	Senior Electrical Engineer	8	Remote-Phone	N/A
22	<b>P1</b>	Mechanical/Plumbing Engineer	Mechanical Engineer	16	Remote-Phone	N/A
23	<b>P2</b>	Mechanical/Plumbing Engineer	Associate	10	Face-to-Face	Interviewee's Office
24	<b>P3</b>	Mechanical/Plumbing Engineer	Project Engineer	14	Remote-Phone	N/A

## **Appendix G:        Emails Sent to AEC Design Professionals**

### **Appendix G1:        Sample Email Sent to AEC Design Professionals for Survey Participation**

Mr. / Ms. / Mrs. / Prof. / Dr. "Last Name",

Good day sir/madam. My name is Mustapha Bello and I am a PhD Candidate at Carnegie Mellon University's School of Architecture and Department of Civil and Environmental Engineering. The name of my research advisor is Prof. Omer Akin, also of Carnegie Mellon's School of Architecture.

I am writing to request your input in my dissertation. My thesis topic is "Design for Construction Safety (DFCS)". As part of my research method, I will be eliciting information on certain design suggestions for safety to determine their feasibility or usefulness. I have designed surveys to collect this information. This will NOT require construction safety expertise. The questions mostly focus on participants' willingness to implement the measures on their projects.

You were included as a potential study participant after an extensive internet search and based on a certain set of criteria. As a design professional in the Architecture/Engineering/Construction industry, your answers to the questions will be very helpful in the research study. Contacted AEC design professionals include Architects, Civil/Structural/Construction Engineers and Mechanical/Electrical/Plumbing Engineers.

Your responses, together with that of others, will be collectively analyzed, interpreted and summarized. All responses will remain confidential. The survey is expected to take 10-15 minutes at the most. Please let me know if you can participate. Your time is much appreciated.

Thank you.

Mustapha A. Bello  
PhD Candidate  
AECM Program  
School of Architecture &  
Department of Civil and Environmental Engineering  
Carnegie Mellon University  
Pittsburgh, PA 15213, U.S.A

**Appendix G2:**      Sample Email Sent to AEC Design Professionals for Interview Participation

Mr. / Ms. / Mrs. / Prof. / Dr. “Last Name”,

Good day sir/madam. My name is Mustapha Bello and I am a PhD Candidate at Carnegie Mellon University’s School of Architecture and Department of Civil & Environmental Engineering. The name of my research advisor is Prof. Omer Akin, also of Carnegie Mellon’s School of Architecture.

I am writing to request your input in my dissertation. My research investigates the perceptions of AEC (Architecture/Engineering/Construction) design professionals on whether/how certain design measures impact construction safety. You are therefore NOT required to have construction safety expertise. Contacted AEC design professionals include Architects, Civil/Structural/Construction Engineers and Mechanical/Electrical/Plumbing Engineers. You were included as a potential study participant after an extensive internet search and based on a certain set of criteria especially experience. Thus, your input will prove very useful in my research.

I am conducting interviews to collect the information. The interview is expected to take 30-45 minutes. If you can participate, please let me know if you would prefer a face-to-face interview or a telephone interview. I will be happy to come to your preferred location, anywhere in the Pittsburgh metropolitan area. Also, please inform me of your available dates and times if you are willing to participate. Your responses to my questions will remain confidential. Your time is greatly appreciated.

Thank you.

Mustapha A. Bello  
PhD Candidate  
AECM Program  
School of Architecture &  
Department of Civil and Environmental Engineering  
Carnegie Mellon University  
Pittsburgh, PA 15213, U.S.A

**Appendix G3:**      Sample Email Sent to AEC Design Professionals for  
Software Testing Interview Participation

Mr. / Ms. / Mrs. / Prof. / Dr. "Last Name",

Good day sir/madam. This is Mustapha Bello. You might remember me from the interview I conducted with you on Design for Construction Safety.

I am currently working on the final research task of my dissertation. This final task involves the testing of software applications developed to aid and improve the implementation of Design-for-Construction-Safety (DFCS) on projects. As your earlier input proved very useful, I am hoping you would grant me a software testing interview.

The interview is expected to take 30-45 minutes. It is intended to be a face-to-face interview. The tasks are not tedious and do not require any software/programming expertise. I would like to get your perceptions on the functionality and usability of the software. I can and will be present at your preferred location for the interview. Please let me know if you can participate. Your time and effort are greatly appreciated.

Thank you.

Mustapha A. Bello  
PhD Candidate  
AECM Program  
School of Architecture &  
Department of Civil and Environmental Engineering  
Carnegie Mellon University  
Pittsburgh, PA 15213, U.S.A

**Appendix H:        Software Testing Interview Guides**

**Appendix H1:**        Pilot Interview Guide: For DFCS Toolbox  
                              [For Civil/Structural Engineer or MEP Engineer]

## **Interview on Design for Construction Safety**

Dear AEC Professional,

Thank you for agreeing to participate in this research study. This interview is part of a doctoral dissertation in “Design for Construction Safety”.

Design-for-Construction Safety (DFCS) is the explicit consideration of construction worker safety in the design of a project. It also involves including worker safety considerations in the constructability review process.

As part of this study, software applications developed to aid and improve the implementation of DFCS are to be tested. The primary function of these applications is to provide DFCS measures that could be selected for implementation on projects.

The intended users of the software applications are design professionals in the AEC industry. Among such professionals are architects, civil/structural engineers, mechanical engineers, electrical engineers, and plumbing engineers. As one of such professionals, your input will prove very useful in determining the effectiveness of the software and necessary improvements.

Your commentary and responses will remain confidential. No identifying information will be published. The interview is expected to take 30-45 minutes. This document was prepared to facilitate the interview and the software application testing.

If you have any questions or concerns about the study, here are my full contact details:

Mustapha A. Bello  
Carnegie Mellon University  
405 Margaret Morrison Carnegie Hall  
Pittsburgh, PA 15213  
Email: mbello@andrew.cmu.edu  
Phone: (412)330-8832

You may also contact my advisor, Prof. Omer Akin, School of Architecture, Carnegie Mellon University, 412 MMCH, Pittsburgh, PA 15213 (Email: oa04@andrew.cmu.edu). Once again, your participation is much appreciated.

Sincerely,  
Mustapha A. Bello  
PhD Candidate  
School of Architecture &  
Department and Civil and Environmental Engineering  
Carnegie Mellon University

### *The Issue of Liability for Worker Safety*

A study by Gambatese et al (2005) found most designers believe DFCS will increase their liability exposure. Avoiding liability for construction worker safety underlies the paragraphs in most model contracts that explicitly states the design professional as not being responsible for construction site safety methods or programs. Engineers in the United States use the Engineers Joint Construction Documents Committee (EJCDC) E-500 contract document. The issue of engineers' involvement in construction safety is addressed in sections 6.01, A.1.05, A.2.02 and D1.01. The most relevant to DFCS is section 6.01.H which is presented.

6.01.H. Engineer shall not at any time supervise, direct, or have control over Contractor's work, nor shall Engineer have authority over or responsibility for the means, methods, techniques, sequences, or procedures of construction selected or used by Contractor, for security or safety at the Site, for safety precautions and programs incident to the Contractor's work in progress, nor for any failure of Contractor to comply with Laws and Regulations applicable to Contractor's furnishing and performing the Work.

One could argue that the model contract precludes engineers from making design decisions in the interest of construction worker safety. However, one can also infer that so long as the engineer does not prescribe means, methods, techniques, sequences or procedures, the engineer can be involved in construction worker safety although the engineer is not responsible for site safety. It is thus important that DFCS measures do not interfere with the contractor's means and methods.

**SECTION 1:**        GENERAL INFORMATION

Profession: \_\_\_\_\_

Job Title / Position: \_\_\_\_\_

Years of Experience:        \_\_\_\_\_

## SECTION 2: PRE-TESTING QUESTIONS

1. Have you ever made modifications to a project in the design phase to eliminate a potential safety risk that would impact construction worker health and safety?

Yes ☐

No ☐

2. Have you ever had any discussions with owners and/or contractors that include the features to be included in the design, to ensure construction worker health and safety during project construction?

Yes ☐

No ☐

3. Have you ever been asked to address construction worker health and safety in the design phase?

Yes ☐

No ☐

4. Have you ever worked with or hired a construction health and safety consultant in the design phase?

Yes ☐

No ☐

5. How willing are you to design for construction worker safety?

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
0	1	2	3	4	5	6	7	8	9	10
←Extremely Unwilling						Extremely Willing→				

6. Have you ever used any tool to enhance or aid construction safety considerations on a project?

Yes ☐

No ☐

7. Do you use any AEC design software?

Yes ☐

No ☐

Which design software do you use?

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8. Please rate the listed project issues/criteria relative to one another.

	Project Issues	← More Important											More Important →										Project Issues
		≥9.5	9	8	7	6	5	4	3	2	1		2	3	4	5	6	7	8	9	≥9.5		
1.	Aesthetics																					Construction Worker Safety	
2.	Aesthetics																					Final Occupant Safety	
3.	Aesthetics																					Project Cost	
4.	Aesthetics																					Project Schedule	
5.	Aesthetics																					Quality of Work	
6.	Construction Worker Safety																					Final Occupant Safety	
7.	Construction Worker Safety																					Project Cost	
8.	Construction Worker Safety																					Project Schedule	
9.	Construction Worker Safety																					Quality of Work	
10.	Final Occupant Safety																					Project Cost	
11.	Final Occupant Safety																					Project Schedule	
12.	Final Occupant Safety																					Quality of Work	
13.	Project Cost																					Project Schedule	
14.	Project Cost																					Quality of Work	
15.	Project Schedule																					Quality of Work	

### **SECTION 3:           HYPOTHETICAL DFCS IMPLEMENTATION PROJECT**

The plans of a building project are provided. You are an AEC design professional involved in this project. Your firm was the design-build company that was awarded the contract for the design and construction of the project. Both the AEC design professionals and construction workers are employees of the company. Thus, your company is both responsible and liable for the safety of the construction workers.

The project owner asked that Design-for-Construction-Safety (DFCS) be implemented on the project. The owner indicated willingness to accommodate the cost and schedule implications.

You were asked to supervise DFCS implementation on the project from the standpoint of your design discipline. You are to make safety constructability considerations in the design. This includes designing features and making design modifications that can enhance the safety of workers during the construction of the project.

***Please familiarize yourself with the plans of the building project.***

**SECTION 4:       MANUAL IMPLEMENTATION OF DFCS ON THE PROJECT**

***Please manually identify design modifications to the project that can be made to enhance the safety of construction workers.***

***Please perform this task until personally satisfied.***

**SECTION 5:** DFCS IMPLEMENTATION USING THE DESIGN FOR CONSTRUCTION SAFETY TOOLBOX

***Please use the “Design for Construction Safety Toolbox” to identify design modifications or design features that can be utilized to enhance construction worker safety on the building project.***

***Please perform this task until personally satisfied.***

**SECTION 6:**                      QUESTIONS ON THE DFCS IMPLEMENTATION  
PROCESS OF THE PROJECT

1. How difficult/easy was the identification of design modifications for construction worker safety using the manual method as utilized in this session?

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
0	1	2	3	4	5	6	7	8	9	10
←Extremely Difficult					Extremely Easy→					

Why? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

2. Did the Design for Construction Safety Toolbox inhibit/improve the DFCS implementation process compared to the manual method as practiced in this experiment?

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
0	1	2	3	4	5	6	7	8	9	10
←Extremely Inhibited					Extremely Improved→					

Why? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

3. How difficult/easy was the identification of design modifications for construction worker safety using the Design for Construction Safety Toolbox as utilized in this session?

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
0	1	2	3	4	5	6	7	8	9	10
←Extremely Difficult					Extremely Easy→					

Why? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

4. What do you like about the Design for Construction Safety Toolbox software?

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5. Compared to the AEC design software you have used, how do you find using the Design for Construction Safety Toolbox?

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
0	1	2	3	4	5	6	7	8	9	10
←Extremely Difficult					Extremely Easy→					

Why? 

---

---



---

6. To what extent did the details provided with the 'design suggestions or modifications' help in your selection of which to implement on the project (using the Design for Construction Safety Toolbox software)?

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
0	1	2	3	4	5	6	7	8	9	10
←Not Helpful					Extremely Helpful→					

How? 

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---



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7. Would any additional details on the 'design suggestions' provided by the Design for Construction Safety Toolbox be helpful in the selection of DFCS modifications for the project?

Yes ☐

No ☐

Other ☐

\_\_\_\_\_

What details?

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8. Should the Design for Construction Safety Toolbox be integrated into other AEC design software such as Building Information Modeling (BIM) tools to enhance its effectiveness and use?

Yes ☐

No ☐

Other ☐

\_\_\_\_\_

9. What recommendations do you have for improving the Design for Construction Safety Toolbox software?

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**SECTION 7:**        OTHER QUESTIONS

Would you like your participation in this study to be confidential? \_\_\_\_\_

Do you have any general comments on DFCS?

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Do you have any general comments on the interview or study?

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## **Interview on Design for Construction Safety**

Dear AEC Professional,

Thank you for agreeing to participate in this research study. This interview is part of a doctoral dissertation in "Design for Construction Safety".

Design-for-Construction Safety (DFCS) is the explicit consideration of construction worker safety in the design of a project. It also involves including worker safety considerations in the constructability review process.

As part of this study, software applications developed to aid and improve the implementation of DFCS are to be tested. The primary function of these applications is to provide DFCS measures that could be selected for implementation on projects.

The intended users of the software applications are design professionals in the AEC industry. Among such professionals are architects, civil/structural engineers, mechanical engineers, electrical engineers, and plumbing engineers. As one of such professionals, your input will prove very useful in determining the effectiveness of the software and necessary improvements.

Your commentary and responses will remain confidential. No identifying information will be published. The interview is expected to take 30-45 minutes. This document was prepared to facilitate the interview and the software application testing.

If you have any questions or concerns about the study, here are my full contact details:

Mustapha A. Bello  
Carnegie Mellon University  
405 Margaret Morrison Carnegie Hall  
Pittsburgh, PA 15213  
Email: mbello@andrew.cmu.edu  
Phone: (412)330-8832

You may also contact my advisor, Prof. Omer Akin, School of Architecture, Carnegie Mellon University, 412 MMCH, Pittsburgh, PA 15213 (Email: oa04@andrew.cmu.edu). Once again, your participation is much appreciated.

Sincerely,  
Mustapha A. Bello  
PhD Candidate  
School of Architecture &  
Department and Civil and Environmental Engineering  
Carnegie Mellon University

### *The Issue of Liability for Worker Safety*

A study by Gambatese et al (2005) found most designers believe DFCS will increase their liability exposure. Avoiding liability for construction worker safety underlies the paragraphs in most model contracts that explicitly states the design professional as not being responsible for construction site safety methods or programs. Architects in the United States use the American Institute of Architects (AIA) A201 contract document. The issue of architects' involvement in construction safety is addressed in sections 3.3.1, 4.2.2, 4.2.7, 5.3.1, 10.1, 10.2 and 10.6. The most relevant to DFCS is section 3.3.1 which is presented.

3.3.1 The Contractor shall supervise and direct the Work, using the Contractor's best skill and attention. The Contractor shall be solely responsible for and have control over construction means, methods, techniques, sequences and procedures and for coordinating all portions of the Work under the Contract, unless the Contract Documents give other specific instructions concerning these matters. If the Contract Documents give specific instructions concerning construction means, methods, techniques, sequences or procedures, the Contractor shall evaluate the jobsite safety thereof and, except as stated below, shall be fully and solely responsible for the jobsite safety of such means, methods, techniques, sequences or procedures. If the Contractor determines that such means, methods, techniques, sequences or procedures may not be safe, the Contractor shall give timely written notice to the Owner and Architect and shall not proceed with that portion of the Work without further written instructions from the Architect. If the Contractor is then instructed to proceed with the required means, methods, techniques, sequences or procedures without acceptance of changes proposed by the Contractor, the Owner shall be solely responsible for any resulting loss or damage.

One could argue that the model contract precludes architects from making design decisions in the interest of construction worker safety. However, one can also infer that so long as the architect does not prescribe means, methods, techniques, sequences or procedures, the designer can be involved in construction worker safety although the designer is not responsible for site safety. It is thus important that DFCS measures do not interfere with the contractor's means and methods.

**SECTION 1:**        GENERAL INFORMATION

Profession: \_\_\_\_\_

Job Title / Position: \_\_\_\_\_

Years of Experience:        \_\_\_\_\_

## SECTION 2: PRE-TESTING QUESTIONS

1. Have you ever made modifications to a project in the design phase to eliminate a potential safety risk that would impact construction worker health and safety?

Yes ☐

No ☐

2. Have you ever had any discussions with owners and/or contractors that include the features to be included in the design, to ensure construction worker health and safety during project construction?

Yes ☐

No ☐

3. Have you ever been asked to address construction worker health and safety in the design phase?

Yes ☐

No ☐

4. Have you ever worked with or hired a construction health and safety consultant in the design phase?

Yes ☐

No ☐

5. How willing are you to design for construction worker safety?

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
0	1	2	3	4	5	6	7	8	9	10
←Extremely Unwilling						Extremely Willing→				

6. Have you ever used any tool to enhance or aid construction safety considerations on a project?

Yes ☐

No ☐

7. Do you use any AEC design software?

Yes ☐

No ☐

Which design software do you use?

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8. Please rank the listed project issues/criteria by importance.

- Aesthetics
- Construction Worker Safety
- Final Occupant Safety
- Project Cost
- Project Schedule
- Quality of Work

### **SECTION 3:           HYPOTHETICAL DFCS IMPLEMENTATION PROJECT**

The plans of a building project are provided. You are an AEC design professional involved in this project. Your firm was the design-build company that was awarded the contract for the design and construction of the project. Both the AEC design professionals and construction workers are employees of the company. Thus, your company is both responsible and liable for the safety of the construction workers.

The project owner asked that Design-for-Construction-Safety (DFCS) be implemented on the project. The owner indicated willingness to accommodate the cost and schedule implications.

You were asked to supervise DFCS implementation on the project from the standpoint of your design discipline. You are to make safety constructability considerations in the design. This includes designing features and making design modifications that can enhance the safety of workers during the construction of the project.

***Please familiarize yourself with the plans of the building project.***

**SECTION 4:       MANUAL IMPLEMENTATION OF DFCS ON THE PROJECT**

***Please manually identify design modifications to the project that can be made to enhance the safety of construction workers.***

***Please perform this task until personally satisfied.***

**SECTION 5:** DFCS IMPLEMENTATION USING THE DESIGN FOR CONSTRUCTION SAFETY TOOLBOX

***Please use the “Design for Construction Safety Toolbox” to identify design modifications or design features that can be utilized to enhance construction worker safety on the building project.***

***Please perform this task until personally satisfied.***

**SECTION 6:**                      QUESTIONS ON THE DFCS IMPLEMENTATION  
PROCESS OF THE PROJECT

1. How difficult/easy was the identification of design modifications for construction worker safety using the manual method as utilized in this session?

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
0	1	2	3	4	5	6	7	8	9	10
←Extremely Difficult					Extremely Easy→					

Why? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

2. Did the Design for Construction Safety Toolbox inhibit/improve the DFCS implementation process compared to the manual method as practiced in this experiment?

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
0	1	2	3	4	5	6	7	8	9	10
←Extremely Inhibited					Extremely Improved→					

Why? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

3. How difficult/easy was the identification of design modifications for construction worker safety using the Design for Construction Safety Toolbox as utilized in this session?

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
0	1	2	3	4	5	6	7	8	9	10
←Extremely Difficult					Extremely Easy→					

Why? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

4. What do you like about the Design for Construction Safety Toolbox software?

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5. Compared to the AEC design software you have used, how do you find using the Design for Construction Safety Toolbox?

<input type="radio"/> 0	<input type="radio"/> 1	<input type="radio"/> 2	<input type="radio"/> 3	<input type="radio"/> 4	<input checked="" type="radio"/> 5	<input type="radio"/> 6	<input type="radio"/> 7	<input type="radio"/> 8	<input type="radio"/> 9	<input type="radio"/> 10	<input type="radio"/> N/A
←Extremely Difficult											Extremely Easy→

Why? 

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---



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6. To what extent did the details provided with the 'design suggestions or modifications' help in your selection of which to implement on the project (using the Design for Construction Safety Toolbox software)?

<input type="radio"/> 0	<input type="radio"/> 1	<input type="radio"/> 2	<input type="radio"/> 3	<input type="radio"/> 4	<input type="radio"/> 5	<input type="radio"/> 6	<input type="radio"/> 7	<input type="radio"/> 8	<input type="radio"/> 9	<input type="radio"/> 10	
←Not Helpful											Extremely Helpful→

How? 

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---



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7. Would any additional details on the 'design suggestions' provided by the Design for Construction Safety Toolbox be helpful in the selection of DFCS modifications for the project?

Yes ☐

No ☐

Other ☐

\_\_\_\_\_

What details?

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8. Should the Design for Construction Safety Toolbox be integrated into other AEC design software such as Building Information Modeling (BIM) tools to enhance its effectiveness and use?

Yes ☐

No ☐

Other ☐

\_\_\_\_\_

9. What recommendations do you have for improving the Design for Construction Safety Toolbox software?

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**SECTION 7:**        OTHER QUESTIONS

Would you like your participation in this study to be confidential? \_\_\_\_\_

Do you have any general comments on DFCS?

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Do you have any general comments on the interview or study?

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**Appendix H3:**      Research Interview Guide: For DFCS-TIPS Application  
[For Civil/Structural Engineers and MEP Engineers]

## **Interview on Design for Construction Safety**

Dear AEC Professional,

Thank you for agreeing to participate in this research study. This interview is part of a doctoral dissertation in "Design for Construction Safety".

Design-for-Construction Safety (DFCS) is the explicit consideration of construction worker safety in the design of a project. It also involves including worker safety considerations in the constructability review process.

As part of this study, software applications developed to aid and improve the implementation of DFCS are to be tested. The primary function of these applications is to provide DFCS measures that could be selected for implementation on projects.

The intended users of the software applications are design professionals in the AEC industry. Among such professionals are architects, civil/structural engineers, mechanical engineers, electrical engineers, and plumbing engineers. As one of such professionals, your input will prove very useful in determining the effectiveness of the software and necessary improvements.

Your commentary and responses will remain confidential. No identifying information will be published. The interview is expected to take 30-45 minutes. This document was prepared to facilitate the interview and the software application testing.

If you have any questions or concerns about the study, here are my full contact details:

Mustapha A. Bello  
Carnegie Mellon University  
405 Margaret Morrison Carnegie Hall  
Pittsburgh, PA 15213  
Email: mbello@andrew.cmu.edu  
Phone: (412)330-8832

You may also contact my advisor, Prof. Omer Akin, School of Architecture, Carnegie Mellon University, 412 MMCH, Pittsburgh, PA 15213 (Email: oa04@andrew.cmu.edu). Once again, your participation is much appreciated.

Sincerely,  
Mustapha A. Bello  
PhD Candidate  
School of Architecture &  
Department and Civil and Environmental Engineering  
Carnegie Mellon University

### *The Issue of Liability for Worker Safety*

A study by Gambatese et al (2005) found most designers believe DFCS will increase their liability exposure. Avoiding liability for construction worker safety underlies the paragraphs in most model contracts that explicitly states the design professional as not being responsible for construction site safety methods or programs. Engineers in the United States use the Engineers Joint Construction Documents Committee (EJCDC) E-500 contract document. The issue of engineers' involvement in construction safety is addressed in sections 6.01, A.1.05, A.2.02 and D1.01. The most relevant to DFCS is section 6.01.H which is presented.

6.01.H. Engineer shall not at any time supervise, direct, or have control over Contractor's work, nor shall Engineer have authority over or responsibility for the means, methods, techniques, sequences, or procedures of construction selected or used by Contractor, for security or safety at the Site, for safety precautions and programs incident to the Contractor's work in progress, nor for any failure of Contractor to comply with Laws and Regulations applicable to Contractor's furnishing and performing the Work.

One could argue that the model contract precludes engineers from making design decisions in the interest of construction worker safety. However, one can also infer that so long as the engineer does not prescribe means, methods, techniques, sequences or procedures, the engineer can be involved in construction worker safety although the engineer is not responsible for site safety. It is thus important that DFCS measures do not interfere with the contractor's means and methods.

**SECTION 1:**        GENERAL INFORMATION

Profession: \_\_\_\_\_

Job Title / Position: \_\_\_\_\_

Years of Experience:        \_\_\_\_\_

## SECTION 2: PRE-TESTING QUESTIONS

1. Have you ever made modifications to a project in the design phase to eliminate a potential safety risk that would impact construction worker health and safety?

Yes ☐

No ☐

2. Have you ever had any discussions with owners and/or contractors that include the features to be included in the design, to ensure construction worker health and safety during project construction?

Yes ☐

No ☐

3. Have you ever been asked to address construction worker health and safety in the design phase?

Yes ☐

No ☐

4. Have you ever worked with or hired a construction health and safety consultant in the design phase?

Yes ☐

No ☐

5. How willing are you to design for construction worker safety?

<input type="radio"/> 0	<input type="radio"/> 1	<input type="radio"/> 2	<input type="radio"/> 3	<input type="radio"/> 4	<input type="radio"/> 5	<input type="radio"/> 6	<input type="radio"/> 7	<input type="radio"/> 8	<input type="radio"/> 9	<input type="radio"/> 10
←Extremely Unwilling						Extremely Willing→				

6. Have you ever used any tool to enhance or aid construction safety considerations on a project?

Yes ☐

No ☐

7. Do you use any AEC design software?

Yes ☐

No ☐

Which design software do you use?

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8. Please rank the listed project issues/criteria by importance.

- Aesthetics
- Construction Worker Safety
- Final Occupant Safety
- Project Cost
- Project Schedule
- Quality of Work

### **SECTION 3:           HYPOTHETICAL DFCS IMPLEMENTATION PROJECT**

The plans of a building project are provided. You are an AEC design professional involved in this project. Your firm was the design-build company that was awarded the contract for the design and construction of the project. Both the AEC design professionals and construction workers are employees of the company. Thus, your company is both responsible and liable for the safety of the construction workers.

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You were asked to supervise DFCS implementation on the project from the standpoint of your design discipline. You are to make safety constructability considerations in the design. This includes designing features and making design modifications that can enhance the safety of workers during the construction of the project.

***Please familiarize yourself with the plans of the building project.***

**SECTION 4:       MANUAL IMPLEMENTATION OF DFCS ON THE PROJECT**

***Please manually identify design modifications to the project that can be made to enhance the safety of construction workers.***

***Please perform this task until personally satisfied.***

**SECTION 5:        DFCS IMPLEMENTATION USING THE DFCS-TIPS APPLICATION**

***Please use the “DFCS-TIPS” software to identify design modifications or design features that can be utilized to enhance construction worker safety on the building project.***

***Please perform this task until personally satisfied.***

**SECTION 6: QUESTIONS ON THE DFCS IMPLEMENTATION PROCESS OF THE PROJECT**

1. How difficult/easy was the identification of design modifications for construction worker safety using the manual method as utilized in this session?

<input type="radio"/> 0	<input type="radio"/> 1	<input type="radio"/> 2	<input type="radio"/> 3	<input type="radio"/> 4	<input checked="" type="radio"/> 5	<input type="radio"/> 6	<input type="radio"/> 7	<input type="radio"/> 8	<input type="radio"/> 9	<input type="radio"/> 10
←Extremely Difficult					Extremely Easy→					

Why? \_\_\_\_\_  
\_\_\_\_\_

2. Did the DFCS-TIPS software inhibit/improve the DFCS implementation process compared to the manual method as practiced in this experiment?

<input type="radio"/> 0	<input type="radio"/> 1	<input type="radio"/> 2	<input type="radio"/> 3	<input type="radio"/> 4	<input checked="" type="radio"/> 5	<input type="radio"/> 6	<input type="radio"/> 7	<input type="radio"/> 8	<input type="radio"/> 9	<input type="radio"/> 10
←Extremely Inhibited					Extremely Improved→					

Why? \_\_\_\_\_  
\_\_\_\_\_

3. How difficult/easy was the identification of design modifications for construction worker safety using the DFCS-TIPS software as utilized in this session?

<input type="radio"/> 0	<input type="radio"/> 1	<input type="radio"/> 2	<input type="radio"/> 3	<input type="radio"/> 4	<input checked="" type="radio"/> 5	<input type="radio"/> 6	<input type="radio"/> 7	<input type="radio"/> 8	<input type="radio"/> 9	<input type="radio"/> 10
←Extremely Difficult					Extremely Easy→					

Why? \_\_\_\_\_  
\_\_\_\_\_

4. What do you like about the DFCS-TIPS software?

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

5. To what extent did the following details help in your selection of 'DFCS suggestions or modifications' for the project (using the DFCS-TIPS software)?

- a. Safety incidents considered preventable through implementation of the DFCS suggestions or modifications

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
0	1	2	3	4	5	6	7	8	9	10
←Not Helpful						Extremely Helpful→				

- b. Potential impediments to implementing the DFCS suggestions or modifications

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
0	1	2	3	4	5	6	7	8	9	10
←Not Helpful						Extremely Helpful→				

- c. Potential solutions to the impediments of implementing the DFCS suggestions or modifications

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
0	1	2	3	4	5	6	7	8	9	10
←Not Helpful						Extremely Helpful→				

- d. Tier of Feasibility

(Amount of research on the DFCS suggestions or modifications and the level of confidence in the effectiveness of the suggestions)

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
0	1	2	3	4	5	6	7	8	9	10
←Not Helpful						Extremely Helpful→				

6. To what extent did the details (see above) provided with the DFCS suggestions or modifications help in your selection of which to implement on the project (using the DFCS-TIPS software)?

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
0	1	2	3	4	5	6	7	8	9	10
←Not Helpful						Extremely Helpful→				

How? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

7. Would any additional details on the 'design suggestions' provided by the DFCS-TIPS software be helpful in the selection of DFCS modifications for the project?

Yes ☐

No ☐

Other ☐

\_\_\_\_\_

What details?

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

8. Compared to other AEC design software you have used, how do you find using the DFCS-TIPS software?

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
0	1	2	3	4	5	6	7	8	9	10		
←Extremely Difficult											Extremely Easy→	N/A

Why? \_\_\_\_\_

\_\_\_\_\_  
 \_\_\_\_\_

9. Should DFCS-TIPS be integrated into other AEC design software such as Building Information Modeling (BIM) tools to enhance its effectiveness and use?

Yes ☐

No ☐

Other ☐

\_\_\_\_\_

10. What recommendations do you have for improving the DFCS-TIPS software?

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

**SECTION 7:**        OTHER QUESTIONS

Would you like your participation in this study to be confidential? \_\_\_\_\_

Do you have any general comments on DFCS?

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Do you have any general comments on the interview or study?

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---

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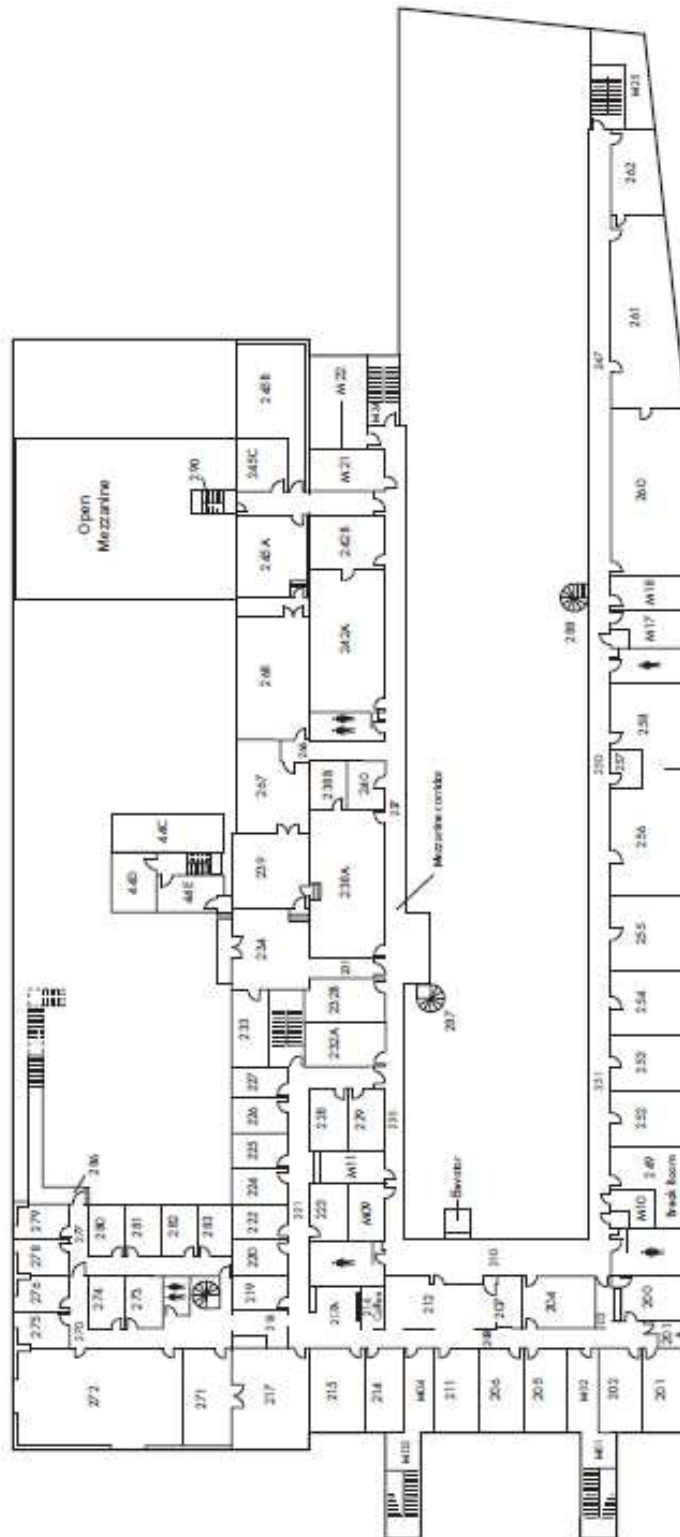
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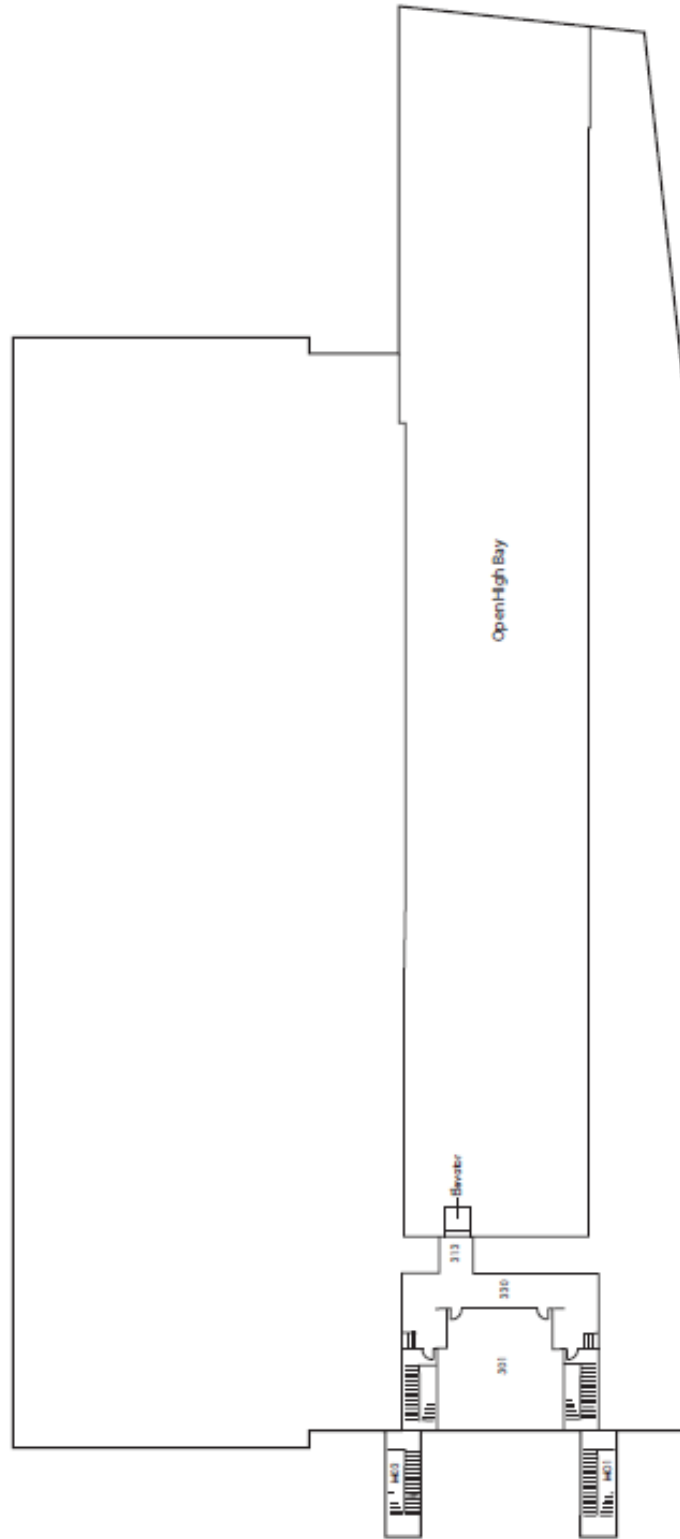
## Appendix H4: Hypothetical Project Building Plans



Mezzanine Floor Plan



Upper Mezzanine Floor Plan



## **Appendix I:      DFCS-TIPS Application Coding Sample**

[Visual Basic for Application (VBA) in Microsoft Access]

### DFCS-TIPS – Form frmInterface (Code)

Option Compare Database

Option Explicit

```
Private Sub cmdAddMeasure_Click()  
    DoCmd.OpenForm "frmMeasures", acNormal, , , acFormAdd  
End Sub
```

```
Private Sub cmdAddSolutions_Click()  
    OpenMeasuresInput "Solution"  
End Sub
```

```
Private Sub cmdDeleteProject_Click()  
On Error GoTo Err_Handler
```

```
    Dim strMsg As String
```

```
    If Nz(Me.lstProjects.Value, 0) = 0 Then  
        MsgBox "Please select a project to delete."  
        Exit Sub  
    End If
```

```
    strMsg = "Are you sure you want to delete this project?"  
    strMsg = MsgBox(strMsg, vbYesNo, "DFCS-TIPS")
```

```
    If strMsg = vbYes Then  
        With DoCmd  
            .SetWarnings False  
            .Hourglass True  
            .OpenQuery "qryDeleteProjectMeasuresfromInterface", acViewNormal  
            .OpenQuery "qryDeleteProjectfromInterface", acViewNormal  
            .Hourglass False  
            .SetWarnings True  
        End With
```

```
        Me.lstProjects.Requery  
    End If
```

Exit\_Handler:

```
    Exit Sub
```

Err\_Handler:

```
    DoCmd.SetWarnings True  
    DoCmd.Hourglass False  
    MsgBox Err.Number & ": " & Err.Description  
    GoTo Exit_Handler
```

```
End Sub
```

```
Private Sub cmdEditMeasure_Click()  
On Error GoTo Err_Handler
```

```
    If DCount("MeasuresID", "tlkpMeasures", "Original = 0") <= 0 Then  
        MsgBox "There are no measures to edit."  
        GoTo Exit_Handler  
    End If
```

```

DoCmd.OpenForm "frmMeasures", acNormal

With Form_frmMeasures
    .cmdNext.Visible = True
    .cmdPrev.Visible = True
    .cmdDelete.Visible = True
    .cmdNext.SetFocus
End With

Exit_Handler:
Exit Sub
Err_Handler:
DoCmd.SetWarnings True
DoCmd.Hourglass False
MsgBox Err.Number & ": " & Err.Description
GoTo Exit_Handler
End Sub

Private Sub cmdAddProject_Click()
DoCmd.OpenForm "frmProject", acNormal, , , acFormAdd
End Sub

Private Sub cmdEditProject_Click()
If Nz(Me.IstProjects.Value, 0) = 0 Then
MsgBox "Please select a project to edit"
Exit Sub
End If

DoCmd.OpenForm "frmProject", acNormal, , "ProjectID = " & Me.IstProjects.Value
End Sub

Private Sub cmdExit_Click()
DoCmd.Quit
End Sub

Private Sub cmdUsingDFCS_Click()
DoCmd.OpenForm "frmUsingDFCS", acNormal
End Sub

Private Sub cmdWhyDFCS_Click()
DoCmd.OpenForm "frmWhyDFCS", acNormal
End Sub

```

#### DFCS-TIPS – Form\_frmProject (Code)

```

Option Compare Database
Option Explicit

Private Sub cmdClose_Click()
DoCmd.RunCommand acCmdSaveRecord
Forms!frmInterface!IstProjects.Requery
DoCmd.Close acForm, Me.Name
End Sub

Private Sub cmdPrint_Click()
DoCmd.OpenReport "rptProjectMeasures", acViewPreview
End Sub

```

```

Private Sub cmdSelect_Click()
    Me.Recalc
    OpenMeasuresInput "Measure"
End Sub

Private Sub cmdView_Click()
    DoCmd.OpenForm "frmProjectMeasuresView", acNormal
End Sub

```

#### DFCS-TIPS – Form frmProjectMeasuresInput (Code)

Option Compare Database

Option Explicit

```

Private Sub cmdClose_Click()
    DoCmd.Close acForm, Me.Name
End Sub

```

```

Private Sub cmdIndex_Click()
    DoCmd.OpenForm "frmProjectMeasuresIndex", acNormal
'    DoCmd.Close acForm, Me.Name
End Sub

```

```

Private Sub cmdProvide_Click()
On Error GoTo Err_Handler

```

```

    Me.fsubAECDesignProf.Requery
    Me.fsubProjectFeatures.Requery
    Me.fsubStageOfDesignPhase.Requery

```

```

With DoCmd
    .SetWarnings False
    .Hourglass True
    .OpenQuery "qryDeleteMeasures", acViewNormal
    .OpenQuery "qryAppendMeasuresOutput", acViewNormal
    .Hourglass False
    .SetWarnings True
End With

```

```

    DoCmd.OpenForm "frmProjectMeasuresOutputSelect", acNormal
'    DoCmd.Close acForm, Me.Name

```

Exit\_Handler:

```
Exit Sub
```

Err\_Handler:

```

    DoCmd.SetWarnings True
    DoCmd.Hourglass False
    MsgBox Err.Number & ": " & Err.Description
    GoTo Exit_Handler

```

End Sub

```

Private Sub cmdSearch_Click()
    DoCmd.OpenForm "frmProjectMeasuresSearch", acNormal
'    DoCmd.Close acForm, Me.Name
End Sub

```

#### DFCS-TIPS – Form\_frmProjectMeasuresOutputSelect (Code)

Option Compare Database

Option Explicit

Private Sub cmdClose\_Click()

DoCmd.Close acForm, Me.Name

End Sub

Private Sub cmdComplete\_Click()

On Error GoTo Err\_Handler

Me.fsubProjectMeasuresSelect.Requery

' If adding a new solution to an existing measure, open different form

If gblnAddSolution = True Then

DoCmd.OpenForm "frmMeasuresAddSolution", acNormal

DoCmd.Close acForm, Me.Name

' If add new measures to a project, add data to project measures table

Else

With DoCmd

.SetWarnings False

.Hourglass True

.OpenQuery "qryAppendSelectedMeasuresOutputtoProject", acViewNormal

.Hourglass False

.SetWarnings True

End With

If CurrentProject.AllForms("frmProjectMeasuresInput").IsLoaded Then

DoCmd.Close acForm, "frmProjectMeasuresInput"

End If

DoCmd.Close acForm, Me.Name

End If

Exit\_Handler:

Exit Sub

Err\_Handler:

DoCmd.SetWarnings True

DoCmd.Hourglass False

MsgBox Err.Number & ": " & Err.Description

GoTo Exit\_Handler

End Sub

Private Sub cmdDeselectAll\_Click()

On Error GoTo Err\_Handler

With DoCmd

.SetWarnings False

.Hourglass True

.OpenQuery "qryMeasuresDeselectAll", acViewNormal

.Hourglass False

.SetWarnings True

End With

Me.fsubProjectMeasuresSelect.Requery

Exit\_Handler:

```

Exit Sub
Err_Handler:
DoCmd.SetWarnings True
DoCmd.Hourglass False
MsgBox Err.Number & ": " & Err.Description
GoTo Exit_Handler
End Sub

Private Sub cmdSelectAll_Click()
On Error GoTo Err_Handler

With DoCmd
.SetWarnings False
.Hourglass True
.OpenQuery "qryMeasuresSelectAll", acViewNormal
.Hourglass False
.SetWarnings True
End With

Me.fsubProjectMeasuresSelect.Requery

Exit_Handler:
Exit Sub
Err_Handler:
DoCmd.SetWarnings True
DoCmd.Hourglass False
MsgBox Err.Number & ": " & Err.Description
GoTo Exit_Handler
End Sub

Private Sub Form_Open(Cancel As Integer)
cmdDeselectAll_Click
End Sub

```

#### DFCS-TIPS – Form frmProjectMeasuresView (Code)

```

Option Compare Database
Option Explicit

Private Sub cmdDelete_Click()
On Error GoTo Err_Handler

With DoCmd
.SetWarnings False
.Hourglass True
.OpenQuery "qryDeleteProjectMeasures", acViewNormal
.Hourglass False
.SetWarnings True
End With

Me.fsubProjectMeasuresView.Requery

' DoCmd.Close acForm, Me.Name

Exit_Handler:
Exit Sub
Err_Handler:
DoCmd.SetWarnings True

```

```

        DoCmd.Hourglass False
        MsgBox Err.Number & ": " & Err.Description
        GoTo Exit_Handler
    End Sub

Private Sub cmdClose_Click()
    DoCmd.Close acForm, Me.Name
End Sub

Private Sub cmdDeselectAll_Click()
    On Error GoTo Err_Handler

    With DoCmd
        .SetWarnings False
        .Hourglass True
        .OpenQuery "qryProjectMeasuresDeselectAll", acViewNormal
        .Hourglass False
        .SetWarnings True
    End With

    Me.fsubProjectMeasuresView.Requery

Exit_Handler:
    Exit Sub
Err_Handler:
    DoCmd.SetWarnings True
    DoCmd.Hourglass False
    MsgBox Err.Number & ": " & Err.Description
    GoTo Exit_Handler
End Sub

Private Sub cmdSelectAll_Click()
    On Error GoTo Err_Handler

    With DoCmd
        .SetWarnings False
        .Hourglass True
        .OpenQuery "qryProjectMeasuresSelectAll", acViewNormal
        .Hourglass False
        .SetWarnings True
    End With

    Me.fsubProjectMeasuresView.Requery

Exit_Handler:
    Exit Sub
Err_Handler:
    DoCmd.SetWarnings True
    DoCmd.Hourglass False
    MsgBox Err.Number & ": " & Err.Description
    GoTo Exit_Handler
End Sub

Private Sub cmdSelectMore_Click()
    OpenMeasuresInput ""
    DoCmd.Close acForm, Me.Name
End Sub

```

#### DFCS-TIPS – Form\_frmMeasures (Code)

Option Compare Database

Option Explicit

Private Sub cmdClose\_Click()

    Me.Undo

    DoCmd.Close acForm, Me.Name

End Sub

Private Sub cmdDelete\_Click()

On Error GoTo Err\_Handler

    Dim strMsg As String

    strMsg = "Are you sure you want to delete this entered measure?"

    strMsg = MsgBox(strMsg, vbYesNo)

    If strMsg = vbNo Then

        GoTo Exit\_Handler

    End If

    With DoCmd

        .SetWarnings False

        .Hourglass True

        .OpenQuery "qryDeleteMeasuresSingle", acViewNormal

        .Hourglass False

        .SetWarnings True

    End With

    Me.Requery

    If DCount("MeasuresID", "tlkpMeasures", "Original = 0") <= 0 Then

        DoCmd.Close acForm, Me.Name

        GoTo Exit\_Handler

    End If

Exit\_Handler:

    Exit Sub

Err\_Handler:

    DoCmd.SetWarnings True

    DoCmd.Hourglass False

    MsgBox Err.Number & ": " & Err.Description

    GoTo Exit\_Handler

End Sub

Private Sub cmdNext\_Click()

On Error GoTo Err\_Handler

    If ValidateFields = True Then

        DoCmd.RunCommand acCmdRecordsGoToNext

    End If

Exit\_Handler:

    Exit Sub

Err\_Handler:

    If Err.Number <> 2046 Then

        MsgBox Err.Number & ": " & Err.Description

    End If

```

    GoTo Exit_Handler
End Sub

Private Sub cmdPrev_Click()
On Error GoTo Err_Handler

    If ValidateFields = True Then
        DoCmd.RunCommand acCmdRecordsGoToPrevious
    End If

Exit_Handler:
    Exit Sub
Err_Handler:
    If Err.Number <> 2046 Then
        MsgBox Err.Number & ": " & Err.Description
    End If
    GoTo Exit_Handler
End Sub

Private Sub cmdSave_Click()
    If ValidateFields = True Then
        DoCmd.Close acForm, Me.Name
    End If
End Sub

Private Function ValidateFields() As Boolean
On Error GoTo Err_Handler

    ValidateFields = False

    If Nz(Me.DFCSMeasures.Value, "") = "" Then
        MsgBox "Please enter DFCS Measures value."
        GoTo Exit_Handler:
    End If

    If Nz(Me.AECDesignProfession.Value, "") = "" Then
        MsgBox "Please enter AEC Design Profession value."
        GoTo Exit_Handler:
    End If

    If Nz(Me.ProjectFeatures.Value, "") = "" Then
        MsgBox "Please enter Project Features value."
        GoTo Exit_Handler:
    End If

    If Nz(Me.StageofDesignPhase.Value, "") = "" Then
        MsgBox "Please enter Stage of Design Phase value."
        GoTo Exit_Handler:
    End If

    ValidateFields = True

Exit_Handler:
    Exit Function
Err_Handler:
    MsgBox Err.Number & ": " & Err.Description
    GoTo Exit_Handler
End Function

```

## **Appendix J: Design-Phase DFCS Measures and Elicited Information used in DFCS-TIPS Application Database**

\* = Research Deliverable  
S = Sourced from Survey

V = Validated  
I = Sourced from Interview

(V-I) = Validated through Interview  
(V-II) = Validated through 2 Interviews  
(V-SI) = Validated through Survey and Interview

	<b>AEC Design Profession</b>	<b>Project Features</b>	<b>Stage of Design Phase</b>	<b>Tier of Feasibility of the DFCS Measure</b>	<b>*DFCS Measures</b>	<b>*Applicable Safety Incidents</b>	<b>*Potential Impediments to Implementation</b>	<b>Potential Solutions to the Impediments</b>
1	Architect	Project / Site Orientation	Design Development	2B	Around parking areas, ramps, and other elevated traffic surfaces, increase the height of the perimeter wall above the traffic surface to prevent driving off the traffic surface prior to placement of permanent wheelstops, curbs, and guardrails.	(V-I) [Accident: 200021988]: At approximately 12:34 a.m. on July 11, 2000, Employee #1 was operating a 1997 Caterpillar rubber-wheeled integrated tool carrier equipped with a multi-purpose bucket, a vehicle similar to a front-end loader. He was working near the bottom of a ramp that led to where excavated soil was being stockpiled. Employee #1 was driving to the right of the ramp to dump a load when his right front wheel went up the ramp and the vehicle overturned on its side. He suffered minor injuries and was taken to the hospital, where he was treated for multiple lacerations and released. Employee #1 was not wearing a seat belt at the time of the accident, and later stated that he had not been trained to wear one. He did state that he had been trained to keep his bucket low when traveling with a full load.	Increased Cost; Exposure to liability	Revised contract language; Revised insurance policy; Investigate avenues of potential cost savings on other project features
2	Architect	Project / Site Orientation	Preliminary Design	1B	Avoid locating electrical rooms under pipes carrying liquids that could pose a shock hazard.	(V-I) [Accident: 000743799]: An employee was using a miller roughneck 2e constant-current AC welding generator (serial no. Jk727114) to perform an arc welding operation. The employee, who was not wearing gloves, was standing on wet ground that was lined with steel reinforcing rods. The 27-year-old employee was found lying on his back by coworkers. The electrode holder, which contained a new welding rod with an unused factory tip was found under dripping water near his body. The dead employee was last seen welding reinforcement grid joints for a concrete wall for a new swimming pool. The employee had been electrocuted, as evidenced by visible burns on the front of his right shoulder (3 inches in diameter) and on his chest near the top of his left breast bone (1 inch in diameter). He also had a puncture wound on the inside of his left hand, between his thumb and his first finger.	Absence of Designer Interest and Motivation	Identify alternative design measure to address the associated safety hazards

	AEC Design Profession	Project Features	Stage of Design Phase	Tier of Feasibility of the DFCS Measure	*DFCS Measures	*Applicable Safety Incidents	*Potential Impediments to Implementation	Potential Solutions to the Impediments
3	Architect	Roof	Design Development	1A	Design appropriate and permanent fall protection systems for roofs to be used for construction and maintenance purposes. Consider permanent anchorage points, lifeline attachments, and/or holes in perimeter for guardrail attachment.	(V-I) [Accident: 200841591]: On June 21, 2007, Employee #1, an iron worker, was walking backward on a roof while positioning an angle iron in preparation for making connections. He accidentally walked off the flat, leading edge of the roof and fell approximately 20 ft, striking a heavy angle iron. Employee #1 suffered severe head trauma and multiple fractures. He was wearing a full body harness with lanyard, but there were no attachment points to which he could tie off or anchor himself.		
4	Architect	Stairways / Ramps	Preliminary Design	2B	Locate exterior stairways and ramps on the sheltered side of the structure or fully enclose them to protect them from rain, snow, and ice to minimize fall hazards.	[Accident: 200772382]: Employee #1, a carpenter, was clearing snow on the second floor of an apartment building under construction when he lost his footing, slipped and fell to the ground. He was hospitalized with his injuries.	Exposure to Liability	Revised contract language; Revised insurance policy
5	Architect	Building Materials	Design Development	2B	Avoid specifying the use of masonry materials or liquids which contain toxic substances. When materials cannot be avoided, the level of toxicity should be clearly noted.	(V-I) [Accident: 201507381]: On March 7, 2007, Employee #1 was in a shallow pit (approximately 2 feet deep) where wet cement was being poured and formed into a foundation to support tanks. While working in the wet cement, which was approximately 6 inches deep, his skin was exposed to the wet cement which resulted in severe burns to his feet. Without the knowledge of the site foreman or coworkers, he was wearing leather boots with laces which were not company approved. When coworkers noticed this, they helped Employee #1 leave the wet cement and wash his feet. He reentered the wet cement wearing company-approved, protective foot wear, which included rubber boots sealed with duct tape near the upper middle area of the lower leg. He worked the remainder of the shift in the wet cement and began to experience pain at approximately 3:00 p.m. but continued to work the rest of the shift. Later that evening, he was admitted to the hospital with second- and third-degree burns on his right foot and second degree burns on his left foot.	Schedule problems and time constraints; Decreased project quality and diminished design creativity	Investigate avenues of decreasing the time needs of other project features; Identify alternative design features to address the associated safety hazards

	AEC Design Profession	Project Features	Stage of Design Phase	Tier of Feasibility of the DFCS Measure	*DFCS Measures	*Applicable Safety Incidents	*Potential Impediments to Implementation	Potential Solutions to the Impediments
6	Architect	Roof	Design Development	2A	Provide permanent catwalks or work platforms for ceiling installation and maintenance on tall, long span structures.	[Accident: 170736862]: Employee #1 was working from a rolling scaffold platform 6 ft above grade, installing a drop ceiling at Gifford Micro Sciences. He was working alone and had no ground helper. Employee #1 was reaching to install a wire in the drop ceiling when the scaffold moved away from the wall and he fell. He landed on the right side of his body and suffered a fracture of his distal radius. The wheels of the scaffold were not locked at the time of the accident. According to Employee #1, this was done so that the scaffold could be easily moved during the installation process.		
7	Architect	Stairways / Ramps	Preliminary Design	2B	Protect exterior walkways and platforms from the weather (which can make them slippery) by providing a covering, extending the roof line, or locating them on the sheltered side of the structure.	(V-I) [Accident: 200770832]: Employee #1 was moving a large hot water heater when he slipped on the snow. He sustained injuries to his right leg, for which he was hospitalized.	Increased Cost; Decreased project quality and diminished design creativity; Designers' lack of safety expertise; Absence of designer interest and motivation	Engage outside safety experts to review designs; Utilize designers with formal safety training; Investigate avenues of potential cost savings on other project features; Identify alternative design features to address the associated safety hazards; Identify alternative design measure to address the associated safety hazards

	AEC Design Profession	Project Features	Stage of Design Phase	Tier of Feasibility of the DFCS Measure	*DFCS Measures	*Applicable Safety Incidents	*Potential Impediments to Implementation	Potential Solutions to the Impediments
8	Architect	Stairways / Ramps	Design Development	2A	Use consistent tread and riser dimensions throughout the stairway run and the project.	(V-I) [Accident: 170170971]: Employee #1 and a coworker, both carpenters, were installing redwood boards on an approximately 10 ft high deck. The decking had been laid to within 5 to 6 ft of the end of the structure. Employee #1 walked atop the 4 ft by 4 ft joists out to the 8 in. end beam, intending to measure the boards so they would come out even with the end, and to sight along the edge to insure that all the ends were parallel. When he reached the end, he placed one hand against the building wall, turned around on the 8 in. beam, and bent down to step onto the partially completed stairway. He misjudged the distance to the closest tread, lost his balance, and fell backward onto the stairs. His head struck a tread, and he fell, head first, another 4 1/2 ft to the ground. He landed on his head and his neck was broken in three places.		
9	Architect	Stairways / Ramps	Construction Documents	1A	Provide a non-slip surface treatment on permanent ramps to help prevent slipping and falling.	(V-I) [Accident: 202340782]: Employee #1, an Ironworker, was carrying a stair stringer into the building and slipped while walking up a ramp at the entrance. Employee #1 fell against a wood guardrail post and the post gave way at its base and he fell. The guardrails had been removed to the left of the post on that side of the shaft to allow for hoisting, so the post had no bracing towards that side and it tipped and broke in that direction. Employee #1 fell 32 ft into the elevator shaft at the side entrance of the building. Employee #1 suffered fractured ribs, and other blunt impact injuries which were not life threatening. Employee #1 was hospitalized.		
10	Architect	Building Materials	Design Development	2B	Limit the spread of fire by the use of fire walls, parapets, fire stops, deluge systems, etc.	[Accident: 14549935]: Employee #1 and employee #2 were stripping finish from a kitchen cabinet at 4861 east shore drive. They were using a lacquer thinner. A flash fire, suspected to have started in the air conditioning and heating system, broke out and spread to the kitchen. Employee #1 ran to the back door, which was deadbolted. Employee #2 ran in the opposite direction and was able to get out of the house. When employee #2 got out and noticed that employee #1 was not around, he ran to the back door. Employee #2 kicked in the back door and was able to get employee #1 out. Employee #1 was severely burned over 75% of his body. Employee #2 sustained minor burns on his right arm and shoulder. It is suspected that the flash fire started from vapor accumulation from the lacquer thinner in the air conditioning and heating system.	Decreased project quality and diminished design creativity	Identify alternative design features to address the associated safety hazards

	AEC Design Profession	Project Features	Stage of Design Phase	Tier of Feasibility of the DFCS Measure	*DFCS Measures	*Applicable Safety Incidents	*Potential Impediments to Implementation	Potential Solutions to the Impediments
11	Architect	Finishing	Construction Documents	2B	Design the covers over sumps, outlet boxes, drains, etc. to be flush with the finished floor to eliminate these features as tripping hazards.	[Accident: 200801702]: On January 6, 2007, an employee and coworkers were erecting walls on the third story of a commercial building. The employee was carrying 2-ft by 6-ft panels for other coworkers to erect the walls. The employee and coworkers had the second wall section on the north side of the building finished and ready for installation. The foreman for the company was on the phone with the owner and noticed the employee walking towards the edge of the unguarded floor edge. He then saw him trip and fall over the side of the building. The employee fell 36 feet and suffered a collapsed lung, a broken pelvis, and broken ribs. He was hospitalized.	Exposure to Liability; Increased Cost; Designers' lack of safety expertise; Absence of designer interest and motivation	Revised contract language; Revised insurance policy; Engage outside safety experts to review designs; Utilize designers with formal safety training; Investigate avenues of potential cost savings on other project features; Identify alternative design measure to address the associated safety hazards
12	Architect	Project / Site Orientation	Preliminary Design	2B	Orient the project to allow for the construction of temporary roads, fire lanes, and approach roads during construction.	(V-I) [Accident: 202446530]: At approximately 2:30 p.m. on July 13, 2007, Employee #1, a construction foreman, was driving a 2003 Chevy, single cab, long bed, four-wheel drive pickup truck along an uphill roadway leading to a construction site. A scraper operator, unaware of Employee #1's pickup, backed his scraper down the roadway away from the entrance to the site to permit a water truck operator enough clearance to pass the scraper and apply water on the lot. Employee #1, who was in the scraper's blind spot, could not maneuver his vehicle out of the way of the backing scraper in time. The scraper backed up and over the front driver's side of the pickup truck. Employee #1's left hand and wrist sustained serious injuries, and he was air-lifted to Loma Linda University Medical Center.	Increased Cost; Decreased project quality and diminished design creativity; Designers' lack of safety expertise	Engage outside safety experts to review designs; Utilize designers with formal safety training; Investigate avenues of potential cost savings on other project features; Identify alternative design features to address the associated safety hazards
13	Architect	Stairways / Ramps	Design Development	2A	Provide access by means of a ladder or stairway between horizontal surfaces when there is a change in elevation exceeding 15 inches.	[Accident: 824268]: Employee #1 was climbing concrete forms to access an elevation. He lost his balance and fell. Employee #1, who was not using fall protection or a ladder, was hospitalized.		

	AEC Design Profession	Project Features	Stage of Design Phase	Tier of Feasibility of the DFCS Measure	*DFCS Measures	*Applicable Safety Incidents	*Potential Impediments to Implementation	Potential Solutions to the Impediments
14	Architect	Walkways	Preliminary Design	2A	Consider providing a covering over walkways to protect them from snow and ice.	[Accident: 14321111]: Employee #1 was moving a 540 lb steel I-beam from one side of a doorway to the other. As he lifted one end of the beam his feet slipped on ice and he fell to the floor. The beam landed on Employee #1's head, killing him.		
15	Architect	Walkways	Preliminary Design	2B	Provide multiple means of access to elevated walkways and platforms which can be used for efficient maneuverability during emergency situations.	(V-I) [Accident: 14554372]: The production facilities in the plant were undergoing renovation and installation of new parts on the second through fourth floors. An oil fuel line to a water chiller was cut so that the chiller could be removed. The dump valve for the oil pot, which is located under the fifth floor accumulator, is connected to this line but was not locked out or tagged. Several days after the line was cut another employee opened the valve to dump the oil and ammonia in the pot to the regenerator in the basement. The oil and ammonia was blown out of the open pipe and formed a vapor cloud. Employees #1 through #13, working in the basement through fourth floors, were exposed to the ammonia fumes. They were hospitalized.	Increased Cost	Investigate avenues of potential cost savings on other project features

	AEC Design Profession	Project Features	Stage of Design Phase	Tier of Feasibility of the DFCS Measure	*DFCS Measures	*Applicable Safety Incidents	*Potential Impediments to Implementation	Potential Solutions to the Impediments
16	Architect	Stairways / Ramps	Design Development	1A	Use steel or concrete instead of wood for stairways in areas where fire sources are present.	(V-I) [Accident: 202330684]: On August 18, 2004, the owner and Employee #1 of Old Master Painters, Co. were working in the basement of a private residence. They had a verbal contract with the homeowner to strip the paint from the floor of a basement room approximately 11 ft by 11 ft. At 11:00 a.m., they began the work. The owner used a chemical (the employee did not know what it was because he only works part-time) on the floor to remove the old paint and then a thinner to speed up the process. This appeared to work, so they decided to take a lunch break and allow the chemical to do its work. After lunch, Mr. Ortiz went to a store to purchase more chemical stripper and thinner. They went back into the basement at approximately 3:15 p.m. to finish the work. They applied a layer of the stripper on the floor and then put about a gallon of thinner on top of it. They saw the paint beginning to fish scale. They decided to let the chemical work and began to leave the basement. The owner was the first up the stairway. He saw a flame come out of nowhere, heard a whoosh, and felt intense heat. He heard Employee #1 scream and could not get back down the steps, so he ran for help. When he got back with help, they knocked out the basement windows and tried to put out the fire with a garden hose. Emergency medical personnel were summoned. Employee #1 was found on the stairway and pronounced dead by the Medical Examiner. He had burns to 99 percent of his body. The Montgomery County Fire Inspector has determined that the most likely cause of the accident was the cycling on of the dehumidifier at a time when the quantity of flammable vapors was between the upper and lower explosive limits, resulting in a flash fire.		
17	Architect	Stairways / Ramps	Construction Documents	1A	Use perforated steel or steel grating for stair treads on exterior stairways to prevent slipping and falling, or when there is a need to see through the stairs in tight, congested work areas.	(V-I) [Accident: 201163979]: At approximately 1:50 p.m. on June 28, 2002, Employee #1, who had only been working for 2 to 3 days at the job site, was walking up a metal staircase to fetch a ladder when he fell 68 inches over the handrail and to the ground. A coworker, who was positioned down and around the staircase, heard Employee #1 yell and watch him fall head first to the ground. His coworker immediately called for medical assistance. Employee #1 was transported to Cedar Sinai Medical Center, where he stayed for 24 hours then subsequently died from his head injuries.		

	AEC Design Profession	Project Features	Stage of Design Phase	Tier of Feasibility of the DFCS Measure	*DFCS Measures	*Applicable Safety Incidents	*Potential Impediments to Implementation	Potential Solutions to the Impediments
18	Architect	Stairways / Ramps	Design Development	2A	Design intermediate vertical members on stairrails and guardrails to be at most 19 inches apart while the space between pickets should be such that a 6" sphere cannot pass through.	(V-I) [Accident: 202475042]: Employee #1, a laborer, was pushing copper cooling plates weighing over 250 lb along a 24 in. high, horizontal conveyor system toward the edge of a 45 ft high platform. There was a 23 in. long gap in the midrail of the metal guardrail system that surrounded the open sides of this platform, creating a 23 in. wide by 45 in. high opening in the guardrail. Apparently, Employee #1 fell through this opening and onto a pile of cooling plates. He was killed.		
19	Architect	Walkways	Design Development	2A	Reduce trip hazards by providing a small amount of slope on exterior walkways and platforms to prevent ponding.	(V-I) [Accident: 170883110]: Employee #1 was walking across an asphalt surface when he slipped in a puddle of water and attempted to grab hold of a portable loading ramp. He could not grasp it and continued to slip and slide on the asphalt, falling to the ground. Employee #1 twisted and fractured his ankle. He was assisted by the foreman, who called the paramedics.		
20	Architect	Permanent Ladders	Design Development	2A	In the design of permanent ladders and ladder wells, design the inside width of ladder wells to be at least 36 inches for ease of ascent/descent.	(V-I) [Accident: 170190003]: Employee #1 was climbing a ladder that was fixed to the outside wall of a condominium. He was carrying a 25 lb can of Freon-22 to service an air-conditioning unit that was located about 6 1/2 ft from the edge of the condominium roof, 19 ft 7 in. above ground level. The climbing space width at the top of the ladder was only 10 in. wide each way from the center of the ladder (20 in. total), and the space was obstructed by the tiled roof at the top of the ladder. While climbing the narrow portion of the ladder, Employee #1 fell to the concrete floor and was killed.		
21	Architect	Permanent Ladders	Design Development	1A	Avoid designing manhole covers, doors, or other objects which swing into climber access space for those utilizing a permanent ladder.	(V-I) [Accident: 170377980]: Employee #1 was standing on the fourth rung of a 12 ft fixed vertical ladder, about 8 ft above a stair landing. He had just finished removing some tools from the roof by lowering them with a rope through a roof hatch. To close the hatch, Employee #1 reached over his head to grab the hatch handle with one hand, while holding onto the hatch sill with the other. Because of the way the hatch was configured, he had to let go of the sill for the hatch cover to close. Employee #1 either slipped or lost his grip and fell backward off the ladder. He struck a 42 in. tall handrail on the landing and then fell 22 ft 6 in. down the stairwell to the bottom floor, for a total distance of 30 ft 6 in. Employee #1 suffered cuts to his head and multiple bruises. His coworker had already left the work site when the accident occurred.		

	AEC Design Profession	Project Features	Stage of Design Phase	Tier of Feasibility of the DFCS Measure	*DFCS Measures	*Applicable Safety Incidents	*Potential Impediments to Implementation	Potential Solutions to the Impediments
22	Architect	Stairways / Ramps	Preliminary Design	1A	In areas which receive snow, provide a covering, overhang, or extend the roof line over exterior ramps and where not feasible, specify a snow melt system.	(V-I) [Accident: 200770832]: Employee #1 was moving a large hot water heater when he slipped on the snow. He sustained injuries to his right leg, for which he was hospitalized.		
23	Architect	Permanent Ladders	Construction Documents	1A	In the design of permanent ladders, design ladder steps/rungs to be corrugated, knurled, dimpled, coated with a skid-resistant material, or treated to minimize slipping. Do not coat wood ladders with an opaque material.	(V-I) [Accident: 202475653]: At approximately 6:30 a.m. on February 11, 2009, Employee #1, a 40-year-old male, of WF Construction Inc, was working at a site in La Verne, California. WF Construction was a sub-contractor at accident site engaged in remodeling work on an existing two story building, and had been working there for about three weeks with a crew of seven employees. Employee #1 was not an independent contractor but a full time employee of WF Construction Inc and was employed for about two years as an electrician. At time of incident Employee #1, was coming down a fixed ladder after doing some electrical work on roof. When he slipped and fell in middle of ladder, and fell approximately six-feet onto a sub-roof after the fall. Employee #1 suffered a fracture to his left wrist in this fall. Employee #1 was transported to Pomona Valley Medical Center by paramedics where he was treated and released same day. Employee #1 stated during an interview that he was not carrying any tools in his hands while coming down and observed no defects in the ladder. The fixed ladder was inspected by Cal/Osha investigator at site after the accident and found to be all right for use. Cal/Osha observed no safety violations directly relating to the accident. However, a couple of nonaccident related violations were observed and citations were issued to sub-contractor. The general contractor / building owner was not at site at accident time and came later after learning about the accident. The general contractor had no employees of his own at this site.		

	AEC Design Profession	Project Features	Stage of Design Phase	Tier of Feasibility of the DFCS Measure	*DFCS Measures	*Applicable Safety Incidents	*Potential Impediments to Implementation	Potential Solutions to the Impediments
24	Architect	Walkways	Design Development	2B	Design a small amount of slope into walkways to prevent ponding.	(V-I) [Accident: 201183209]: On November 14, 2006, employees were working at the Public Health Center. At approximately 5:10 p.m., Employee #1 was on the second floor walking down the central hall on the right side of the hallway towards the rest room when she stepped into a puddle of water. Employee #1's right foot slipped forward and she fell onto her left knee, which was bent. A coworker arrived and called an ambulance. Employee #1 was transported to the hospital. Employee #1 had shattered the lower one-half to one-third of her patella (left knee cap). Employee #1 was hospitalized and underwent surgery.	Designers' lack of safety expertise	Engage outside safety experts to review designs; Utilize designers with formal safety training
25	Architect	Roof	Design Development	1B	Design in a means of attaching a railing of safety lines for roofing operations to ensure fall protection for workers.	(V-I) [Accident: 200841591]: On June 21, 2007, Employee #1, an iron worker, was walking backward on a roof while positioning an angle iron in preparation for making connections. He accidentally walked off the flat, leading edge of the roof and fell approximately 20 ft, striking a heavy angle iron. Employee #1 suffered severe head trauma and multiple fractures. He was wearing a full body harness with lanyard, but there were no attachment points to which he could tie off or anchor himself.	Designers' lack of safety expertise	Engage outside safety experts to review designs; Utilize designers with formal safety training
26	Architect	Permanent Ladders	Design Development	1B	Orient permanent ladders such that the person faces the structure while climbing.	(V-I) [Accident: 170872055]: Employee #1 was on the roof of a mill plant, switching gates for the cotton seed meal to enter the building. After finishing this task, he walked down the 45 degree sloped roof to the edge, where he had to turn around and climb down a ladder facing out. Employee #1 missed the handrail and lost his balance. He could tell he was going to fall, so he jumped to avoid the concrete footing at the base of the ladder. Employee #1 fractured his right leg, for which he was hospitalized.	Designers' lack of safety expertise	Engage outside safety experts to review designs; Utilize designers with formal safety training
27	Architect	Stairways / Ramps	Design Development	2B	Build stair landings up above an uneven grade or slope the stair landing.	(V-I) [Accident: 201485265]: Employee #1 sustained an injury that caused bleeding of the brain after slipping and falling on a wet concrete step. Employee #1 was hospitalized for two days.	Increased Cost; Schedule problems and time constraints; Designers' lack of safety expertise	Engage outside safety experts to review designs; Utilize designers with formal safety training; Investigate avenues of potential cost savings on other project features; Investigate avenues of decreasing the time needs of other project features

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28	Architect	Permanent Ladders	Design Development	1B	Provide safety gates at the top of walk through and side access permanent ladders.	(V-I) [Accident: 201630977]: At approximately 5:00 p.m. on April 17, 2000, Employee #1 was given the task of retrieving two vent covers from a storage area. When Employee #1 returned to the work area he inadvertently entered through a door that had an uncovered ladder hole opening. Employee #1 stepped into the hole and fell approximately 14 ft to the floor. Employee #1 sustained a fractured left leg and wrist. Employee #1 was hospitalized.	Exposure to Liability; Designers' lack of safety expertise	Revised contract language; Revised insurance policy; Engage outside safety experts to review designs; Utilize designers with formal safety training
29	Architect	Windows	Construction Documents	2B	Provide inserts in window jambs for guardrail attachment.	[Accident: 170245328]: Employee #1, age 20, was one of a crew of four working on the framing of a condominium building. They were lifting an overhead structural beam into place when it became wedged between an outer guardrail support and a plumb support. Employee #1 stepped onto the sill of a third-floor window and reached up and out, trying to free the beam. The guardrail that was nailed to the outside of the building came free as Employee #1 leaned against it. He fell 25 ft and was killed.	Exposure to Liability; Increased Cost; Schedule problems and time constraints	Revised contract language; Revised insurance policy; Investigate avenues of potential cost savings on other project features; Investigate avenues of decreasing the time needs of other project features
30	Architect	Permanent Ladders	Design Development	2A	In the design of permanent ladders, design individual step/rung ladders to extend at least 42 in. above an access level or landing platform either by the continuation of the rung spacing as horizontal grab bars or by providing vertical grab bars that have the same lateral spacing as the ladder rails.	(V-I) [Accident: 170723159]: Employee #1 was on an upper level checking an air compressor and a filtering system. He fell from the upper level when he started down the ladder. Employee #1 said that he slipped and lost his footing as he began to come down the ladder. This ladder is a wooden ladder built in place by the contractor when the building was constructed. The side rails of the ladder did not extend 42 inches above the upper level. Employee #1 did not have a good handhold when he attempted to descend the ladder.		

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31	Architect	Egress	Design Development	2A	Design doors to swing open in the direction of exit travel.	(V-I) [Accident: 200881563]: On December 23, 2008, Employee #1 was working in a sanding furniture building, when a fire broke out and started to burn the building. The fire blocked the roll up door, which was being used as the only exit from the suite. While trying to exit, Employee #1 became overcome by the smoke and died within the suite.		
32	Architect	Permanent Ladders	Construction Documents	2A	In the design of permanent ladders, design vertical bars to be on the outside of the horizontal bands, clear and projecting from the wall.	(V-I) [Accident: 201158250]: On August 30, 2003, Employee #1 was installing a horizontal expansion joint on the roof of a single story building. He was wearing shoes, gloves, and a back belt with his DeWalt drill and metal snip gun tucked into the belt. There was a fixed metal ladder and at its top was a roof opening. He was descending the ladder with both gloved hands on the ladder. He had not progressed very far when his right hand slipped. He attempted to grab a rung with his left hand and his head hit the edge of the roof opening. He fell 17 ft to the concrete floor and was hospitalized with multiple fractures including his spleen.		
33	Architect	Stairways / Ramps	Design Development	2A	Provide at least one handrail or stairrail along stairways with 4 or more risers, or which rise more than 30 inches in height, whichever is less.	[Accident: 201942448]: On March 14, 2007, Employee #1 was working as a structural metal worker for a special trade contractor that engineered, manufactured, and installed interior and exterior architectural envelopes and building claddings. He was assigned to caulk expansion joints on a balcony 33 inches wide by 14 feet long on the forty-sixth floor of a building. This caulking normally took about five minutes. The balcony had a top railing 43 inches high, supported by three separate metal posts 38.6 inches apart. The balcony's design called for laminated glass panels for the balcony's mid-railings. These normally acted as barriers to prevent an employee from falling underneath the top railing. Three of the four sections that were supposed to have these laminated glass panels were missing them instead. There were only two units in the entire building in which the laminated glass panels for the mid-railings were missing. Employee #1 was not using his personal fall protection equipment, having left it on his cart on another floor. There was tape printed with the word "Danger" but nothing designating the area as either a controlled access zone (CAZ) or requiring that personal fall protection gear be worn by someone working on the balcony. Employee #1 fell 46 floors, or 378 feet, to the ground, and he was killed.		

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34	Architect	Stairways / Ramps	Design Development	1A	Maintain a uniform stair slope throughout the project.	(V-I) [Accident: 14222640]: At approximately 11:45 a.m. on September 12, 2000, Employee #1 was on the third floor of a town home under construction showing a coworker how to install handrails on the stairs. He had been measuring the area where the handrails were to be installed and showing the coworker the area. As he was walking down, he stepped at the edge of a stair, lost his footing, and fell approximately 32 ft onto a concrete floor. The medical examiner's office gave the preliminary cause of death as multiple blunt trauma to the head.		
35	Architect	Finishing	Construction Documents	1A	Specify high solids, and no, or low, V.O.C. coating systems.	(V-I) [Accident: 170609028]: At 7:58 a.m. on May 17, 1995, Employee #1, of Multiple Plant Services, Inc., was applying QSC 713 VOC primer inside an approximately 16 foot deep hole. He was overcome by organic vapors, and suffered nausea and dizziness before losing consciousness. Employee #1 was taken to Queen of Angels, Hollywood Presbyterian Hospital, Los Feliz, CA, for treatment and hospitalization. The causal factors of the accident were that the atmosphere of the hole was not tested for entry and the respirator cartridge (TC-21C-244) was not approved for protection against organic vapors.		
36	Architect	Permanent Ladders	Design Development	2A	In the design of permanent ladders, provide fixed ladder cages, wells, or other safety devices where the length of climb is less than 24 feet but the top of the ladder is at a distance greater than 24 feet above lower levels.	(V-I) [Accident: 201042041]: Employee #1 was descending a fixed ladder one-handed while carrying tools in the other hand. He lost his handhold approximately 53 feet above the ground level and fell to the ladder platform. He then went over the platform guardrail backward, struck his head on a metal plate attached to the outside of a lower adjacent stairwell, and fell to the ground. He was killed in the fall.		

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37	Architect	Stairways / Ramps	Preliminary Design	1A	Avoid using spiral stairways. If spiral stairways are used, provide a handrail to prevent stepping on areas where the tread width is less than 6 inches.	(V-I) [Accident: 14409767]: At approximately 9:30 a.m., Employee #1 and coworkers, of C & B Acoustical & Drywall Materials, Inc., unloaded drywall from a truck to take upstairs to where the drywallers were working. Employee #1 and a coworker were carrying two sheets of 4 by 10 ft drywall, weighing 120 lb, up a spiral staircase. The coworker said that both he and Employee #1 were carrying the sheets of drywall up the stairs with their bodies toward the open side of the stairs. Employee #1 was in the lead at the top of the stairs. The coworker was at the bottom when his end of the drywall sheets made contact with the wall and caused the top portion to move right toward the inside open side of the stairs. Employee #1 lost his balance. He stepped backward off the stairs and fell approximately 10 feet. His head struck against the concrete floor and he was killed.		
38	Architect	Permanent Ladders	Design Development	1A	In the design of permanent ladders and ladder wells, keep the inside of the ladder wells clear of projections that could hamper safe movement on the ladder.	(V-I) [Accident: 300859188]: At approximately 1:45 p.m. on July 19, 2002, Employee #1, a service technician, was in the electrical control room at the CALFED Bank building in Upland, California. He was climbing an indoor fixed ladder to access the roof in order to perform repair and maintenance on the HVAC system. There was a 3-in.-diameter vertical steel conduit just 1 in. from the left rail of the ladder. Employee #1's left sleeve of his short-sleeve shirt became entangled with an extruding clamp screw on the conduit, and he fell approximately 8 ft onto the concrete floor. Employee #1 sustained multiple fractures of his left rib cage and punctured his left lung. He was transported to Arrowhead Regional Medical Center in Colton, California, where he underwent surgery. A clear width of at least 15 in. was not provided on each side from the centerline of the ladder.		
39	Architect	Permanent Ladders	Preliminary Design	1B	To reduce the chance of falls, consider stairs in lieu of a permanent ladder when the ladder will be used frequently to move material and equipment.	(V-I) [Accident: 14480511]: Employee #1 was last seen climbing a fixed ladder secured to a column in a warehouse, heading toward a Milwaukee 20-ton overhead crane. He fell from either the ladder or the rest platform (landing) and suffered a crushed chest, a fractured pelvis, and numerous internal injuries. Employee #1 was killed. The cage of the fixed ladder started at 32 feet above the floor. The rest platform, which was not equipped with guardrails, was also located 32 feet above the floor.	Increased Cost (V-SI); Decreased project quality and diminished design creativity	Investigate avenues of potential cost savings on other project features; Identify alternative design features to address the associated safety hazards

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40	Architect	Multi-level Project	Design Development	1B	Use a uniform railing height throughout the project site.	(V-I) [Accident: 201080504]: At approximately 1:27 p.m. on June 17, 1997, Employee #1 had just finished lunch in the employee break-room and was beginning to descend the stairs to her workstation. According to Employee #1, she lost her balance as she was closing the door that was located at the top of the stairs. Employee #1 sustained contusions to her head, shoulder and knees when she fell down a flight of six stairs. Employee #1 was not hospitalized. The narrative noted that the required placement, height, and extension of the stair handrail at the top of the stairs were not in compliance with the building code.	Decreased project quality and diminished design creativity	Identify alternative design features to address the associated safety hazards
41	Architect	Permanent Ladders	Design Development	2A	Design permanent ladder steps/rungs to be spaced between 10 and 12 inches apart, parallel, level, and uniformly spaced throughout the ladder.	(V-I) [Accident: 14499115]: Employee #1 was climbing a 112 ft fixed metal ladder to the racking board. He was reaching for an offset rung when he slipped and fell, striking the flowline and the mud tank before landing on the ground. Employee #1 was killed. The ladder was used to ascend to heights greater than 20 ft, but was not equipped with a cage or well. No ladder safety device was provided, nor were there any offset landing platforms.		
42	Architect	Egress	Design Development	1A	Eliminate tripping hazards around doors.	(V-I) [Accident: 201039484]: At approximately 7:30 p.m. on May 2, 2007, Employee #1 was approaching the east entrance to building Number 600 while talking to a coworker inside the building. Employee #1 tripped over a door stop that was 2-in. in diameter, 2-in. tall and 24-in. from the wall. Employee #1 struck his shoulder as he fell and suffered a fracture of his collarbone. Employee #1 was transported the hospital where he was treated and released.		
43	Architect	Permanent Ladders	Design Development	1B	In the design of permanent ladders, design ladder wells to completely encircle the ladders to provide unobstructed protection.	(V-I) [Accident: 200630325]: Employee #1 was repairing the heating unit on the roof of a grocery store. He used a 16-rung metal ladder fixed to the side of the building to access the 17 ft. 6 in. roof. As he was climbing, he fell straight back off the ladder, striking his head on the pavement as he landed. CPR was started immediately and Employee #1 was transported to the hospital, where he later died. The ladder had round, 3/4 in. diameter by 18 in. long rungs, each 11 1/4 in. apart, that were 7 1/2 in. from the wall. The metal side rails were 2 1/2 in. wide by 3/8 in. thick, and extended sufficiently beyond the surface of the roof. It was not known from what height Employee #1 fell, or whether he was ascending or descending the ladder.	Increased Cost	Investigate avenues of potential cost savings on other project features

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44	Architect	Walkways	Construction Documents	3A	Use serrated grating, instead of checkered steel plate, for walking surfaces on steel structures to prevent slipping hazards.	[Accident: 201032349]: Employee #1 was standing on the 21 in. wide by 62 1/2 in. long steel diamond plate deck on the second-level catwalk. It was located 69 in. above the first-level steel deck, which was approximately 7 ft above floor level. On two sides of the second-level catwalk deck were 43 in. high steel pipe guardrails, with midrails and toe boards. There was also a fixed, nearly vertical ladder at the north end of the catwalk, between the first and second levels. The 3 ft wide ladder had 13 in. long by 2 1/2 in. wide metal rungs, spaced 12 in. apart. Employee #1 apparently fell from the second deck to the first, where he was found lying unconscious about 3 ft from the ladder by two coworkers who heard a noise and turned around. He suffered fractures to both hands, multiple contusions, and a ruptured spleen. Paramedics were called and Employee #1 was taken to Harbor General Hospital, where he was hospitalized for 12 days and his spleen was surgically removed. It is believed that Employee #1 fell from the unguarded 17 in. wide endspace on the second level where the fixed ladder terminated.		
45	Architect	Floor Openings	Design Development	3A	Eliminate tripping hazards (changes in elevation, curbs, etc.) around floor openings.	[Accident: 170062319]: Employee #1, an iron worker, was spreading steel decking when he either slipped or tripped, and fell forward through a floor opening. He was killed.		
46	Architect	Floor Openings	Design Development	3A	Provide permanent guardrails around floor openings.	[Accident: 170062319]: At approximately 10:45 a.m. on Monday, June 21, 1993, Employee #1, a 38-year-old cement finisher, and a coworker were working alone on the second floor of a newly constructed addition to a manufacturing building. The concrete pour for half of the second floor, which measured 84 ft by 119 ft, had almost been completed and the two men were completing the finish on the fresh concrete. The remainder of the concrete subcontractor's crew of 13 men had descended to the first floor. Employee #1 was working with a bull float and apparently was backing up to an unguarded floor opening measuring 2 ft 8 in. by 18 ft 1 11/16 in. when he either tripped on the projecting edge and fell, or stepped, into the opening. He fell 16 ft 8 in. to a concrete floor. Employee #1 sustained head injuries and remained in a coma at the hospital until his death on Friday, July 2, 1993, at approximately 3:30 a.m. His coworker did not see what happened and there was no other eyewitness to the event.		

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47	Architect	Roof	Design Development	3A	Eliminate tripping hazards around roof openings.	[Accident: 201982402]: At approximately 2:30 p.m. on November 30, 2000, Employee #1 was performing roofing work for by D & E Roofing, L.L.C. when he accidentally tripped or slipped and fell 17 ft 6 in. to the concrete floor. Employee #1 fell through an uncovered roof hatch opening.		
48	Architect	Roof	Design Development	3A	Place skylights on a raised curb (10-12 inches).	[Accident: 200374734]: On May 21, 2009, Employee #1 and two coworkers were on a metal roof, installing new tin roofing panels and corrugated fiberglass skylights. During the work, Employee #1 stepped onto a newly installed skylight, fracturing and falling through it. He fell approximately 17 ft to the concrete floor and was killed.		
49	Architect	Egress	Preliminary Design	3B	Provide at least two means of egress on large maintenance platforms or walkways to ensure a safe exit for workers during emergencies.	[Accident: 14554372]: The production facilities in the plant were undergoing renovation and installation of new parts on the second through fourth floors. An oil fuel line to a water chiller was cut so that the chiller could be removed. The dump valve for the oil pot, which is located under the fifth floor accumulator, is connected to this line but was not locked out or tagged. Several days after the line was cut another employee opened the valve to dump the oil and ammonia in the pot to the regenerator in the basement. The oil and ammonia was blown out of the open pipe and formed a vapor cloud. Employees #1 through #13, working in the basement through fourth floors, were exposed to the ammonia fumes. They were hospitalized.	Decreased project quality and diminished design creativity	Identify alternative design features to address the associated safety hazards
50	Architect	Finishing	Design Development	3B	Design the finished floor around mechanical equipment to be at one level (no steps, blockouts, slab depressions, etc.) to reduce tripping hazards.	[Accident: 924076]: Employee #1 was working in a central equipment control room that contained telephone circuits and other equipment. Apparently, he was trying to calibrate a tone onto a telephone circuit from a group of telephone banks. He had been asked to walk to another part of the building and adjust a channel to bring up a tone for the telephone circuit that was being serviced. As he started to walk to the other telephone banks, Employee #1 either fell off or tripped over a 14 in. elevated step. He died six days later of severe head trauma.	Decreased project quality and diminished design creativity	Identify alternative design features to address the associated safety hazards
51	Architect	Stairways / Ramps	Preliminary Design	3B	Place exterior stairs on the sunny side of the structure to prevent the buildup of slippery moss or ice.	[Accident: 14321111]: Employee #1 was moving a 540 lb steel I-beam from one side of a doorway to the other. As he lifted one end of the beam his feet slipped on ice and he fell to the floor. The beam landed on Employee #1's head, killing him.	Decreased project quality and diminished design creativity	Identify alternative design features to address the associated safety hazards

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52	Architect	Roof	Design Development	3A	Provide a guardrail around roof accesses and roof work areas.	[Accident: 200643815]: On June 19, 2007, Employee #1, age 19, of Crossland Construction Company, Inc., was decking a roof. As he was working, he we walked to the edge and subsequently fell 30 ft onto a concrete surface. Employee #1 was killed. At the time of the accident, he was wearing a harness and lanyard, but he was not tied off to the YO YO system.		
53	Architect	Finishing	Construction Documents	3A	Design signs to be integral parts of walls and floors using color, tiles, or floor coverings.	[Accident: 201096831]: At approximately 12:10 p.m. on September 26, 2003, Employee #1, a sheet metal worker with Rarig Construction, was sweeping scraps of metal on a roof after roofing activity. After tripping sideways over a parapet wall, he made an unsuccessful attempt to grab the top of the wall, and then fell 30 ft to a concrete surface, striking his hands and face first. He was hospitalized at Stanford Medical Center (Berkley, CA) with numerous facial, arm, and leg fractures. Employee #1 was not wearing fall protection. Guardrails, warning lines, catch platforms, scaffold platforms and eave barriers were not present where he fell.		
54	Architect	Multi-level Project	Preliminary Design	3A	Avoid the design of split-level floors as these can become tripping hazards.	[Accident: 200650364]: On December 29, 1999, Employee #1, an installer for a security alarm company, entered a house under construction through the ground-level garage and stepped onto a styrofoam insulation panel that he thought was debris on the floor. However, the panel was covering a stairway opening to the lower, sub-ground level of the split-level home. Employee #1 fell 9 ft down the opening and sustained multiple contusions and abrasions. The stairway opening was not adequately guarded or covered. Installers, such as Employee #1, normally do not use blueprints and he did not realize the home had multiple levels.		
55	Architect	Stairways / Ramps	Design Development	3B	Provide a handrail or stairrail along each unprotected stairway edge, and when the gap between the stairway and the structure is greater than 6 inches.	[Accident: 200555209]: At approximately 7:15 a.m. on March 11, 2008, Employee #1 was transiting a set of stairs to conduct clean-up operations on the upper levels of a construction project. Neither the stairs nor the stair landings had a railing system installed. Employee #1 fell approximately 17 ft from the second stair platform to the concrete. Employee #1 was taken to a local hospital and died on March 24, 2008.	Decreased project quality and diminished design creativity	Identify alternative design features to address the associated safety hazards

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56	Architect	Permanent Ladders	Design Development	3A	In the design of permanent ladders, provide a minimum clear distance of 16 inches between the side rails of adjacent ladders.	[Accident: 300859188]: At approximately 1:45 p.m. on July 19, 2002, Employee #1, a service technician, was in the electrical control room at the CALFED Bank building in Upland, California. He was climbing an indoor fixed ladder to access the roof in order to perform repair and maintenance on the HVAC system. There was a 3-in.-diameter vertical steel conduit just 1 in. from the left rail of the ladder. Employee #1's left sleeve of his short-sleeve shirt became entangled with an extruding clamp screw on the conduit, and he fell approximately 8 ft onto the concrete floor. Employee #1 sustained multiple fractures of his left rib cage and punctured his left lung. He was transported to Arrowhead Regional Medical Center in Colton, California, where he underwent surgery. A clear width of at least 15 in. was not provided on each side from the centerline of the ladder.		
57	Architect	Walkways	Construction Documents	3A	Reduce trip hazards by providing a non-slip walking surface on walkways and platforms adjacent to open water or exposed to the weather.	[Accident: 170719843]: Employee #1 was building forms on the second deck. He was carrying lumber to the site of an incomplete lumber form when he slipped and fell against a guardrail and injured his left side. Employee #1 was taken to St. Francis Hospital, Santa Barbara, CA, where he was treated and released.		
58	Architect	Egress	Design Development	3A	Design doors to swing away from passageways and platforms when opened.	[Accident: 200623544]: Employee #1 was helping other employees pour a concrete catch basin into a mold. The weight of the wet concrete caused the side door to swing open. The door hit the employee in the head. Employee #1 was killed.		
59	Architect	Permanent Ladders	Design Development	3A	Design permanent ladders to be vertical, or not exceeding 15 degrees forward, and straight throughout their length.	[Accident: 170604524]: Employee #1 fell about 10 feet as he was stepping off a 16-foot aluminum ladder that was set at a flatter pitch than required. He was using the ladder in the combined exhaust and emergency exit in the Wilshire/Western Station of Metro Rail Project B-231. The ladder appeared to be fairly new.		

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60	Architect	Permanent Ladders	Design Development	3A	To accommodate workers of different sizes and to increase safe maneuverability, design permanent ladder cages to extend at least 27 inches, but not more than 30 inches, from the centerline of the ladder step or rung, and not less than 27 inches wide.	[Accident: 170190003]: Employee #1 was climbing a ladder that was fixed to the outside wall of a condominium. He was carrying a 25 lb can of Freon-22 to service an air-conditioning unit that was located about 6 1/2 ft from the edge of the condominium roof, 19 ft 7 in. above ground level. The climbing space width at the top of the ladder was only 10 in. wide each way from the center of the ladder (20 in. total), and the space was obstructed by the tiled roof at the top of the ladder. While climbing the narrow portion of the ladder, Employee #1 fell to the concrete floor and was killed.		
61	Architect	Roof	Preliminary Design	3B	Minimize the roof pitch to reduce the chance of workers slipping off the roof.	[Accident: 170869929]: On June 9, 2001, four employees of a construction company were installing 4-ft by 8-ft sheets of 0.5-in. sheeting with nails and a hammer on the single story home with a 6-to-12 pitch roof. Each employee was on a different part of the roof. Employee #1 had installed three pieces of sheeting starting at the edge of the roof and going up the hip. At approximately 8:15 a.m., Employee #1 was on the east side of the home, starting to install the fourth sheet of sheeting on the north hip over the garage. Employee #1 was approximately 10 ft from the edge of the roof when the piece of sheeting slipped out of his hand. Employee #1 took a step down and back, towards the piece he had just dropped and tried to grab the piece. Employee #1 slipped and slid 10 ft to the edge of the roof and fell off of the structure. Employee #1 hit his head on the ground and received serious head and spinal injuries. Employee #1 was taken to the hospital where he died on June 12, 2001, due to complications from these injuries.	Decreased project quality and diminished design creativity	Identify alternative design features to address the associated safety hazards
62	Architect	Permanent Ladders	Construction Documents	3A	In the design of permanent ladders, design the ladder steps/rungs of individual step/rung ladders to be shaped to prevent slipping off the end of the steps/rungs.	[Accident: 202549705]: On October 29, 2008, Employee # 1 was instructed by his immediate supervisor to conduct roofing operations on top of the commercial building. Employee # 1 was climbing a steel ladder attached to the building and slipped from the sixteenth rung, falling approximately 16 ft to the concrete ground. Employee #1 fractured both heels of his feet and was hospitalized.		

	AEC Design Profession	Project Features	Stage of Design Phase	Tier of Feasibility of the DFCS Measure	*DFCS Measures	*Applicable Safety Incidents	*Potential Impediments to Implementation	Potential Solutions to the Impediments
63	Architect	Stairways / Ramps	Preliminary Design	3B	Provide a covering, or extend the roof line over exterior stairs, ramps, and walkways to reduce the buildup of moss or the accumulation of ice in winter.	[Accident: 14321111]: Employee #1 was moving a 540 lb steel I-beam from one side of a doorway to the other. As he lifted one end of the beam his feet slipped on ice and he fell to the floor. The beam landed on Employee #1's head, killing him.	Decreased project quality and diminished design creativity; Increased Cost	Investigate avenues of potential cost savings on other project features; Identify alternative design features to address the associated safety hazards
64	Architect	Roof	Design Development	3B	To reduce fall hazards, locate skylights away from rooftop mechanical/HVAC equipment.	[Accident: 201145703]: At 9:15 a.m. on August 5, 2004, Employee #1 was working by himself, up on the roof of the library building, which had existing conduit and pipes in addition to several skylights. Employee #1 was making forms for the HVAC units to sit them on. He was working within 6 ft of an existing skylight. Employee #1 accidentally tripped on one of the pipes near the unprotected skylight. He fell and hit the 48-in. by 48-in. skylight. The skylight broke, and Employee #1 fell 11 ft 4 in. down onto the library floor. He fractured his left wrist and was hospitalized over 24-hours. The employer did not ensure that Employee #1 was protected from falling through the skylight by installing a guardrail system around the skylight or by having Employee #1 use a personal fall protection system. There were no direct witnesses to the incident.	Decreased project quality and diminished design creativity; Increased Cost	Investigate avenues of potential cost savings on other project features; Identify alternative design features to address the associated safety hazards
65	Architect	Multi-level Project	Preliminary Design	3A	In multi-story buildings, design each floor plan to have a smaller area than the story below to prevent objects and workers from falling more than one story.	[Accident: 170075329]: On December 16, 2003, an employee fell from the fourth floor balcony of a residential building and was instantly killed.		

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66	Architect	Permanent Ladders	Design Development	3B	To reduce fall hazards, design the top edge of a permanent ladder cage to be a minimum of 42 inches above the top of the platform, or the point of access at the top of the ladder.	[Accident: 201361946]: On March 15, 2003, Employee #1, a pipefitter, and a coworker were working on a heat exchanger on a platform at the Plant 81. The platform was 26 ft above the ground. They were removing blinds from flanges at module A. Employee #1 needed additional tools, located in a tool room at ground level, to complete the work. He also needed to use the restroom. Employee #1 walked to the end of the platform to access the fixed industrial caged ladder. He was later found at the foot of the fixed ladder. It appeared that Employee #1 fell through the cage ladder head first striking the concrete floor. He died at the scene.	Decreased project quality and diminished design creativity	Identify alternative design features to address the associated safety hazards
67	Architect	Stairways / Ramps	Preliminary Design	3A	Locate exterior stairways and ramps away from the north side of the structure to minimize the buildup of slippery moss and ice to minimize fall hazards.	[Accident: 14321111]: Employee #1 was moving a 540 lb steel I-beam from one side of a doorway to the other. As he lifted one end of the beam his feet slipped on ice and he fell to the floor. The beam landed on Employee #1's head, killing him.		
68	Architect	Permanent Ladders	Construction Documents	3A	Design permanent ladders without extraneous attachments that can compromise ascent/descent to prevent injury from punctures or lacerations, and prevent snagging of clothing.	[Accident: 300859188]: At approximately 1:45 p.m. on July 19, 2002, Employee #1, a service technician, was in the electrical control room at the CALFED Bank building in Upland, California. He was climbing an indoor fixed ladder to access the roof in order to perform repair and maintenance on the HVAC system. There was a 3-in.-diameter vertical steel conduit just 1 in. from the left rail of the ladder. Employee #1's left sleeve of his short-sleeve shirt became entangled with an extruding clamp screw on the conduit, and he fell approximately 8 ft onto the concrete floor. Employee #1 sustained multiple fractures of his left rib cage and punctured his left lung. He was transported to Arrowhead Regional Medical Center in Colton, California, where he underwent surgery. A clear width of at least 15 in. was not provided on each side from the centerline of the ladder.		

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69	Architect	Roof	Design Development	3A	Locate roof openings away from the edge of the structure.	[Accident: 201116407]: At approximately 2:30 p.m. on July 25, 2003, Employee #1 was carrying and installing roofing materials on the roof. In order to perform his work, he had to remove the vent dormer cover and put it back when the work was done. He was setting roofing tile down on the roof that was 18-feet high. He started from the top of the roof and walked backward toward the opening from the right to the left. Employee #1 stepped into the roof opening and fell approximately 18 feet. The dormer cover was removed about 15 minutes before the accident. The opening was 14-inches by 14-inches and was 11 feet away from the edge of the roof. Employee #1 sustained a fractured left wrist and a laceration to his right knee. He was taken to Henry Mayo Hospital where he was hospitalized for three days.		
70	Architect	Roof	Design Development	3B	Design a permanent guardrail that surrounds each skylight.	[Accident: 170127344]: Employee #1 was walking across a roof when he stepped on a green fiberglass skylight and fell through the roof onto a pile of bricks. He was killed. There was no guardrail or skylight screen to protect employees from falling through the roof.	Decreased project quality and diminished design creativity; Absence of designer interest and motivation	Identify alternative design features to address the associated safety hazards; Identify alternative design measure to address the associated safety hazards
71	Architect	Walkways	Preliminary Design	3A	Locate exterior walkways and platforms away from the north side of the structure to prevent the buildup of slippery moss and ice due to lack of sun to minimize fall hazards.	[Accident: 14321111]: Employee #1 was moving a 540 lb steel I-beam from one side of a doorway to the other. As he lifted one end of the beam his feet slipped on ice and he fell to the floor. The beam landed on Employee #1's head, killing him.		

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72	Architect	Stairways / Ramps	Design Development	3A	When the top edge of a stairrail system also serves as a handrail, the height of the top edge should be between 36 and 37 in. from the upper surface of the stairrail to the surface of the stair.	[Accident: 201320942]: At approximately 2:40 p.m. on March 29, 2007, an employee, maintenance electrician had been assigned by his supervisor to install a motion sensing spot light at the top of a stair. According to the sole eye witness, a forklift operator, the employee had completed the installation of the light and they were in the process of adjusting the motion detector sensitivity. The employee had just come down from the step ladder, folded it and leaned it against the wall. The forklift operator stated that it seemed like the employee took one step back, lost his balance and went through the rail. Upon arrival of emergency Medical Services, the employee was unconscious. He died on April 1, 2007. The wooden top rail on the stair platform measured 1.25 inches by 2.25 inches. The rail had rounded edges as it was likely manufactured to serve as a stair hand rail. The OSHA construction requirements for wooden top and intermediate rails require a minimum of 2 inches by 4 inch lumber be utilized. The existing rail did not meet the requirements of a standard guard rail. The top rail measured 35.25 inches from the platform surface. Two rugs were placed on the platform effectively lowering that height by another inch. There was no intermediate rail.		
73	Architect	Stairways / Ramps	Design Development	3A	In the design of stairs/rails, provide a minimum clearance of 1-1/2 inches along the top and sides of the top rail.	[Accident: 201080504]: At approximately 1:27 p.m. on June 17, 1997, Employee #1 had just finished lunch and was beginning to descend the stairs. According to Employee #1, she lost her balance as she was closing the door that was located at the top of the stairs. Employee #1 sustained contusions to her head, shoulder and knees when she fell down a flight of six stairs. Employee #1 was not hospitalized. The narrative noted that the required placement, height, and extension of the stair handrail at the top of the stairs were not in compliance with the building code.		

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74	Architect	Egress	Construction Documents	3A	Select door hardware that can keep doors in an open position without props or blocking.	[Accident: 201031242]: Employee #1 was closing and securing an exit door on the second floor of a school building annex. The door led from inside the building to the walkway leading to the second floor of the science building and to the elevator for the employee parking lot. She faced the door, placed both hands on it, and pulled it toward her, but the door was stuck. She then repositioned herself and went behind the door, placed her right hand on the handle and her left hand on the edge of the door, and pushed it hard with her shoulder and hip. The door suddenly came loose and pulled Employee #1 forward, knocking her off balance. As she tried to regain her balance, her right foot tripped over the door stop, and she fell forward, landing on her right knee and bent left leg. Employee #1 suffered a fractured left femur and damage to a previously implanted plastic kneecap, which required surgical repair this incident. The door was a standard sized unit with a glass window. It opened toward the outside and was equipped with a door stop latch to hold the door open.		
75	Architect	Windows	Design Development	3B	Design window sills at a consistent level throughout the project.	[Accident: 200960136]: Employee #1, carpenter, was part of a four-man work crew installing pre-made roof trusses. He was standing on the second floor at the edge of an unprotected 7 ft tall by 6 ft wide picture window opening from which the bottom sill had been removed. Employee #1 was reaching out of the opening for a 2 by 8 that was leaning upright beside it when he fell approximately 14.5 ft through the opening to the sloping ground. He sustained minor lacerations, contusions, and sprains, and was transported to the hospital for treatment and observation. Employee #1 was wearing regular work clothes and shoes, but no other form of personal protective equipment.	Decreased project quality and diminished design creativity	Identify alternative design features to address the associated safety hazards

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76	Architect	Permanent Ladders	Design Development	3A	In the design of permanent ladders and ladder cages, design the bottom of the ladder cage to be between 7 and 8 feet above the point of access to the bottom of the ladder. Flare the bottom of the cage not less than 4 inches between the bottom horizontal band and the next higher band.	[Accident: 202468070]: At approximately 1:05 p.m. on April 3, 2009, Employee #1, a Service Technician for a HVAC company, was servicing an HVAC unit. The HVAC unit was located on the flat roof of an approximately 20 ft warehouse, storage building. Employee #1 was going up the affixed ladder and was approximately 15 ft high, when he lost his balance and fell. He sustained multiple unspecified body fractures. Employee #1 was taken to Providence Holy Cross in Mission Hills, California, where he was hospitalized. The investigation concluded that accident was caused as a result of the affixed ladder not being outfitted with a cage or well.		
77	Architect	Building Materials	Design Development	4B	Ensure that all materials meet the expected environmental and work site conditions.	[Accident: 202075073]: On August 23, 2002, Employee #1 was spraying a highly flammable waterproofing chemical. For some reason, the vapors that were produced from the chemical ignited, causing an explosion. Employee #1 was killed.	Increased Cost; Exposure to liability	Revised contract language; Revised insurance policy; Investigate avenues of potential cost savings on other project features
78	Architect	Stairways / Ramps	Preliminary Design	4A	Design stairways and ramps to run parallel and immediately adjacent to the structure, rather than perpendicular to the structure to minimize weather effects that could result in fall hazards.	[Accident: 170243612]: Employee #1 was descending a flight of stairs from a work platform. The temperature was below freezing and the stairs had been cleared of snow and ice approximately 1 hour earlier, when hot water was poured on them. Employee #1 apparently fell and was found at the base of the stairs. He suffered a fractured skull and died without regaining consciousness. The stair risers were metal, and the pans were partially filled with sand. Guardrails were in place. Employee #1 was wearing rubber boots at the time of the accident. There were no witnesses.		

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79	Architect	Floor Openings	Design Development	4A	Group floor openings together to create one larger opening rather than many smaller openings, as these can be more easily guarded.	[Accident: 202448080]: At approximately 9:00 a.m. on April 30, 2008, Employee #1, a superintendent of ER1 at the jobsite, was working on the second floor of a church construction site in Chino Hills, California. He stepped on a temporary floor cover of one of the floor openings and fell 19 ft 3 in. to the concrete floor. Employee #1 sustained a fatal multiple blunt force trauma. A Medical Engine Number 66 from the Chino Valley Fire Department arrived on scene and provided emergency aid to Employee #1. The ambulance arrived at the scene and transported Employee #1 to the Chino Valley Medical Center, where he was pronounced dead minutes later. The floor opening was 44.5-in. by 48 in. and was designed for vents and ducts of a heating, ventilating and air conditioning system plan. The floor cover was made of two pieces of plywood, approximately 43.875-in. by 24-in. by 0.75-in., butted together and fastened into the 2 by 4 wood support. The 2 by 4s were fastened into the metal closure plate using three 2-in. Tec screws on each of four sides of the hole. A smaller piece of plywood, 8.875-in. by 24-in. by 0.75-in. joined the two pieces of plywood together on top center.		
80	Architect	Roof	Design Development	4A	Avoid the design of elevated exterior structures, equipment, etc. next to roof edges.	[Accident: 200082923]: On February 13, 2007, an employee was installing steel gas lines for a new rooftop HVAC system. The employee was connecting the gas pipes when he backed off the roof. The employee fell approximately 15-ft and dislocated his shoulder.		
81	Architect	Project / Site Orientation	Preliminary Design	4A	Consider area drainage of excavations during construction when developing the plot plan.	[Accident: 767558]: On October 26, 1992, Employees #1 and #2 were in an excavation, working on a water main to remove a 6 in. valve that separated at the valve end, filling the trench with water. Employee #1 drowned and Employee #2 suffered multiple injuries to his chest and leg.		

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82	Architect	Permanent Ladders	Design Development	4A	In the design of permanent ladders and ladder wells, design the bottom of the ladder well between 7 and 8 feet above the bottom of the ladder.	[Accident: 202468070]: At approximately 1:05 p.m. on April 3, 2009, Employee #1, a Service Technician for a HVAC company, was servicing an HVAC unit. The HVAC unit was located on the flat roof of an approximately 20 ft warehouse, storage building. Employee #1 was going up the affixed ladder and was approximately 15 ft high, when he lost his balance and fell. He sustained multiple unspecified body fractures. Employee #1 was taken to Providence Holy Cross in Mission Hills, California, where he was hospitalized. The investigation concluded that accident was caused as a result of the affixed ladder not being outfitted with a cage or well.		
83	Architect	Walkways	Construction Documents	4A	Design walkways and platforms on steel structures to be constructed of nonconductive and slip-resistant materials, such as concrete, wood, or plastic.	[Accident: 201106853]: On May 31, 2005, Employee #1 was performing bolting functions on a steel structure when he slipped and fell 12 ft. He landed on an uneven foundation and suffered major back injuries. Employee #1 was wearing fall protection but was not connected at the time of the incident as he was moving his fall protection gear to another section. He was hospitalized.		
84	Architect	Permanent Ladders	Design Development	4A	In the design of permanent ladders and ladder wells, design the inside face of the well on the climbing side of the ladder to extend between 27 and 31 inches from the centerline of the step/rung.	[Accident: 170190003]: Employee #1 was climbing a ladder that was fixed to the outside wall of a condominium. He was carrying a 25 lb can of Freon-22 to service an air-conditioning unit that was located about 6 1/2 ft from the edge of the condominium roof, 19 ft 7 in. above ground level. The climbing space width at the top of the ladder was only 10 in. wide each way from the center of the ladder (20 in. total), and the space was obstructed by the tiled roof at the top of the ladder. While climbing the narrow portion of the ladder, Employee #1 fell to the concrete floor and was killed.		

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85	Architect	Permanent Ladders	Preliminary Design	4B	Provide a ladder cage or barrier on the back side of permanent ladders.	[Accident: 202468070]: At approximately 1:05 p.m. on April 3, 2009, Employee #1, a Service Technician for a HVAC company, was servicing an HVAC unit. The HVAC unit was located on the flat roof of an approximately 20 ft warehouse, storage building. Employee #1 was going up the affixed ladder and was approximately 15 ft high, when he lost his balance and fell. He sustained multiple unspecified body fractures. Employee #1 was taken to Providence Holy Cross in Mission Hills, California, where he was hospitalized. The investigation concluded that accident was caused as a result of the affixed ladder not being outfitted with a cage or well.	Decreased project quality and diminished design creativity	Identify alternative design features to address the associated safety hazards
86	Architect	Permanent Ladders	Design Development	4B	Design the side rails of through or side-step permanent ladders to extend at least 42 inches above the top level or landing platform.	[Accident: 201361946]: On March 15, 2003, Employee #1, a pipefitter, and a coworker were working on a heat exchanger on a platform at the Plant 81. The platform was 26 ft above the ground. They were removing blinds from flanges at module A. Employee #1 needed additional tools, located in a tool room at ground level, to complete the work. He also needed to use the restroom. Employee #1 walked to the end of the platform to access the fixed industrial caged ladder. He was later found at the foot of the fixed ladder. It appeared that Employee #1 fell through the cage ladder head first striking the concrete floor. He died at the scene.	Decreased project quality and diminished design creativity	Identify alternative design features to address the associated safety hazards
87	Architect	Stairways / Ramps	Construction Documents	4A	Provide cleats on steel or wood ramps, or create grooves on concrete ramps, to help prevent slipping and falling.	[Accident: 202340782]: Employee #1, an Ironworker, was carrying a stair stringer into the building and slipped while walking up a ramp at the entrance. Employee #1 fell against a wood guardrail post and the post gave way at its base and he fell. The guardrails had been removed to the left of the post on that side of the shaft to allow for hoisting, so the post had no bracing towards that side and it tipped and broke in that direction. Employee #1 fell 32 ft into the elevator shaft at the side entrance of the building. Employee #1 suffered fractured ribs, and other blunt impact injuries which were not life threatening. Employee #1 was hospitalized.		

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88	Architect	Permanent Ladders	Design Development	4A	In the design of permanent ladders and ladder cages, keep the inside of the cage clear of projections to ensure safe movement on the ladder.	[Accident: 300859188]: At approximately 1:45 p.m. on July 19, 2002, Employee #1, a service technician, was in the electrical control room at the CALFED Bank building in Upland, California. He was climbing an indoor fixed ladder to access the roof in order to perform repair and maintenance on the HVAC system. There was a 3-in.-diameter vertical steel conduit just 1 in. from the left rail of the ladder. Employee #1's left sleeve of his short-sleeve shirt became entangled with an extruding clamp screw on the conduit, and he fell approximately 8 ft onto the concrete floor. Employee #1 sustained multiple fractures of his left rib cage and punctured his left lung. He was transported to Arrowhead Regional Medical Center in Colton, California, where he underwent surgery. A clear width of at least 15 in. was not provided on each side from the centerline of the ladder.		
89	Architect	Permanent Ladders	Construction Documents	4A	For through-ladder extensions, omit permanent ladder steps/rungs within the extension. Flare the extension side rails to provide between 24 and 30 inches clearance between the side rails.	[Accident: 170723159]: Employee #1 was on an upper level checking an air compressor and a filtering system. He fell from the upper level when he started down the ladder. Employee #1 said that he slipped and lost his footing as he began to come down the ladder. This ladder is a wooden ladder built in place by the contractor when the building was constructed. The side rails of the ladder did not extend 42 inches above the upper level. Employee #1 did not have a good handhold when he attempted to descend the ladder.		

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90	Architect	Permanent Ladders	Design Development	4B	In the design of permanent ladders, if the total length of a climb equals or exceeds 24 feet, provide a cage or well, and multiple ladder sections, each section not to exceed 50 feet, with each ladder section offset from adjacent sections, with a landing platform at intervals of no more than 50 feet.	[Accident: 201042041]: Employee #1 was descending a fixed ladder one-handed while carrying tools in the other hand. He lost his handhold approximately 53 feet above the ground level and fell to the ladder platform. He then went over the platform guardrail backward, struck his head on a metal plate attached to the outside of a lower adjacent stairwell, and fell to the ground. He was killed in the fall.	Absence of Designer Interest and Motivation	Identify alternative design measure to address the associated safety hazards
91	Architect	Permanent Ladders	Construction Documents	4A	In the design of permanent ladders, design horizontal bands to be fastened to the side rails of rail ladders, or directly to the structure for individual-rung ladders.	[Accident: 201158250]: On August 30, 2003, Employee #1 was installing a horizontal expansion joint on the roof of a single story building. He was wearing shoes, gloves, and a back belt with his DeWalt drill and metal snip gun tucked into the belt. There was a fixed metal ladder and at its top was a roof opening. He was descending the ladder with both gloved hands on the ladder. He had not progressed very far when his right hand slipped. He attempted to grab a rung with his left hand and his head hit the edge of the roof opening. He fell 17 ft to the concrete floor and was hospitalized with multiple fractures including his spleen.		
92	Civil / Structural Engineer	Floor Design	Construction Documents	2B	Consider the use of welded wire mesh for slab reinforcing to allow placement of the steel in large sections rather than the placement of many small pieces of reinforcing bars.	[Accident: 171058340]: At approximately 2:40 p.m. on November 3, 1999, Employee #1, a 19-year-old iron worker and rod buster for JD Steel, and a coworker were at the construction site in Salt Lake City, UT. They had just loaded approximately 300 lb of rebar onto the tray portion of a bottle cart and secured it with #9 wire. The coworker went to an upper level to receive the load and begin work. Employee #1 was moving the cart by himself to position it for a crane lift when it tipped over, resulting in a compound fracture of his lower right leg. The cart was not properly loaded, nor was the load adequately secured.	Decreased project quality and diminished design creativity	Identify alternative design features to address the associated safety hazards

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93	Civil / Structural Engineer	Member Design	Design Development	1B	Design structural member depths to allow adequate head room clearance around stairs, platforms, valves, and all areas of egress.	(V-I) [Accident: 170361919]: Employee #1 was climbing onto a catwalk when he stood up under a large steel beam that was 60 1/2 in. above the catwalk and struck his head with enough force to break the suspension in his hard hat. He did not seek medical treatment at the time, but over a year later he began experiencing numbness in his extremities. He was diagnosed with severe stenosis of his neck vertebra and underwent surgery. The steel beam was neither marked nor padded.	Increased Cost	Investigate avenues of potential cost savings on other project features
94	Civil / Structural Engineer	Foundation / Earthwork Design	Preliminary Design	1A	Provide an initial earthwork bench at the level of the work area to allow sufficient room for construction equipment and materials.	(V-I) [Accident: 565069]: Employee #1 was the superintendent of a building construction site. Earth work had just begun on one end and the dirt was excavated and transferred to the other end as fill. Two other contractors had equipment on site performing dirt work by the hour. Employee #1, a qualified operator of heavy equipment, was operating a compactor in a circular clockwise direction coordinating with a small dozer moving the layer of wet dirt around. Employee #1 consistently stayed to the right of the compactor until the last pass when he made a much larger circle and came over behind the dozer. The compactor was at an angle to the edge of the fill dirt and Employee #1 apparently just drove it over the 40 inch high edge of fill dirt. The compactor overturned, crushing Employee #1 to death.		
95	Civil / Structural Engineer	Member Connections	Preliminary Design	1A	Consider the erection process when designing and locating member connections.	(V-I) [Accident: 930727]: At approximately 2:40 p.m. on February 25, 1992, Employees #1 and #2, iron workers, were working on the steel erection of section 2a of the airport office building at the Denver International Airport construction site in Denver, CO. The two workers were connecting a steel beam to a steel column on the seventh level of the building. One worker was seated on the beam that was being connected to the column, while the other worker was standing at the base of the column, at the top of a sheer concrete wall. The base of the column was secured to the concrete wall by temporary welds to an embedded steel plate. When the crew had a problem connecting the beam to the structural steel column, a determination was made by the steel erecting crew to pull the top of the column 1 in. to the north to facilitate the connection. The pull was performed by tensioning a cable guy wire, using a come-along, by applying a fork at the column being connected, and by using a sleeper. While one employee was seated on the beam, the temporary welds at the column base fractured. The column collapsed, and Employees #1 and #2 fell to their death.		

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96	Civil / Structural Engineer	Floor Design	Preliminary Design	1A	For elevated floors, use permanent metal formed decking with concrete fill rather than a concrete slab which requires temporary formwork.	(V-I) [Accident: 14367064]: After Employees #1 through #6 finished a third floor pour of concrete, the southwest bay formwork collapsed. Employees finishing the edge of the bay fell 50 ft to the ground. The three in the center landed on the second floor among concrete and other materials. The six employees sustained broken bones, concussions, and bruises. An engineering study determined that various components of the formwork structure were underdesigned and overloaded.		
97	Civil / Structural Engineer	Member Design	Design Development	1B	In order to allow sufficient walking surface, use a minimum beam width of 6 inches.	(V-I) [Accident: 951434]: Employee #1, who was installing plywood decking on the second floor of a single-family home under construction, was headed to the ladder to go down and get more material. He was walking across a 3 in. wide by 9 ft long steel beam when he slipped and fell 11 ft onto a concrete floor. Employee #1 struck his head and was transported to the hospital, where he died at 2:30 p.m. on October 24, 1997.	Increased Cost (V-SI)	Investigate avenues of potential cost savings on other project features
98	Civil / Structural Engineer	Wall / Masonry Design	Design Development	2B	Minimize the size and weight of masonry blocks.	[Accident: 901892]: At approximately 3:30 p.m. on November 6, 2006, two employees of an excavation subcontractor left the worksite of a two-story warehouse under construction. At that time, the partially braced front masonry wall, (8-in.-wide by 160-ft long by 20-ft high was still standing. Concerned over personal equipment left at the site they returned 30 minutes later to find about 80 ft of the front wall had collapsed. The employees retrieved their gear and were about to leave when they heard the ringing of a cell phone coming from under the pile of concrete blocks. Pulling away several of the 8-in. by 8-in. by 16-in concrete blocks they found Employee #1's body. Employee #1 was pronounced dead at the hospital.	Increased Cost (V-II); Schedule problems and time constraints	Investigate avenues of potential cost savings on other project features; Investigate avenues of decreasing the time needs of other project features

	AEC Design Profession	Project Features	Stage of Design Phase	Tier of Feasibility of the DFCS Measure	*DFCS Measures	*Applicable Safety Incidents	*Potential Impediments to Implementation	Potential Solutions to the Impediments
99	Civil / Structural Engineer	Member Design	Construction Documents	2B	Provide adequate fire protection on all structural framing to protect the members from fire damage.	[Accident: 14415681]: Employee #1, a self-employed welder, was welding rebar onto a steel structure of a building in order to hang brooms. There was a flash and then a fireball, and a series of explosions. Employee #1 was burned on 91 percent of his body. He died approximately two days later.	Exposure to Liability; Increased Cost (V-II); Schedule problems and time constraints (V-II); Designer's lack of safety expertise	Revised contract language; Revised insurance policy; Engage outside safety experts to review designs; Utilize designers with formal safety training; Investigate avenues of potential cost savings on other project features; Investigate avenues of decreasing the time needs of other project features
100	Civil / Structural Engineer	Foundation / Earthwork Design	Preliminary Design	2B	Keep detailed work above grade; simplify all below grade work to reduce worker exposure to cave-ins.	(V-I) [Accident: 202353546]: On March 26, 2004, Employee #1 was digging a footer for the under pinning operation within a trench. The trench dimensions were 5.33-ft in length by 2.25-ft in height by 1.67-ft in depth, and was located between two existing block columns. As he worked from a crouched position within the excavation, a side of trench collapsed covering him with dirt. The weight of the collapsed trench fractured his back. Employee #1 was transported to a medical center for treatment and hospitalized for postoperative care.	Exposure to Liability; Increased Cost (V-II); Schedule problems and time constraints (V-II); Decreased project quality and diminished design creativity (V-II)	Revised contract language; Revised insurance policy; Investigate avenues of potential cost savings on other project features; Investigate avenues of decreasing the time needs of other project features; Identify alternative design features to address the associated safety hazards

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101	Civil / Structural Engineer	Stairs / Railings	Construction Documents	1A	In the design of stairs/railings, design handrails and the top rails of stairrail systems to withstand at least 200 lbs. applied within 2 in. of the top edge in any downward or outward direction and/or 50 lbs/linear foot applied at any point along the top edge.	(V-I) [Accident: 202341889]: At approximately 4:30 p.m. on November 2, 2007, Employee #1 was cleaning up the fire escape on a five-story apartment building after he had finished using it as a work platform for a day of brick pointing. He was walking from the fifth level fire escape to the roof when the guardrail on the stairs broke and he fell approximately 35 ft to the second-floor fire escape. Employee #1 was transported to Beth Israel Hospital, where he was pronounced dead on arrival.		
102	Civil / Structural Engineer	Member Design	Design Development	2B	Use light, precast materials and reliable attachments for elevated, exterior building components.	[Accident: 668194]: On December 13, 1988, after numerous attempts to pour and delays due to cold weather, the pour for level 2 (area A-B-5-6 in particular) began. This area was poured with 4 3/4 in. of concrete (mat included). Approximately two hours later, a 3 in. sheet of insulation was placed, followed by an additional 3 in. slab of concrete (actually closer to 4 in.). As the last of the concrete was being placed by the six concrete workers, the 22 gauge epicore metal deck collapsed. Employees #1 through #5 fell 42 feet while a coworker clung to the building structure. They sustained broken bones and bruises.	Increased Cost (V-II); Schedule problems and time constraints (V-II)	Investigate avenues of potential cost savings on other project features; Investigate avenues of decreasing the time needs of other project features
103	Civil / Structural Engineer	Tank Design	Design Development	1B	When designing tanks, design appropriate tank anchor points on the interior of the tank for construction and maintenance purposes.	(V-I) [Accident: 14406144]: Employee #1 was using a pry bar to position a 6 ft by 20 ft by 1/4 in. steel sheet on the roof of a tank. He fell 43 ft from the roof to the inside floor of the tank. Employee #1 died. He was equipped with a safety harness and a lifeline, but did not have a place to tie off on top of the tank.	Increased Cost; Schedule problems and time constraints	Investigate avenues of potential cost savings on other project features; Investigate avenues of decreasing the time needs of other project features

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104	Civil / Structural Engineer	Floor Design	Preliminary Design	1A	Use a metal deck and concrete fill rather than a slab that requires temporary formwork.	(V-I) [Accident: 966606]: On November 12, 1987, Employee #1, a laborer working with a carpenter crew doing cleanup work after concrete forms had been stripped, was struck on the head and shoulders by falling formwork. The formwork, which consisted of 3/4 in. plywood and 2 in. by 4 in. and 4 in. by 4 in. wood bracing, fell 13 ft 5 in. Employee #1 was hospitalized on that day, lapsed into a coma on November 18, 1987, and died on December 4, 1987, from head injuries complicated by subdural and intracerebral hemorrhaging.		
105	Civil / Structural Engineer	Permanent Ladders	Construction Documents	1A	Design each rung on fixed permanent ladders to be capable of supporting a load of at least 300 lbs. applied in the middle of the rung.	(V-I) [Accident: 201033636]: At approximately 2:25 p.m. on March 7, 2001, Employee #1 was working at a building which was approximately 15 ft high. On the back side of the building, on the north east corner there was a permanent wooden ladder for access to the roof. The ladder had wooden rungs measuring 24 inches in length, 3.5 inches in width, and 3 inches thick. It ran parallel to the wall and was approximately 4 inches away from the wall. The bottom part of the ladder was covered by a sheet metal cover which was locked so people from the ground level could not access the roof top. Employee #1 was to paint over graffiti on a structure on the roof top. According to Employee #1 he was climbing up the ladder and as he reached the last rung it broke loose and he fell onto a parked car. Employee #1 suffered a broken heel, multiple fractures of left wrist, dislocated fingers, and a broken hip. He was hospitalized.		
106	Civil / Structural Engineer	Member Connections	Design Development	2B	Design connections to be welded in the shop rather than in the field.	(V-I) [Accident: 170809404]: Employee #1 was preparing to weld a series of six bar joists into position in a bay of a new building under construction. The bar joists collapsed and Employee #1 fell 28 ft to a concrete floor. Employee #1 later died from his injuries.	Increased Cost; Schedule problems and time constraints	Investigate avenues of potential cost savings on other project features; Investigate avenues of decreasing the time needs of other project features

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107	Civil / Structural Engineer	Member Connections	Design Development	1B	Install belaying bolts on pitched roofs for workers to connect fall restraint systems.	(V-I) [Accident: 171045024]: Employee #1 was employed as a roofer on a commercial construction site. Employee #1 and a coworker, leased employees, were working on a 4:12 pitched roof with their controlling employer. They were organizing materials and rolling out felt in preparation for the application of the roofing material. Fall protection consisted of safety belts with safety lines tied to beams inside open skylights near the peak of the roof. It was rainy and stormy. As Employee #1 was moving the anchor point of his safety line in order to move across the roof, he slipped on the plywood sheeting, fell to his back, and started sliding downward. His new rain gear added to the slide. Since his safety line was not anchored, Employee #1 fell over the eave approximately 28 ft to the ground, fracturing his ankle and injuring his back. Inadequate fall protection led to alleged violations against the controlling employer.	Exposure to Liability; Increased Cost; Schedule problems and time constraints	Revised contract language; Revised insurance policy; Investigate avenues of potential cost savings on other project features; Investigate avenues of decreasing the time needs of other project features
108	Civil / Structural Engineer	Tank Design	Design Development	1B	When designing tanks, provide connection points adjacent to tank and vessel entrances for attachment of a lifeline and safety harness.	(V-I) [Accident: 14406144]: Employee #1 was using a pry bar to position a 6 ft by 20 ft by 1/4 in. steel sheet on the roof of a tank. He fell 43 ft from the roof to the inside floor of the tank. Employee #1 died. He was equipped with a safety harness and a lifeline, but did not have a place to tie off on top of the tank.	Increased Cost; Schedule problems and time constraints	Investigate avenues of potential cost savings on other project features; Investigate avenues of decreasing the time needs of other project features
109	Civil / Structural Engineer	Member Connections	Design Development	1B	Consider using pre-fabricated metal timber fasteners for wood connections instead of end nailing or toe nailing.	(V-I) [Accident: 1001296]: At 4:15 pm on september 8, 1986, five employees were installing trusses an the roof of a grain storage building. The employees had installed 23 of the total of 25 trusses. Employees #1 and 2 were standing on the trusses, bracing them together with 2 by 4's. Two other employees were on ladders at the walls where the trusses rested, nailing the trusses to the walls. A gust of wind blew the trusses over in a domino effect, causing the trusses to fall 23 feet to the ground. Employees #1 and 2 fell with the trusses. They were hospitalized. The trusses had been supported by guy ropes in both directions.	Exposure to Liability; Increased Cost	Revised contract language; Revised insurance policy; Investigate avenues of potential cost savings on other project features

	<b>AEC Design Profession</b>	<b>Project Features</b>	<b>Stage of Design Phase</b>	<b>Tier of Feasibility of the DFCS Measure</b>	<b>*DFCS Measures</b>	<b>*Applicable Safety Incidents</b>	<b>*Potential Impediments to Implementation</b>	<b>Potential Solutions to the Impediments</b>
110	Civil / Structural Engineer	Equipment Support	Design Development	2B	Design ceiling hangers and connections to support anticipated construction live loads including the weight of a worker.	(V-I) [Accident: 567156]: Employees #1, #2, and #3 were installing a fire sprinkler system in a ceiling. The ceiling collapsed, causing the three employees to fall approximately 22 ft to a concrete floor. Employees #1, #2, and #3 suffered multiple broken bones and fractures, and all three were hospitalized. The ceiling they were working on was under construction and could not support the weight of the three employees and their tools.	Increased Cost	Investigate avenues of potential cost savings on other project features
111	Civil / Structural Engineer	Permanent Ladders	Construction Documents	2B	Design permanent fixed ladders for any anticipated loads caused by ice buildup, wind, rigging, and impact loads resulting from the use of ladder safety devices.	(V-I) [Accident: 200211795]: On July 20, 2005, an employee was climbing the fixed ladder of the derrick on a work-over service rig at a well site. The crew was in the process of rigging up when the accident occurred. The employee was climbing the ladder in order to reach the rod basket. At a point approximately 45 to 50 feet above the rig floor, a ladder rung broke off when the employee grasped it and started to pull himself up. The employee fell and was killed.	Exposure to Liability; Increased Cost	Revised contract language; Revised insurance policy; Investigate avenues of potential cost savings on other project features

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112	Civil / Structural Engineer	Member Connections	Design Development	2A	Design column splice connections which are not located at or just below the floor level. This can present safety hazards for construction workers.	[Accident: 200758720]: At approximately 12:30 p.m. on October 7, 2008, An employee was working as a ground man and was assisted by a coworker, also a ground man, where a steel column was being rigged on the ground and was to be hoisted and set in place on a concrete foundation. A rubber tired, Grove RT 745 Crane was being used to assist in the rigging process. A lifting mechanism that consisted of a choker, shackle, ropes and a cotter pin was being used. Based on the task at hand, the ground man would have attached the hinge pin through the shackle and then through the column splice lug hole and back through the other side of the shackle hole. A cotter pin would then be placed through the end tip of the hinge pin. A nylon rope would also be attached to the handle side of the hinge pin. Another nylon rope would be connected to the cotter pin so that when the steel column was erected, the rope would be pulled, the cotter pin would fall out and then the rope connected to the hinge pin would be pulled and that portion of the rigging apparatus would fall to the ground. The investigation revealed that during the initial set up, the cotter pin was placed down side up; so if the rope is pulled, the pin would not pop out. The coworker signaled the crane operator to begin the lift. As the column was being raised, the ground man noticed the inverted cotter pin and motioned the crane operator to stop. At that time, the ground man adjusted the cotter pin and motioned the crane operator to continue the lift. The rigging connection released from the column shortly after the column was hoisted to about a 45 degree angle. The mechanism had been placed under and not through the splice lug hole. The employee was killed when a 44.2 foot steel column, weighing about 2,300 lbs fell on him. The coworker stated that he did not notice that the rigging connection was not connected through the splice lug hole on the steel column. There was no work rule in place to address specific rigging procedures when erection operations involved rigging steel columns and beams hoisting said items. Also, there was no documentation that employees who performed rigging work were trained on implementing safe rigging connections when steel columns were being hoisted and set in place. The weather at the time of the accident was clear and sunny with no precipitation.		

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113	Civil / Structural Engineer	Member Design	Preliminary Design	2B	To reduce worker exposure to falls, use pre-fabricated members for work over water, railways, roads, etc.	(V-I) [Accident: 201121225]: At approximately 9:00 a.m. on August 24, 1998, Employee #1 was installing plywood panel formwork for an overhead light railway at an airport. Employee #1 walked across existing shoring that was lightly nailed but not properly secured. The nails pulled out under the Employee #1's weight and he fell about 4 ft to the bottom of the concrete channel of the railroad bed. Employee #1 suffered impact injuries to his head and back and was hospitalized.	Exposure to Liability; Increased Cost	Revised contract language; Revised insurance policy; Investigate avenues of potential cost savings on other project features
114	Civil / Structural Engineer	Foundation / Earthwork Design	Design Development	2B	Avoid designing piles at angles flatter than 4:12 (horizontal:vertical).	(V-I) [Accident: 14369292]: Employee #1 was one of four pile drivers working with a crane rig, boom hammer, and leads. They were using a Lima 80T crawler tractor crane, #3284, 700 HC to drive 30 ft long, 10 in. by 1/2 in. I-beams into an excavation that was 53 in. deep by 15 ft wide by 31 ft long. Rainwater in the pit was causing the leads to set incorrectly. The water was forcing the leads and plate to walk (move) toward the back (north) side of the excavation. The chain/binder was removed from the leads and the pile drivers prior to moving (walking) the crane rig in (northward) to set up the pile hammer and boom correctly for continued vertical driving. The pile drivers and the foreman were to hold the leads steady. At that time, apparently, the hammer came down on the pile and struck it at an angle. This caused the lower leads to swing and twist out and around and strike Employee #1 in the upper front leg area. He sustained crushing injuries to his lower extremities and died.	Exposure to Liability	Revised contract language; Revised insurance policy
115	Civil / Structural Engineer	Wall / Masonry Design	Design Development	2B	Use masonry blocks of consistent size and shape.	[Accident: 14531313]: Employees #1, #2, and #4, all laborers, and Employee #3, an operating engineer, were working on a construction project when the coffee truck arrived at approximately 9:30 a.m. The approximately 25 site workers gathered in the vicinity of the coffee truck for a break. They congregated around the base of an approximately 60 ft long by 23 ft high concrete block wall. The first 10 vertical ft of the wall was composed of 8 in. by 8 in. concrete blocks, and the remainder was built of 12 in. by 8 in. by 16 in. blocks. No masonry work had been done on the block wall for approximately one week. The wall started to fall in, and there was a loud noise when the it struck and pushed over a metal tubular welded-frame scaffold that was standing adjacent to the wall. All the workers scrambled to safety except for Employees #1 through #3, who were trapped under the debris and killed. Employee #4 ran and fell to the ground just beyond the downed block wall, injuring his left knee and calf.	Decreased project quality and diminished design creativity	Identify alternative design features to address the associated safety hazards

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116	Civil / Structural Engineer	Floor Design	Design Development	2B	Design the top layer of floor slab reinforcing to be spaced at no more than 6 inches on center each way to provide a stable, continuous walking surface before placement of the concrete.	[Accident: 125890947]: At approximately 7:15 a.m. on June 20, 1997, Employee #1, a construction supervisor, lost his balance and fell onto some uncapped rebar. His upper right leg became impaled, resulting in lacerations and a puncture wound. Coworkers lifted him off the rebar, rendered first aid, and called paramedics. Employee #1 was transported to the hospital, where he was treated for three days. On June 30, 1997, he returned to work on restricted duty.	Increased Cost; Schedule problems and time constraints	Investigate avenues of potential cost savings on other project features; Investigate avenues of decreasing the time needs of other project features

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117	Civil / Structural Engineer	Member Connections	Design Development	2A	Locate column splices at approximately 4 feet above the finished floor level to facilitate safe and accessible splice work.	[Accident: 200758720]: At approximately 12:30 p.m. on October 7, 2008, An employee was working as a ground man and was assisted by a coworker, also a ground man, where a steel column was being rigged on the ground and was to be hoisted and set in place on a concrete foundation. A rubber tired, Grove RT 745 Crane was being used to assist in the rigging process. A lifting mechanism that consisted of a choker, shackle, ropes and a cotter pin was being used. Based on the task at hand, the ground man would have attached the hinge pin through the shackle and then through the column splice lug hole and back through the other side of the shackle hole. A cotter pin would then be placed through the end tip of the hinge pin. A nylon rope would also be attached to the handle side of the hinge pin. Another nylon rope would be connected to the cotter pin so that when the steel column was erected, the rope would be pulled, the cotter pin would fall out and then the rope connected to the hinge pin would be pulled and that portion of the rigging apparatus would fall to the ground. The investigation revealed that during the initial set up, the cotter pin was placed down side up; so if the rope is pulled, the pin would not pop out. The coworker signaled the crane operator to begin the lift. As the column was being raised, the ground man noticed the inverted cotter pin and motioned the crane operator to stop. At that time, the ground man adjusted the cotter pin and motioned the crane operator to continue the lift. The rigging connection released from the column shortly after the column was hoisted to about a 45 degree angle. The mechanism had been placed under and not through the splice lug hole. The employee was killed when a 44.2 foot steel column, weighing about 2,300 lbs fell on him. The coworker stated that he did not notice that the rigging connection was not connected through the splice lug hole on the steel column. There was no work rule in place to address specific rigging procedures when erection operations involved rigging steel columns and beams hoisting said items. Also, there was no documentation that employees who performed rigging work were trained on implementing safe rigging connections when steel columns were being hoisted and set in place. The weather at the time of the accident was clear and sunny with no precipitation.		

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118	Civil / Structural Engineer	Member Connections	Design Development	1A	Use a single size, or a minimum number of sizes possible, of bolts, nails, and screws. If more than one size is required, specify sizes which vary greatly and are easily distinguishable.	(V-I) [Accident: 977314]: A 50 foot long steel girder, weighing 3500 pounds, was hoisted into place by a hydraulic boom crane. One end was bolted through the web to a flange that had been welded to a vertical beam. Two of the three 3/4 inch bolts and nuts were installed. The girder was supported approximately 12 feet from the other end by a vertical column which was shimmed one inch off the concrete floor by two 7/8 inch high nuts and 1/8 inch thick washers opposite each other, and 90 degrees from the two half inch bolts which protruded from the concrete floor. The bolts were set through 3/4 inch holes in the bottom plate. The nuts were wrench-tightened with one washer on each bolt. One ironworker, who was straddling the girder, had loosely fitted one of two 3/4 inch bolts and nuts to secure the girder to the column. The crane support was slacked off. The girder was "shaken" by the ironworker to see if it would support itself. The load was then unhooked by a second ironworker standing mid-way on the girder. After the load was disconnected, Employee #1 sustained severe head injuries when the column/girder fell approximately 20 feet to the floor. Employee #1 was leaning over trying to connect a second bolt when the beam fell.		
119	Civil / Structural Engineer	Foundation / Earthwork Design	Preliminary Design	2B	Take heave into account when locating piles.	[Accident: 201502697]: An employee, employed as a pile driver apprentice, sustained a serious injury to his right foot, middle toe, when his foot was caught by a concrete pile being driven. The employee was in the process of removing the choker from a pile that was being driven, when the soil at the base of the pile sunk. The employee's foot was caught by the moving pile and he was pinned between the pile and earth wall. The employee as a result of the injury suffered a secondary infection to his middle toe which resulted in amputation.	Designers' lack of safety expertise; Absence of designer interest and motivation	Engage outside safety experts to review designs; Utilize designers with formal safety training; Identify alternative design measure to address the associated safety hazards
120	Civil / Structural Engineer	Wall / Masonry Design	Preliminary Design	2B	Consider other materials such as precast concrete or lighter weight, stick or modular components instead of bricks and blocks.	(V-I) [Accident: 823229]: Employee #1 was on the work platform of a three brick high scaffold. He has laid three courses of brick on an angle iron. As Employee #1 bent down to obtain more brick from the stock platform, the three courses of brick fell 18 in. off the iron angle beam and four bricks struck him on the back of his shoulder. He sustained bruises to his upper shoulder and was hospitalized.	Designers' lack of safety expertise	Engage outside safety experts to review designs; Utilize designers with formal safety training

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121	Civil / Structural Engineer	Permanent Ladders	Construction Documents	1A	Design permanent fixed ladders to be sufficiently strong to be capable of supporting at least two loads of 250 lbs. each concentrated between any two consecutive attachments.	(V-I) [Accident: 171058837]: Employees #1 and #2 were climbing a fixed ladder to the roof of a building. Employee #1 was in the lead when the ladder snapped and he fell 25 ft. Employee #2 fell 8 ft. Both workers sustained injuries that required hospitalization.		
122	Civil / Structural Engineer	Member Connections	Design Development	2B	Use a minimum of two bolts, nails, or screws per connection.	(V-I) [Accident: 14424352]: Some employees were erecting lightweight steel I beams for a floor that was 54 ft high. The employees were on the third-floor level at the northeast corner of a 12-story building under construction. As employee #1 disengaged a tandem lift hook that had become hooked on the lower flange of the beam he was on, a connector fell to the ground from a beam that was not connected by at least two bolts. Employee #1 removed the choker sling from the beam and was placing the sling into a lower empty hook of a stringer while a crawler tower crane was booming away from the steel. The wind moved a load line and stringer into the beam, causing another lower empty hook to engage the lower flange. Employee #1 tried to disengage the hook; and, when the hook became free, the beam moved and caused him to fall to the ground. Employee #1 died of injuries sustained in the fall. Nets were not installed at the lower levels. Tag lines were not used, and the minimum two bolts were not installed at each end connection of the beams.	Decreased project quality and diminished design creativity	Identify alternative design features to address the associated safety hazards

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123	Civil / Structural Engineer	Foundation / Earthwork Design	Design Development	2B	On spread and continuous footings, and mat foundations, design the top layer of reinforcing steel to be spaced at no more than 6 inches on center, each way, to provide a continuous, stable walking surface before the concrete is poured.	(V-I) [Accident: 125890947]: At approximately 7:15 a.m. on June 20, 1997, Employee #1, a construction supervisor, lost his balance and fell onto some uncapped rebar. His upper right leg became impaled, resulting in lacerations and a puncture wound. Coworkers lifted him off the rebar, rendered first aid, and called paramedics. Employee #1 was transported to the hospital, where he was treated for three days. On June 30, 1997, he returned to work on restricted duty.	Exposure to Liability; Increased Cost	Revised contract language; Revised insurance policy; Investigate avenues of potential cost savings on other project features
124	Civil / Structural Engineer	Tank Design	Design Development	2B	When designing tanks, provide a guardrail along the perimeter of the tank roof.	[Accident: 201631819]: At approximately 3:30 p.m. on April 13, 2001, Employee #1 was finishing work on top of an 18-foot-high tank which had no guardrails around the top. He stepped from the top of the tank onto a purlin (part of the roof truss system). The purlin gave way under the weight of Employee #1, subsequently sending him to the floor. Employee #1 sustained fractures to his pelvis and left arm, lacerations, and contusions. He was hospitalized for his injuries.	Increased Cost	Investigate avenues of potential cost savings on other project features
125	Civil / Structural Engineer	Foundation / Earthwork Design	Design Development	3A	Design wood piles such that they are below the water table, and do not specify creosote for protection of the piles from environmental deterioration.	[Accident: 170155246]: Employee #1 was working as a crew member cutting and handling wood treated with creosote. Employee #1 was wearing eye protection, gloves, a long-sleeved shirt, and other protection. Employee #1 wiped the sweat from his face with his gloved hand. Creosote on the glove burned his face. The burn was not considered serious, according to CAL/OSHA. After interviewing coworkers, no safety violation was found, although an information memo was issued.		

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126	Civil / Structural Engineer	Member Connections	Design Development	3A	Design beam-to-column double-connections to have full support for the beams during the connection process.	[Accident: 14424352]: Some employees were erecting lightweight steel I beams for a floor that was 54 ft high. The employees were on the third-floor level at the northeast corner of a 12-story building under construction. As employee #1 disengaged a tandem lift hook that had become hooked on the lower flange of the beam he was on, a connector fell to the ground from a beam that was not connected by at least two bolts. Employee #1 removed the choker sling from the beam and was placing the sling into a lower empty hook of a stringer while a crawler tower crane was booming away from the steel. The wind moved a load line and stringer into the beam, causing another lower empty hook to engage the lower flange. Employee #1 tried to disengage the hook; and, when the hook became free, the beam moved and caused him to fall to the ground. Employee #1 died of injuries sustained in the fall. Nets were not installed at the lower levels. Tag lines were not used, and the minimum two bolts were not installed at each end connection of the beams.		
127	Civil / Structural Engineer	Foundation / Earthwork Design	Design Development	3A	In designing the terrain and road layout, provide a smooth transition between the road and shoulder.	[Accident: 311212864]: On October 12, 2007, Employee #1 was driving a Gradall material handler on a secondary gravel road when the outside tires ran onto the soft shoulder. As the vehicle started to go down the embankment, he was ejected. Employee #1 was killed when the Gradall rolled over on top of him.		
128	Civil / Structural Engineer	Equipment Support	Design Development	3A	When designing supports for overhead equipment, include the weight of workers in the design calculations.	[Accident: 14257406]: At about 2:30 p.m. on February 24, 1984, Employee #1 was installing an angle iron frame for a rooftop exhaust support. The built-up roof was already in place, and he was working from inside the building, using a sheet metal air duct as a work platform. Employee #1 was standing on a 50-in.-long section of duct (the end piece of a horizontal run), which cantilevered approximately 47.5 in. from a support hanger. The only support for the cantilever duct section was a "pocket lock" joint that connected the duct sections to the hanger, which was located about 2.5 in. in front of the joint. The added weight from Employee #1 caused the pocket lock joint to separate, and the duct fell to a concrete floor. Employee #1 also fell, reportedly landing on his head and side. He was taken to Moses Cone Hospital in Greensboro, NC; the hospital reported his death to job site officials at about 5:00 p.m. the same day. Employee #1 was not wearing personal fall protection equipment.		

	AEC Design Profession	Project Features	Stage of Design Phase	Tier of Feasibility of the DFCS Measure	*DFCS Measures	*Applicable Safety Incidents	*Potential Impediments to Implementation	Potential Solutions to the Impediments
129	Civil / Structural Engineer	Member Design	Design Development	3B	Design columns with holes in the web at approximately 21 and 42 inches above the floor level to provide built-in safe support locations for lifelines and guardrails.	[Accident: 200200475]: Employee #1 was working on the seventh floor of an office building under construction. Preparations were underway for the floors to be formed and poured. Employee #1 was on the perimeter edge on the east side of the structure, patching and filling post tensioning holes. He was on the exterior side of an outer column, between floors, when he fell approximately 80 ft to the ground. Employee #1 was killed. At the time of the accident, he was wearing a safety harness and lifeline. There were no witnesses on the seventh floor and the superintendent on the second floor, who saw something drop, initially thought that some trash had been thrown over the side of the building. He went to investigate and saw Employee #1 lying on the ground. Another coworker, who was on the ground about 100 ft away, was facing the building and saw Employee #1 fall.	Decreased project quality and diminished design creativity	Identify alternative design features to address the associated safety hazards
130	Civil / Structural Engineer	Foundation / Earthwork Design	Preliminary Design	3A	Minimize the amount of excavations required in backfilled or other loose soil, and where there are vibrations from railroads, highway traffic, or large machines.	[Accident: 170830715]: Employee #1, a laborer, was placing two 2 in. and one 6 in. plastic pipes in the bottom of a 7 ft deep, 6 ft wide, approximately 30 ft long trench cut in class C soil at the edge of an access road with occasional heavy truck traffic. The area had been previously backfilled with mostly sand and layered gravel in soil and an asphalt pavement top. A spoil pile was within 2 ft of the edge. Inappropriate and inadequate partial benching was attempted. A sedimentation pond was approximately 15 ft from the side of the excavation. The trench caved in and Employee #1 was buried to shoulder height in a half-vertical position. He sustained back injuries and body trauma and was hospitalized, but will recover. The personnel performing inspections did not meet "competent person" criteria and hazard recognition training was not specific for the work. Employee #1 was wearing a hard hat.		
131	Civil / Structural Engineer	Member Design	Construction Documents	3A	Use a single, or multiple, curtain(s) of welded wire mesh for reinforced concrete walls and columns to allow placement of the reinforcing in large sections rather than many small pieces.	[Accident: 171058340]: At approximately 2:40 p.m. on November 3, 1999, Employee #1, a 19-year-old iron worker and rod buster for JD Steel, and a coworker were at the construction site in Salt Lake City, UT. They had just loaded approximately 300 lb of rebar onto the tray portion of a bottle cart and secured it with #9 wire. The coworker went to an upper level to receive the load and begin work. Employee #1 was moving the cart by himself to position it for a crane lift when it tipped over, resulting in a compound fracture of his lower right leg. The cart was not properly loaded, nor was the load adequately secured.		

	AEC Design Profession	Project Features	Stage of Design Phase	Tier of Feasibility of the DFCS Measure	*DFCS Measures	*Applicable Safety Incidents	*Potential Impediments to Implementation	Potential Solutions to the Impediments
132	Civil / Structural Engineer	Member Design	Design Development	3A	Design special attachments or holes in structural members at elevated work areas to provide permanent, stable connections for supports, lifelines, guardrails, scaffolding or lanyards.	[Accident: 200200475]: Employee #1 was working on the seventh floor of an office building under construction. Preparations were underway for the floors to be formed and poured. Employee #1 was on the perimeter edge on the east side of the structure, patching and filling post tensioning holes. He was on the exterior side of an outer column, between floors, when he fell approximately 80 ft to the ground. Employee #1 was killed. At the time of the accident, he was wearing a safety harness and lifeline. There were no witnesses on the seventh floor and the superintendent on the second floor, who saw something drop, initially thought that some trash had been thrown over the side of the building. He went to investigate and saw Employee #1 lying on the ground. Another coworker, who was on the ground about 100 ft away, was facing the building and saw Employee #1 fall.		
133	Civil / Structural Engineer	Foundation / Earthwork Design	Preliminary Design	3A	To reduce the potential of cave-ins, consider using a pile or caisson foundation system which does not require excessively deep excavations and allows construction work to be performed above grade.	[Accident: 950766]: At approximately 1:29 p.m. on April 21, 1994, Employee #1 and four other employees were digging a foundation wall trench that was 16 inches wide, 8 feet deep, and 30 feet long. The walls were near vertical and unshored. The spoils pile was located at the back edge. It was the intent of the backhoe operator not to let the employees in the trench any deeper than 3 feet. When the backhoe operator observed that the employees were in the deeper section, he told them to get out. Employee #1 hesitated, the wall started to collapse, and he ran in the direction of the falling debris. He became engulfed when the remaining portion of the wall collapsed. Employee #1 died of his injuries.		
134	Civil / Structural Engineer	Member Design	Design Development	3A	Design pre-fabricated members to be of one size and shape, or make them easily distinguishable to avoid incorrect placement.	[Accident: 170824056]: Employee #1, a foreman, and Employee #2, a carpenter's helper, were constructing six townhouses. They were using a mobile hydraulic crane to set prefabricated walls, floors, and roofs. The third floor was set onto two exterior walls, then braced and secured, and an interior wall package was set onto the floor in the center. The employees went to check on the bracing below the third floor. While they were on the second floor, they heard a crack and the third floor broke and fell. Employee #1 sustained a minor scratch on his nose, and Employee #2 sustained a bruise on his left arm. The foreman stated that he must have overlooked the manufacturer's recommendation for two separate support posts constructed out of three 2 by 4s instead of the one double 2 by 4 post they had used.		

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135	Civil / Structural Engineer	Foundation / Earthwork Design	Design Development	3A	To prevent cave-ins due to vibration of loose soil, avoid the use of driven piles in deep excavations in areas of loose or backfilled soil.	[Accident: 14425177]: At approximately 1:45 p.m. on March 31, 1994, Employee #1, three coworkers, and one state inspector were working inside an excavation measuring 40 ft long, 20 ft wide, and 8 ft deep. A pile hammer was driving an H-pile into the ground of left Bent #3 for the Highway 370 bridge. Employee #1 was marking the pile penetrations when the wall behind him, under the asphalt roadway, collapsed and pinned him against the pile driver leads and hammer. Employee #1 died.		
136	Civil / Structural Engineer	Foundation / Earthwork Design	Preliminary Design	4A	Design the project such that the cut and cover method can be used for excavation rather than tunneling.	[Accident: 202540449]: On December 24, 2008, Employee #1 was digging with a jackhammer along the wall of an excavation over 5 ft. Initially, the dirt started to fall and then a section of 1.5 ft by 2 ft of compacted soil fell on his right leg, resulting in the fracture of his right tibia and femur. The wall of the excavation was not protected from cave-ins by an adequate protective system. Employee #1 was transported to a medical center and was hospitalized for approximately 12 days, requiring surgery.		
137	Civil / Structural Engineer	Foundation / Earthwork Design	Preliminary Design	4A	In embankments directly adjacent to the road edge, provide an initial bench at the road grade to provide room for crews to work.	[Accident: 201407665]: On June 22, 2006, Employee #1 was working in construction for the Genesee County Road Commission, when he was struck by a motor vehicle. He sustained bruises, contusions, and abrasions, and he was killed.		
138	Civil / Structural Engineer	Member Design	Design Development	4B	Design rebar such that it can be assembled on the ground and erected in large sections.	[Accident: 171058340]: At approximately 2:40 p.m. on November 3, 1999, Employee #1, a 19-year-old iron worker and rod buster for JD Steel, and a coworker were at the construction site in Salt Lake City, UT. They had just loaded approximately 300 lb of rebar onto the tray portion of a bottle cart and secured it with #9 wire. The coworker went to an upper level to receive the load and begin work. Employee #1 was moving the cart by himself to position it for a crane lift when it tipped over, resulting in a compound fracture of his lower right leg. The cart was not properly loaded, nor was the load adequately secured.	Schedule problems and time constraints	Investigate avenues of decreasing the time needs of other project features

	AEC Design Profession	Project Features	Stage of Design Phase	Tier of Feasibility of the DFCS Measure	*DFCS Measures	*Applicable Safety Incidents	*Potential Impediments to Implementation	Potential Solutions to the Impediments
139	Civil / Structural Engineer	Foundation / Earthwork Design	Preliminary Design	4A	Design in regularly spaced benches on embankments to stop loose rock from falling down to the work site.	[Accident: 170378285]: At approximately 11:30 a.m. on September 1, 1995, Employee #1 was working on a sloped embankment at the side of Highway 101. A ditch digging machine above him was being used by another employer to dig a trench. An 8 in. diameter boulder fell and struck Employee #1 on the head and neck, bruising him. He was taken to the hospital for a check-up and then released.		
140	Civil / Structural Engineer	Member Design	Design Development	4A	Design permanent connection points for lifeline and guardrail attachment on columns, which do not protrude into working areas.	[Accident: 200200475]: Employee #1 was working on the seventh floor of an office building under construction. Preparations were underway for the floors to be formed and poured. Employee #1 was on the perimeter edge on the east side of the structure, patching and filling post tensioning holes. He was on the exterior side of an outer column, between floors, when he fell approximately 80 ft to the ground. Employee #1 was killed. At the time of the accident, he was wearing a safety harness and lifeline. There were no witnesses on the seventh floor and the superintendent on the second floor, who saw something drop, initially thought that some trash had been thrown over the side of the building. He went to investigate and saw Employee #1 lying on the ground. Another coworker, who was on the ground about 100 ft away, was facing the building and saw Employee #1 fall.		
141	Civil / Structural Engineer	Member Connections	Design Development	4A	Provide pin-hole or bolted connections on beams and columns to create proper alignment and stability immediately after placement of the members.	[Accident: 170758155]: At approximately 9:15 a.m. on November 20, 1995, Employee #1 and a coworker were erecting I-beams between concrete columns. The employees were 33 ft high, sitting on a previously installed I-beam and one of the columns. A gantry RT 58 crane and a single sling centered on the I-beam were used to lift an I-beam into position. While sitting on the column, Employee #1 made a 1 1/4 in. tack weld to tack one end of the I-beam to a weld plate on the column. The I-beam was not level so Employee #1 got onto the installed I-beam to try to level the I-beam to complete the weld. When Employee #1 tried to shake the I-beam to straighten it, the tack weld broke, and the I-beam tilted to a vertical position. Employee #1 held onto the beam for a second, then fell 33 ft to the concrete surface, striking his head. He was killed. Employee #1 was wearing a safety belt and lanyard, but was not tied off. No other fall protection was in use.		

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142	Mechanical Engineer	Pressurized Equipment	Design Development	1B	Provide relief valves for heat exchangers and chiller refrigerant.	(V-I) [Accident: 14371967]: Employees #1 through #7 were injured by flying debris when a heat exchanger ruptured while being pneumatically pressure tested. The unit was enclosed in a high pressure test room, which failed to contain the blast. Evidence indicates that a high pressure air line was mistakenly connected to a low pressure stream that was then overpressurized. Employees #1, #2, and #3 were hospitalized.	Exposure to Liability; Absence of designer interest and motivation	Revised contract language; Revised insurance policy; Identify alternative design measure to address the associated safety hazards
143	Mechanical Engineer	Underground Equipment	Preliminary Design	2B	Locate underground equipment in an area easily accessible by excavation. Allow sufficient area around the excavation for stockpiling the soil.	[Accident: 170210280]: On the morning of June 29, 1992, Employee #1, of Rumsey & Sons, and five coworkers were installing a water main. After they installed a hydrant and 22 feet of 8 in. ID pipe, the trench measured 6 ft 8 in. At approximately 10:15 a.m., Employee #1 was standing bent over, somewhere around the end of the pipe, facing north. He was cleaning out the pipe or soaping the pipe end. The east side of the excavation started to cave in. A coworker yelled to look out and another coworker jumped up, but the collapsing soil caught him at the knees. Employee #1 started to get up and looked west. Soil and asphalt hit him and pushed him against the west side. He was completely covered by the cave-in. He was uncovered by other employees. EMS and police arrived on scene. Employee #1 was taken to McPherson Hospital and pronounced dead on arrival. One serious and two willful citations were issued.	Increased Cost; Schedule problems and time constraints	Investigate avenues of potential cost savings on other project features; Investigate avenues of decreasing the time needs of other project features
144	Mechanical Engineer	Protective / Safety Guards	Construction Documents	1B	Provide guards around equipment (fan inlets/outlets and exhaust ports) to protect workers from moving parts.	(V-I) [Accident: 200820363]: Employee #1, an oiler, was checking the fluid levels in a high head pump when his loose-fitting rain jacket became caught by the blades of a large fan. He was pulled into the unguarded fan blades and sustained multiple lacerations. Employee #1 was killed.	Exposure to Liability; Increased Cost	Revised contract language; Revised insurance policy; Investigate avenues of potential cost savings on other project features
145	Mechanical Engineer	Equipment Location	Design Development	2B	Ensure that all equipment enclosures meet hazardous location classification requirements.	(V-I) [Accident: 14399497]: On January 21, 1985, Employee #1, a painter, was spray painting lacquer in an enclosed area. He was burned over 55% of his body when the paint fumes were ignited by a gas hot water heater. He died on February 7, 1985.	Increased Cost	Investigate avenues of potential cost savings on other project features

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146	Mechanical Engineer	Equipment Controls	Design Development	2B	Locate valves such that they can be operated easily, or so that a standard type of operating device can be installed. Consider using easily-accessible remote valve operators.	(V-I) [Accident: 200370872]: At approximately 2:45 p.m. on January 11, 2000, Employees #1 through #3 were working on a steam line that was connected to a phosphorus storage tank. All insulation had been removed from the steam line and it was very similar in appearance to a phossey water line located nearby. After Employee #1 had cut loose a control valve, he attempted to make another cut in the regular water line, but cut the phossey water line instead. Employee #1 turned the valve with a pipe wrench to what he thought was the 'off' position, but instead turned it to full flow. The phossey water sprayed onto his hands, abdomen and legs. He was tied off to the tank and could not break free until Employee #3 finally unhooked his lanyard and got him to the water jump tank. Employee #1 suffered serious chemical burns. Employees #2 and #3 were also exposed to the phosphorus solution, and all three employees were hospitalized. Citations were issued for inadequate personal protective equipment, inadequate training, and inadequate means to notify employees of an imminent hazard.	Increased Cost; Schedule problems and time constraints	Investigate avenues of potential cost savings on other project features; Investigate avenues of decreasing the time needs of other project features
147	Mechanical Engineer	Equipment Controls	Design Development	1A	Allow adequate access to equipment controls for ease of operation.	(V-I) [Accident: 825505]: At approximately 11:30 pm on July 24, 1987, a 4 inch diameter strainer ruptured causing a high pressure steam leak. The strainer was part of a steam pipeline which enters the boiler room of the i.b.m. building. The steam leak was located in an underground vault, which is connected to a tunnel leading into the boiler room of the i.b.m. building. The vault has a removable metal grate top from which a work ladder is used to gain access into the vault. The night crew had replaced the ruptured strainer with a new one. In the early morning hours of the next day (7/25), several employees had trouble adjusting the regulator pilot valves. The pilot valves control the steam pressure flow into the i.b.m. building. That morning at about 6 am, employee #1 was called in to take over the adjustments of the pilot valves. From 6:45 to 9 am he was working by himself. At approximately 9 am the 4 inch strainer ruptured again. He hurried into the tunnel trying to escape the steam. He did not make it to safety. His body was found in the tunnel about 30 feet from the doorway leading into the boiler room. The vault was 16 feet, 8 inches long, 8 feet wide and 8 feet, 11 inches high. The tunnel was 223 feet, 7 inches long, 6 feet, 10 inches wide and 10 feet high.		

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148	Mechanical Engineer	Relief Valves	Design Development	1B	Ensure that safety relief valves exhaust and drain away from passageways and work areas.	(V-I) [Accident: 170572457]: At approximately 4:00 p.m. on February 22, 1998, Employee #3, a chemical operator, added the wrong catalyst for a reaction, causing overpressurization of the vessel. The safety relief valve opened, releasing vapors and liquid that settled to the ground near a roll-up door. Employees #4 through #12, contractors doing pipe fitting work on an adjacent reactor, were exposed to the vapors as they left the area. Employee #1 was exposed during clean-up and Employee #2 was performing housekeeping duties near the roll-up doors. Employees #1 through #12 were transported to the hospital complaining of nausea, dizziness, and chest tightness—all symptoms of acute chemical exposure. They were treated and released. The employer was cited for violations of T8CCR 1910.119, T8CCR 1910.120, and T8CCR 1910.1200.	Increased Cost	Investigate avenues of potential cost savings on other project features
149	Mechanical Engineer	Equipment Location	Design Development	1A	To reduce fall hazards, locate rooftop mechanical/HVAC equipment away from the edge of the structure and where not possible, use railings.	(V-I) [Accident: 170700595]: At about 10:00 a.m. on April 22, 1994, Employee #1, an iron worker, was on the roof of a building to install a metal foundation for an HVAC unit. The work was conducted near the roof edge, which had a 16-inch high parapet. He fell backward over the parapet and then fell about 37 ft to a concrete sidewalk. Employee #1 was hospitalized with multiple fractures.		
150	Mechanical Engineer	Pressurized Equipment	Design Development	2A	Provide a safety valve on the discharge of positive displacement type air compressors and multi-stage centrifugal compressors to avoid overpressurization in case the discharge valve is closed.	(V-I) [Accident: 14491922]: At about 6:15 a.m., Employee #1 was adding compressed air to a tank of well water in order to pressurize the tank between 5-10 psi . The 1000-gallon capacity, 4 ft by 10 ft galvanized tank had no safety relief valve, nor was an in-line regulator provided for the air line from compressors operating between 145-175 psi. The tank ruptured and was propelled forward, striking Employee #1 in the head. He was thrown backwards from the ladder he was standing on to the concrete tile floor. Employee #1 was hospitalized and died as a result of his injuries.		

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151	Mechanical Engineer	Fueled Equipment	Design Development	1A	Provide purging cycles and special interlocks for all gas- and oil-fired equipment.	(V-I) [Accident: 201043015]: On April 2, 2007, Employee #1 was assigned to connect pool heaters to a gas line located in the pool pump room at the Sky Las Vegas condominium construction site. Part of that job task required him to purge the gas line of air, dirt and debris until gas came through the line. A water heater had also been installed in the room and had to be purged prior to the lighting of the water heater. Employee #1 opened the gas cock, valve, to the water heater gas line and purged it for a few seconds but no smell of gas was noted. He then purged the gas line that would be connected to the pool heaters for a few seconds but only dirt and debris came out and no smell of gas was noted. The gas line was purged twice more but Employee #1 could not smell the gas as well as Employee #2 who had entered the room. Employee #1 left the room and returned several minutes later at which time an explosion occurred inside the pool pump room. The explosion also affected nearby facilities including the two bathrooms and stairwell. Access was not restricted to the pool pump room and adjacent areas to only the employee involved in the purging process. Ignition sources were not prohibited inside the pool pump room and outside adjacent areas. Artificial illumination was not restricted to listed safety type flashlights and safety lamps. Electric switches were operated. Employees, working with natural gas were not instructed in the safe handling and use of this material. Employee #1 and #2 were hospitalized and treated for burn. Employees #3, #4 and #5 received cuts but were not hospitalized.		
152	Mechanical Engineer	Equipment Controls	Design Development	1A	Provide remotely operated valves or valves with extension handles when valves are located near hazardous materials or in confined spaces.	(V-I) [Accident: 767608]: On or about October 13, 1989, Employee #1, a melter B, entered a confined space to manually operate valves to a pressure vessel containing cal-sil and ferrites. Argon and nitrogen are used as a propellant for this mixture, and these lines were also located in the confined space. Employee #1 was overcome by the gases and died of asphyxia.		

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153	Mechanical Engineer	Equipment Location	Preliminary Design	2A	Ensure that equipment located in a hazardous area meets the requirements for the hazard classification of that area.	(V-I) [Accident: 171060874]: Employee #1 and another employee were spraying lacquer primer on woodwork inside of an apartment. The other employee went out to the van and heard an explosion inside of the apartment. A pilot light on the furnace or water heater ignited the vapors as Employee #1 began to spray the lacquer on the furnace door. The other employee ran to the door of the apartment and saw Employee #1, engulfed in flames, emerge from the door of the apartment. The employee tried to put the flames out and rolled Employee #1 on the ground. That was not effective and another witness brought a blanket to wrap around Employee #1 to extinguish the flames. Employee #1 was flown by helicopter to the local burn center where he was found to have third degree burns over 90 percent of his body. Employee #1 died approximately 14.5 hours later from his injuries.		
154	Mechanical Engineer	Fueled Equipment	Preliminary Design	1A	Provide ventilation systems around fueled equipment operating indoors to maintain the air quality.	(V-I) [Accident: 14319859]: Employee #1 was using a portable 800 watt gasoline-powered generator inside a room that did not have adequate ventilation. The room measured approximately 11 feet 4 inches by 12 feet by 11 feet 4 inches. The doors were closed and the vent for the permanent generator was blocked. Employee #1 was finishing the electrical work inside the room and had a 60 watt light plugged into the portable generator to provide light. The cause of Employee #1's death was asphyxiation due to carbon monoxide poisoning.		
155	Mechanical Engineer	Equipment Location	Preliminary Design	3B	Avoid locating mechanical equipment in or directly adjacent to passageways as these can become major obstructions for those passing by the area.	[Accident: 201853595]: On August 19, 2003, Employee #1, a plumber was found after break on a walkway located on the second level of the REC unit of a refinery. After being taken to the hospital and pronounced dead, an autopsy revealed that the cause of death was due to blunt force trauma to the trunk of the body.	Increased Cost	Investigate avenues of potential cost savings on other project features

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156	Mechanical Engineer	Protective / Safety Guards	Preliminary Design	3B	When designing tanks, locate permanent atmosphere testing devices and forced air ventilation equipment at entrances to tanks and vessels.	[Accident: 200902070]: On August 4, 2007, Employee #1, entered an oxygen deficient atmosphere inside a 6,340 gallon intermodal (ISO) container, which had previously contained ethyl acetate, and had been unloaded using nitrogen. Employee #1 wore an air-purifying respirator with multi-gas/vapor/P100 cartridges and died of asphyxia.	Decreased project quality and diminished design creativity	Identify alternative design features to address the associated safety hazards
157	Mechanical Engineer	Equipment Location	Preliminary Design	3A	To reduce fall hazards, locate rooftop mechanical/HVAC equipment away from skylights.	[Accident: 201145703]: At 9:15 a.m. on August 5, 2004, Employee #1 was working by himself, up on the roof of the library building, which had existing conduit and pipes in addition to several skylights. Employee #1 was making forms for the HVAC units to sit them on. He was working within 6 ft of an existing skylight. Employee #1 accidentally tripped on one of the pipes near the unprotected skylight. He fell and hit the 48-in. by 48-in. skylight. The skylight broke, and Employee #1 fell 11 ft 4 in. down onto the library floor. He fractured his left wrist and was hospitalized over 24-hours. The employer did not ensure that Employee #1 was protected from falling through the skylight by installing a guardrail system around the skylight or by having Employee #1 use a personal fall protection system. There were no direct witnesses to the incident.		
158	Mechanical Engineer	Equipment Controls	Design Development	3A	Position control valves and panels away from passageways and work areas so others can pass unobstructed.	[Accident: 201853595]: On August 19, 2003, Employee #1, a plumber was found after break on a walkway located on the second level of the REC unit of a refinery. After being taken to the hospital and pronounced dead, an autopsy revealed that the cause of death was due to blunt force trauma to the trunk of the body.		
159	Electrical Engineer	Equipment Location	Design Development	2A	Provide adequate passageways and safe access areas around all equipment in control, electrical, and electronic rooms to reduce electrical shock hazards.	[Accident: 645440]: An elevator mechanic was troubleshooting a problem in an elevator control panel located in an elevator control room. The panel contained circuit parts energized at voltages up to 111 volts dc and 240 volts ac. The employee contacted an energized part with his head while his hands were grounded. The employee was electrocuted. (The current entry and exit points were found during an autopsy).		

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160	Electrical Engineer	System Design	Design Development	1A	Ensure that the electrical system design meets all N.E.C. requirements and the requirements of N.F.P.A. for the protection of electronic computer/data processing equipment.	(V-I) [Accident: 14399240]: An employee was checking the fuses in a disconnect box that was installed outdoors. An energized ungrounded circuit conductor was in contact with the side of the box, and the equipment grounding conductor for the box was not continuous. This energized the box, resulting in the employee's electrocution when he touched the box with his bare hand.		
161	Electrical Engineer	System Design	Design Development	2A	Ensure that the withstand rating is adequate for the available fault current.	[Accident: 202363776]: On January 20, 2004, Employees #1 and #2, of Global Electric Communications, were installing a new three-phase run of wire in an energized 480-volt panel at a cabinet shop in Kent, WA. Employee #1 was trying to bolt a bracket to the panel's busbar when an electric arc occurred. He sustained thermal burns and was taken to Harborview Burn Center in Seattle, WA. Employee #2 was trying to show the owner of the cabinet shop what had happened to Employee #1 when another electric arc occurred. He also suffered thermal burns and was transported to the same hospital as Employee #1. The arc that burned Employee #1 was caused by a high fault current created by the bracket, of which Employee #1 had lost control. The bracket became energized and contacted another phase in the circuit breaker. Employee #2 thought the panel had been de-energized by the circuit protection at the source.		
162	Electrical Engineer	Equipment Location	Design Development	2A	Provide electrical/instrumentation system enclosures which ensure worker safety for the expected environmental/climatic conditions.	[Accident: 170402218]: An electric utility crew had opened the exterior cabinet door and the interior safety screen on an outdoor metal-clad switchgear cabinet in anticipation of performing mark-up procedures. A journeyman electrician on the crew left a coworker standing on ice and snow in front of the 23-kilovolt switchgear as the journeyman went to his truck. The journeyman and a chief cable splicer heard an explosion and ran over to find their coworker on the ground. He had contacted energized parts within the switchgear cabinet and had been electrocuted. Current entry and exit wounds were discovered on his upper left arm and on his upper left forearm.		

	<b>AEC Design Profession</b>	<b>Project Features</b>	<b>Stage of Design Phase</b>	<b>Tier of Feasibility of the DFCS Measure</b>	<b>*DFCS Measures</b>	<b>*Applicable Safety Incidents</b>	<b>*Potential Impediments to Implementation</b>	<b>Potential Solutions to the Impediments</b>
163	Electrical Engineer	Component Placement	Construction Documents	1A	Minimize the number of wires, cables, and hoses laid on walking surfaces by the use of elevated cable trays or hose supports.	(V-I) [Accident: 201122397]: Employee #1 was coming down from an elevated area carrying his tool box. Employee #1 did not see a wire which cut across his path of travel. Employee #1 tripped over the wire and fell approximately 16 ft to grade. Employee #1 was hospitalized.		

	AEC Design Profession	Project Features	Stage of Design Phase	Tier of Feasibility of the DFCS Measure	*DFCS Measures	*Applicable Safety Incidents	*Potential Impediments to Implementation	Potential Solutions to the Impediments
164	Electrical Engineer	System Design	Design Development	1A	Ensure that the interrupting rating is adequate to protect all equipment.	(V-I) [Accident: 201794138]: Four employees were installing new cables for an emergency generator. Two of the employees were outside, removing the temporary power cables and coiling them up. These two employees were also running new permanent cables into the emergency generator trailer. The other two employees, an apprentice electrician and a coworker, were working inside the bottom section of a 480-volt, 4000-ampere switchboard, connecting the permanent cables for the emergency generator. In a prejob meeting, the coworker told the apprentice that the disconnect was open, deenergizing the section they were going to work on, but that the upper half of the switchboard was energized. The apprentice and his coworker used test equipment and determined that a 480-volt, 1-ampere meter circuit was energized. The disconnect for the meter circuit was a toggle switch. The meter circuit, which was not protected by the ground-fault circuit interrupter protecting the generator output, included three fuses in a fuse block, three transformers, and two meters. The coworker turned off the meter circuit disconnect switch and placed cardboard over the switch, the fuse block, transformers, and associated wiring. The cardboard was intended to protect the equipment from damage and to protect the workers from electric shock. (The employees did not have any rubber insulating blankets or matting or plastic insulating sheeting in their truck.) The two employees were about to connect the last of the cables, the neutral conductor, which was located near the back of the switchboard, but the cable was too short and needed a splice. The coworker went to the truck to get a crimper and duct tape, while the apprentice remained at the switchboard. When the coworker returned, he saw the apprentice lying on the concrete floor with his head and arms inside the switchboard cabinet. The coworker also noticed that the cardboard that had been covering the meter circuit had slipped further inside the cabinet and that the meter circuit disconnect switch was closed. The left arm of the apprentice was resting on the fuses. The coworker tried to pull him out of the switchboard but failed to move him. The coworker and the remaining two employees pulled the apprentice electrician out of the switchboard cabinet, and one of them administered cardiopulmonary resuscitation. However, their efforts to rescue the apprentice failed; he was pronounced dead at the hospital. He had been electrocuted.		

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165	Electrical Engineer	System Design	Design Development	2B	Design all electrical and instrumentation system components to prevent inadvertent system activation.	[Accident: 14300479]: An employee was using a come-along to pull 0.5-inch electric cables from conduits in the floor. The come-along was being used directly beneath a partially energized panelboard. The lower half of the panelboard had been deenergized and checked for voltage before work was started. However, the upper half of the panelboard remained energized by the automatic activation of another circuit. The come-along contacted the upper busbar within the panelboard, causing an electrical fault. The employee received an electric shock; he also received burns on both forearms and his stomach. He was hospitalized for his injuries.	Increased Cost	Investigate avenues of potential cost savings on other project features
166	Electrical Engineer	Fixture Design	Design Development	1B	Where high light fixtures are incorporated into a structure, design the possibility of the entire light fixture to be lowered for safe repair and installation of new bulbs.	(V-I) [Accident: 14516934]: Two employees were troubleshooting lighting fixtures on the exterior of a building. One of the employees was on a ladder checking the wiring for a lighting fixture. The circuit for this fixture was energized. After determining that the problem was a defective ballast, this employee removed the ballast without deenergizing or otherwise protecting the circuit. He apparently leaned forward to reach the ballast and contacted the energized circuit conductors. He received an electric shock, which caused him to fall 15 feet to the pavement, on which he hit his head. He died later of the head injuries he received in the fall.	Increased Cost (V-II)	Investigate avenues of potential cost savings on other project features
167	Electrical Engineer	Equipment Location	Preliminary Design	1A	Avoid locating electrical rooms under pipes carrying liquids that could pose a shock hazard.	(V-I) [Accident: 655902]: An employee standing on a 1.8-meter-tall stepladder was trying to locate a leak in a covered pipe above a suspended ceiling. The employee reached around the pipe to locate the source of water and accidentally touched an exposed 277-volt, 20-ampere relay switch. He received an electric shock, which caused him to fall from the stepladder to the floor. He was hospitalized for his injuries.		
168	Electrical Engineer	System Design	Design Development	2A	Provide grounding circuits to all 480 volt lighting fixtures.	[Accident: 14323547]: An employee was installing an industrial lighting fixture. He was electrocuted when he inadvertently attempted to tap into an energized 480-volt feeder.		

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169	Electrical Engineer	Equipment Location	Preliminary Design	2A	Ensure that electrical/instrumentation systems located in hazardous areas meet the hazard classification requirements.	[Accident: 171060874]: Employee #1 and another employee were spraying lacquer primer on woodwork inside of an apartment. The other employee went out to the van and heard an explosion inside of the apartment. A pilot light on the furnace or water heater ignited the vapors as Employee #1 began to spray the lacquer on the furnace door. The other employee ran to the door of the apartment and saw Employee #1, engulfed in flames, emerge from the door of the apartment. The employee tried to put the flames out and rolled Employee #1 on the ground. That was not effective and another witness brought a blanket to wrap around Employee #1 to extinguish the flames. Employee #1 was flown by helicopter to the local burn center where he was found to have third degree burns over 90 percent of his body. Employee #1 died approximately 14.5 hours later from his injuries.		
170	Electrical Engineer	System Design	Design Development	2B	Design electrical and instrumentation systems to avoid possible equipment failures, such as desuperheated, control valve, or component failure.	(V-I) [Accident: 14393888]: At approximately 4:50 a.m. on April 6, 1994, an automatic control valve operating on an oxygen letdown station at a liquid air handling plant appeared to become inoperative. It was a Masonellan 3 inch split body globe valve with a domotor actuator and was operating at about 700 pounds of pressure. The plant manager decided that he and two operators, Employees #1 through #3, could throttle the flow at the letdown station by closing the manual block valve. They had closed the manual block valve about two rounds when the automatic control valve unexpectedly slammed shut. This forceful closing was followed by a fire/explosion. The intense reaction of pure oxygen at 700 pounds of pressure consumed/vaporized all material in its vicinity, including the schedule 80 piping system. The three employees received severe burns over most of their bodies. Employee #1 died, and complete recovery of Employees #2 and #3 may not be possible.	Increased Cost	Investigate avenues of potential cost savings on other project features

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171	Electrical Engineer	Equipment Location	Preliminary Design	2A	Avoid locating electrical/instrumentation components under pipes carrying liquids or in other areas where water is present and could pose a shock hazard.	[Accident: 201165156]: At approximately 9:50 p.m. on July 21, 2003, Employee #1, a foreman was working alone at the Kaiser Permanente Venice parking structure in Los Angeles, CA. He was trying to stop water from entering the top of an electrical box and running through the conduits to form a pool in the electrical room. He had removed the front electrical panel and was reaching with his right arm toward the back corner of the switchgear when his right hand apparently contacted the busbar of the electrical switchgear. He was electrocuted. When his body was found, there was also a pool of water at the base of the switchgear. The employer was cited for a violation of T8CCR 2320.4(a)(4).		
172	Electrical Engineer	Fixture Design	Design Development	1A	Provide permanent electrical outlets on flat roofs to allow for easy tie-in during construction and for future roof maintenance.	(V-I) [Accident: 14299796]: Employee #1 and coworkers were laying 3 ft by 4 ft by 2 3/4 in. foam insulation on a corrugated metal roof deck. The insulation was to be screwed to the roof deck to prevent displacement. Employee #1 was backing up on the roof, feeding out extension cord, when he fell through a 4 ft by 4 ft smoke vent opening. There were 11 smoke vent openings 25 ft above ground that were not covered or guarded. Employee #1 was transported to Prince George's County General Hospital, where he was diagnosed with a fractured tailbone.		
173	Electrical Engineer	Component Placement	Preliminary Design	1B	Avoid placing overhead wiring close to windows or equipment. Locate overhead lines to minimize contact.	(V-I) [Accident: 14516363]: Two employees were working on a 27-foot-by-15-foot-by-9-foot metal building, putting sealant between grooves. They were applying swepco heavy duty roof coating with a brush and a straw-type broom. Both employees were experienced in this type of work, having performed this task before. During the course of their work, one of the employees contacted an overhead power line. He was electrocuted. This employee's contact with the power line resulted in an explosion, engulfing him in flames and knocking the other employee from the roof of the building. The employee who fell from the building received a crushed heel, for which he was hospitalized.	Increased Cost; Schedule problems and time constraints	Investigate avenues of potential cost savings on other project features; Investigate avenues of decreasing the time needs of other project features

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174	Electrical Engineer	Equipment Location	Design Development	1A	Ensure that all electrical equipment is adequately cooled and ventilated to reduce the fire hazard of operating equipment.	(V-I) [Accident: 170340491]: Employee #1 entered a concrete mold (confined space) to light a liquid petroleum gas, direct-fired heater after it had gone out. He smelled gas and waited 5 to 10 minutes before relighting. Once relighted, the heater created a flash fire that severely burned Employee #1. Deficiencies included a lack of proper confined space entry and hot work procedures such as no permit; poor ventilation; location of a 100 lb capacity LP-gas cylinder within 1 to 2 ft of the heater; inadequate LP-gas hose assembly; non-qualified LP-gas cylinder; inadequate employee training; failure of the heater safety device (a thermoelectric valve) to prevent gas flow when the flame was extinguished.		
175	Electrical Engineer	Fixture Design	Design Development	1B	Design ventilating and lighting fixtures in a mechanical room and confined space to be operated by the same switch to ensure adequate ventilation whenever workers are in the area.	(V-I) [Accident: 201573359]: On September 27, 2007, Employee #1 and a coworker were in a rectangular room, cleaning concrete from masonry. They were hand-spraying a glycolic acid product and then rinsing it off with a gasoline-powered power-washer. Employee #1 died cardiopulmonary arrest precipitated by inhalation of glycolic acid and carbon monoxide. The room had no cross-ventilation or exhaust ventilation. Employee #1's carboxyhemoglobin levels were used to calculate the carbon monoxide levels in the workplace, which were found to be at 199 ppm, on average, for the duration of exposure. The coroner ruled the death to be accidental.	Exposure to Liability	Revised contract language; Revised insurance policy
176	Electrical Engineer	Component Placement	Construction Documents	2B	Route cable trays above pipelines to minimize the chance of electrical shock due to leaking pipes.	[Accident: 170579189]: An employee was picking up a metal tool from the floor. The tool was lying in water from a leaking pool. A ground fault in some electric machinery had energized a nearby cable tray. The employee, who had his hand on the cable tray when he touched the metal tool, received an electric shock. He was hospitalized for his injury.	Exposure to Liability; Decreased project quality and diminished design creativity	Revised contract language; Revised insurance policy; Identify alternative design features to address the associated safety hazards
177	Electrical Engineer	Component Placement	Preliminary Design	3B	When new electrical lines are to be placed below existing concrete surfaces, roads, or other traffic areas, design the lines to be placed using trenchless technologies.	[Accident: 201761129]: Employee #1 and coworkers were inside a 7 ft to 8 ft deep by 228 ft long by 4 ft to 6 ft wide trench, installing PVC pipe for the electrical system of a church under construction. The trench ran north-south and some sections were benched for the first 3 ft down, to a width of 2 ft at the bottom of the trench. Other sections had vertical walls. Employee #1 was approximately 46 ft from the north end of the trench when the trench walls caved in and buried him. He was killed.	Increased Cost	Investigate avenues of potential cost savings on other project features

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178	Electrical Engineer	System Design	Design Development	3A	Ensure that all equipment is adequately grounded and protected against lightning.	[Accident: 201403896]: Employees #1 through #3 experienced electric shock when lightning struck a building 1,500 ft away from where they were working. All three required hospitalization.		
179	Plumbing Engineer	Piping System Placement	Preliminary Design	2A	When terrain changes grades, route sewer lines to avoid the need for deep trenches.	[Accident: 14565550]: Employee #1 and a coworker, of North Dodge Contracting, Inc., were digging a trench and preparing to lay an 8 in. sewer line. Employee #1, age 16, was in the trench doing clean-out and fine grading, and the coworker was operating the backhoe. The trench varied in depth from 6 ft at the south end to approximately 10 ft where they were working at the north end. A 20 ft length of the east wall collapsed, burying Employee #1. The coworker and two other construction workers dug with shovels and their hands and managed to free his head and shoulders. Rural Metro paramedics arrived and administered emergency treatment as he was being dug out. They transported him to the hospital. He suffered a fractured left arm and shoulder, fractured right clavicle, and fractured ribs. The trench walls were vertical and unshored. The coworker/backhoe operator was in charge of the job and failed to recognize and identify the hazardous working conditions, or to take the necessary steps to prevent a cave-in.		
180	Plumbing Engineer	Piping System Placement	Preliminary Design	1A	Avoid locating utilities which cross under other pipelines, run directly adjacent to existing pipelines, intersect previously backfilled, disturbed, or fissured soil, intersect manhole excavations, or cross different types or conditions of soil.	(V-I) [Accident: 14253090]: On March 1, 1989, workers were laying a 12 in. ductile iron water main in a trench 5 to 5 1/2 ft deep, in the roadway of a paved road. The backhoe had just finished digging and was preparing to hoist the next pipe joint. A small compactor was in the trench, compacting soil over the last two lengths of pipe laid. The trench was parallel to an existing sewer line. Employee #1 and a coworker were in the trench preparing to lay a third pipe. Employee #1, a pipelayer, was using a shovel to level grade the trench bottom. At about 9:30 a.m., soil fell from under pavement along the west wall of the trench (the sewer line side). Employee #1 saw it coming and ran in the direction of the previously laid pipe, but was trapped before he reached safety. He was covered to his hips, with a piece of cemented soil, or pavement, against his hip. Employee #1 suffered a fractured pelvis and a torn urethra. The coworker reported that he was struck by soil, but escaped injury.		

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181	Plumbing Engineer	Relief Valves	Design Development	1A	Provide proper protection to prevent injury or damage caused by escaping fluid from relief or safety valves if vented to the atmosphere.	(V-I) [Accident: 14554893]: On August 29, 1990, four WS Bunch employees, engaged in paint contract work at an Arcadian fertilizer manufacturing plant, were returning from lunch and climbed to the fourth level of a structure used in the manufacturing of urea in order to perform sandblasting operations. The employees were beginning to put on their ppe when a nearby ammonia tank relief valve released twice, releasing anhydrous ammonia into the air. It surrounded Employees #1 through #3. Their coworker had descended one level to retrieve a glove. The exposed employees, who were not wearing their goggles or cartridge respirators, evacuated the tower, showered, and flushed their eyes. Oxygen was administered and they were transported to the nearest hospital by a rescue squad. Employees #1 and #2 were treated for chemical burns of the eyes, nasal passages, and other body parts and were released. Employee #3 was treated for similar burns and was held overnight. The employees who attempted to don their cartridge respirators during the ammonia exposure indicated that the respirators were ineffective in filtering out the ammonia.		
182	Plumbing Engineer	System Design	Design Development	1B	Design steam lines with drips or freeblows to prevent steam hammer or slugging.	(V-I) [Accident: 200271096]: On May 25, 2002, Employee #1 and his supervisor were slowly opening a 30-psi manual steam valve on a 30-in. steam line during plant start up procedures. When they heard what they believed to be a water hammer occurring in the line, they attempted to close the valve. The valve blew apart, the line separated, and Employee #1 was burned over 80 to 90 percent of his body. He died from his injuries on July 30, 2002.	Absence of Designer Interest and Motivation	Identify alternative design measure to address the associated safety hazards
183	Plumbing Engineer	System Design	Design Development	2A	Design adequate protection against over-pressure for all piping components.	[Accident: 170042352]: Employee #1 was struck by, and his legs pinned under, a 1,200 pound section of 12 inch diameter steel pipe. The pipe came loose at a mechanical joint after a high surge in volume and pressure. The loose section became a projectile, striking Employee #1.		
184	Plumbing Engineer	Piping System Placement	Design Development	1A	Eliminate drainage of slippery and dangerous chemicals into passageways and work areas to reduce fall hazards and to minimize the exposure of workers.	(V-I) [Accident: 170197230]: At 10:30 a.m. on May 5, 1991, Employees #1 and #2 and five coworkers at the Sym-Tet chlorine plant were exposed to vapor releases of chlorine and carbon tetrachloride. Employees #1 and #2 were hospitalized in the intensive care unit; the five coworkers were checked and released. A system overpressure release valve had opened, exposing the employees to the chemicals.		

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185	Plumbing Engineer	System Design	Design Development	2B	Minimize flanges in piping under high pressure, or which contains explosive or lethal gases.	[Accident: 784256]: Pressure built up in a rouser, causing a flange to break and releasing a pipe. The pipe went through the roof, causing sparks, which started a fire. Employees #1, #2, and #3 suffered smoke inhalation.	Exposure to Liability; Designers' lack of safety expertise	Revised contract language; Revised insurance policy; Engage outside safety experts to review designs; Utilize designers with formal safety training
186	Plumbing Engineer	Piping System Placement	Design Development	2B	Pipe pump seal water in a manner to avoid slipping, e.g. case drains/base plates to hubs.	(V-I) [Accident: 14549299]: At approximately 7:30 am on August 21, 1986, Employee #1 was walking on a wet concrete floor. He slipped and fell, striking his head on the floor. He suffered a severe head injury. Death resulted from complications caused by a blood clot in the brain. He died at 10:45 am on August 25, 1986.	Exposure to Liability; Designers' lack of safety expertise	Revised contract language; Revised insurance policy; Engage outside safety experts to review designs; Utilize designers with formal safety training
187	Plumbing Engineer	System Design	Preliminary Design	2B	Avoid making direct cross connections between drinking water or utility systems and plant or process streams.	[Accident: 170788004]: On November 25, 1997, Employee #1 became ill after consuming an unusually large quantity of Diet Pepsi from the beverage island near the kitchen before and during his first four to five hours of work. He was sent to the emergency room at the work site and, after being held for observation, was released the next day without any serious injury or illness. Subsequent inspections by several other agencies and a private consultant determined that the beverage island was connected to the HVAC coolant line for its water supply. The island had been installed in June 1997 after a remodeling of the area. What made the circumstances unusual was that chemicals had been added to the HVAC system to prevent a build-up of mineral deposits and biological problems, such as algae. The employer was cited for two general violations related to not having an adequate supply of potable drinking water, and failure to label the piping. Approximately 90 people, including 82 non-employees, were subsequently evaluated, but there were no other reports of serious injury or illness.	Exposure to Liability; Designers' lack of safety expertise	Revised contract language; Revised insurance policy; Engage outside safety experts to review designs; Utilize designers with formal safety training

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188	Plumbing Engineer	Piping System Placement	Preliminary Design	1A	Locate drains away from walkways, work areas, and the structure perimeter to keep them from becoming slippery fall hazards.	(V-I) [Accident: 14549299]: At approximately 7:30 am on August 21, 1986, Employee #1 was walking on a wet concrete floor. He slipped and fell, striking his head on the floor. He suffered a severe head injury. Death resulted from complications caused by a blood clot in the brain. He died at 10:45 am on August 25, 1986.		
189	Plumbing Engineer	System Design	Design Development	2B	Ensure that the shut-off head on all pumps is compatible with the associated piping.	(V-I) [Accident: 170190995]: At approximately 8:45 a.m. on September 29, 1991, Employee #1 was installing a 4 ft long extension gas line at the upper side of a road. He had been beveling the edge of a 27 in. PCV gas header pipe with power beveling equipment for about 30 minutes when a spark from the beveling tools caused a sudden explosion. Employee #1's face and front forearms were burned. The shut-off valve was not set properly and a small amount of gas leaked out, causing the explosion and flash fire. A serious citation was issued to the employer for violating T8CCR 5416(c).	Exposure to Liability	Revised contract language; Revised insurance policy
190	Plumbing Engineer	System Design	Design Development	1A	Provide traps or valves on process sewers and area drains to avoid the spread of fire in case of a ruptured tank.	(V-I) [Accident: 201344934]: On December 14, 2008, Employee #1 was opening a drain valve on a vessel to remove any water that had settled to the bottom of the vessel. The vessel contained a mixture of 80 percent ethane and 20 percent propane. When he opened the valve to drain the water into and enclosed plastic tank an explosion occurred. A fire burned the ethane and propane mixture through the open drain valve. Employee #1 was thrown from the area by the explosion, receiving a broken arm, dislocated shoulder and other injuries. Employee #1 was hospitalized.		

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191	Plumbing Engineer	Piping System Placement	Design Development	1A	Route piping to avoid head knockers (6 ft. - 6 in. minimum above grade) and tripping hazards.	(V-I) [Accident: 202456208]: At approximately 7:00 a.m. on April 24, 2010, Employee #1, a stationary engineer, was opening an overhead main feed water valve in the attempt to supply water to a boiler that had been shut down, and was being restarted. Employee #1 ensured that the boiler was in a safe condition to restart and that all the valves and controls were in the proper position. Then she began to open the main feed water valve to the boiler that is located over-head and can be opened through a chain drop between boilers three and four. While Employee #1 was opening the valve, she stepped backwards to better view the valve, when she tripped over a permanently installed pipe. The pipe was located 11 inches above the floor and took up about 12 inches in width of the walkway. Employee #1 was taken to the employer's on-site infirmary, where she was treated for a fractured left wrist. The incident investigation concluded that the walkway between the boilers did not lead directly to an exit, but did have impaired clearances that were not posted, guarded, or barricaded, and that presented a tripping hazard.		
192	Plumbing Engineer	Piping System Placement	Construction Documents	1A	Design sewer gratings such that the openings are not easily plugged by debris, but not so large as to constitute a tripping hazard.	(V-I) [Accident: 14256440]: Employee #1 and another employee were installing the last section (36 by 50 inches) of grating on a pipe bridge walkway. They were 25 feet above the ground. As Employee #1 picked up the section of grating to hand to the other worker, his shoe apparently caught on the end of an existing piece of grating. He lost his balance and fell through the opening. Employee #1 had on a safety belt but was not tied off.		
193	Plumbing Engineer	System Design	Design Development	2B	Design area drains to be trapped or valved shut to avoid the spread of fire in case of a ruptured pipe.	[Accident: 170081988]: Operators in the cat cracker (vapor recovery) unit were preparing to remove and repair a heat exchanger with leaking tubes. Day shift operators had blocked in the exchanger, bled the propane in the exchanger to the flare, and drained the water. The night shift operator was going to connect a steam hose to the exchanger, and he re-opened the bleed valves to double-check. When he opened the water drain valve, propane in the exchanger sent a flammable vapor cloud out of the drain line. The vapor cloud was ignited, apparently by a heater approximately 150 feet away. Employees #1, #2, and #3, all machinists working on a pump, sustained burns in the approximately 3 second flash fire. The block valve was leaking, allowing propane to enter the exchanger.	Increased Cost	Investigate avenues of potential cost savings on other project features

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194	Plumbing Engineer	System Design	Design Development	1B	Design all impoundments for liquids to provide a means or facility to accommodate emergency bypass conditions.	(V-I) [Accident: 14491260]: Employee #1 was operating 3 dye extraction vats. The three vats were at different stages in the operating cycle. One of the vats started to overflow, spilling hot chemicals onto the floor. Employees #1 and #2 noticed the spill and approached the vat to take corrective measures. They noticed a large puddle, several inches deep, of the spilled mixture of product and caustic soda in front of the tank. The temperature of the spilled mixture was about 95 degrees centigrade. They were afraid to step into the mixture, so Employee #2 pushed a filter press cart into the puddle to use to get across the puddle. Employee #1 climbed into cart and began closing the valve to prevent further overflow. He apparently lost his balance and fell out of the cart and into the puddle of chemicals. Employee #2 quickly pulled him out of the puddle and into a water shower. Both employees were hospitalized for chemical burns. Employee #1 died in the hospital 20 days later.	Designers' lack of safety expertise	Engage outside safety experts to review designs; Utilize designers with formal safety training
195	Plumbing Engineer	Piping System Placement	Construction Documents	1A	Provide anchors or tie-downs for pressurized piping with push-type joints or other mechanical joints.	(V-I) [Accident: 201320447]: On October 4, 2002, Employee #1 was attempting to dewater a newly constructed 20-inch natural gas pipeline. For some reason, a malfunction occurred and the pipe violently separated. Employee #1 was struck by a 10-foot section of the flying pipe. The pipe was not properly anchored at the pipe sections, especially at bends, to restrain movement caused by surges in water and air pressure. Employee #1 was hospitalized and treated for a concussion. Employee #1 died due to his injuries.		
196	Plumbing Engineer	Piping System Placement	Design Development	3A	Route piping drains and overflow outlets to trench drains so the drainage material does not become a slip hazard.	[Accident: 14549299]: At approximately 7:30 am on August 21, 1986, Employee #1 was walking on a wet concrete floor. He slipped and fell, striking his head on the floor. He suffered a severe head injury. Death resulted from complications caused by a blood clot in the brain. He died at 10:45 am on August 25, 1986.		

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197	Plumbing Engineer	Relief Valves	Design Development	3A	Consider rupture disks as a safety device either in conjunction with or as a substitute for safety valves, or to act as an explosion door on vessels and piping subject to explosions.	[Accident: 170209860]: At approximately 11:00 a.m. on February 3, 1994, Employee #1 was working in a room in which the building's main water heater boiler was located when, without warning, the heater exploded. The explosion blew a hole in the adjacent wall, and fragments of the boiler injured Employee #1, but not seriously and not requiring hospitalization. When the water heater's pressure relief valve was removed and inspected, it was found to be clogged by what appeared to be heavy rust deposits, and therefore not in operating condition. The heater was also lacking a water level switch.		
198	Plumbing Engineer	Piping System Placement	Preliminary Design	3A	Avoid designing utilities which cross under existing pipelines, run parallel to immediately adjacent existing pipelines, or intersect manhole excavations.	[Accident: 14253090]: On March 1, 1989, workers were laying a 12 in. ductile iron water main in a trench 5 to 5 1/2 ft deep, in the roadway of a paved road. The backhoe had just finished digging and was preparing to hoist the next pipe joint. A small compactor was in the trench, compacting soil over the last two lengths of pipe laid. The trench was parallel to an existing sewer line. Employee #1 and a coworker were in the trench preparing to lay a third pipe. Employee #1, a pipelayer, was using a shovel to level grade the trench bottom. At about 9:30 a.m., soil fell from under pavement along the west wall of the trench (the sewer line side). Employee #1 saw it coming and ran in the direction of the previously laid pipe, but was trapped before he reached safety. He was covered to his hips, with a piece of cemented soil, or pavement, against his hip. Employee #1 suffered a fractured pelvis and a torn urethra. The coworker reported that he was struck by soil, but escaped injury.		
199	Plumbing Engineer	System Design	Design Development	3A	Size control valves with consideration of noise level.	[Accident: 867572]: Employee #1 was working in a salt brine well located in an isolated rural area. The brine well was a concrete pit 16.25 in. by 8 ft 4 in. by 7 ft 8 in. deep with well pump equipment in the pit. Employee #1 was in the process of releasing pressure off the wellhead by pumping nitrogen into the well to force out the brine. A muffler was used to silence the noise from the 1700 lbs of pressure created at the wellhead. A shutoff valve had been installed on the exit end of the muffler, which caused the muffler to explode, amputating Employee #1's arm and killing him.		

	<b>AEC Design Profession</b>	<b>Project Features</b>	<b>Stage of Design Phase</b>	<b>Tier of Feasibility of the DFCS Measure</b>	<b>*DFCS Measures</b>	<b>*Applicable Safety Incidents</b>	<b>*Potential Impediments to Implementation</b>	<b>Potential Solutions to the Impediments</b>
200	Plumbing Engineer	Piping System Placement	Preliminary Design	3A	When new piping lines are to be placed below existing concrete surfaces, roads, or other traffic areas, design the lines so that they may be placed using trenchless technologies.	[Accident: 201361961]: At approximately 9:30 a.m. on April 3, 2003, Employee #1 was making a joint connection at the south end of an excavation. A 6-in. sewer line was being installed along the west side of an industrial park access road. The depth of the pipe ranged from 5.25 ft to 8.65 ft below grade. The excavation was opened to a width of 5 ft and extended 90 ft in a north-south direction along the west side of the road. The spoils were placed directly on the edge of the excavation so as to not block the road. The walls were not sloped and no shoring was being used. The east wall collapsed and buried Employee #1. The other employees called emergency medical technicians and started to dig Employee #1 out. When the emergency medical technicians arrived, Employee #1 was extricated from the excavation and pronounced dead at the scene.		

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201	Plumbing Engineer	Piping System Placement	Preliminary Design	3A	Do not locate piping in rooms containing high voltage equipment, bare wires, or bus bars.	[Accident: 201561719]: At approximately 12:30 a.m., on or near September 29, 2006, Employee #1, a technical mechanic, and an electrical mechanic were about to replace a sump motor. After the electrical mechanic locked out the sump motor circuit breaker, located in the motor control room ("MCC-006") of the Wet Process Building, he set the outside sump switch to the "off" position and wired the new motor. Prior to returning the pump back to the sump, the employees attached a 3-inch diameter, right-angle pipe to the pump. The electrical mechanic returned to the MCC room to check on the leads to the motor and called the lead electrician to confirm that the readings were acceptable. After he was given clearance, the electrical mechanic removed his lock and energized the circuit to the motor. On his way back to the sump, he notified Employee #1 that the power was on. Arriving at the sump, the electrical mechanic did not see Employee #1 at the site. He went to his truck, which was parked approximately 30 feet west of the sump, and found it empty. Returning to the sump area, the electrical mechanic found Employee #1 face up in a small pond of water, approximately 10 feet from the sump. The electrical mechanic informed dispatch about the accident and quickly returned to the MCC room to deenergize the circuit to the motor and lock it out. After the electrical mechanic determined that the area around Employee #1 was not electrified, Employee #1 was pulled from the pond and administered CPR, until Weber County EMT arrived. Employee #1 apparently received an electric shock that caused his "hypertensive" heart to fibrillate, and he was killed. Upon request from the Deputy to the electrical mechanic, they found that the switch was in the "manual" position. Inspection of the pump revealed that two of the 480-volt, three-phase cable conductors were exposed and "shorted to the pump's steel house."		

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202	Plumbing Engineer	System Design	Design Development	3A	Locate valve controls so that handles can be reached easily, or so that a standard type operating device can be installed.	[Accident: 200370872]: At approximately 2:45 p.m. on January 11, 2000, Employees #1 through #3 were working on a steam line that was connected to a phosphorus storage tank. All insulation had been removed from the steam line and it was very similar in appearance to a phossey water line located nearby. After Employee #1 had cut loose a control valve, he attempted to make another cut in the regular water line, but cut the phossey water line instead. Employee #1 turned the valve with a pipe wrench to what he thought was the 'off' position, but instead turned it to full flow. The phossey water sprayed onto his hands, abdomen and legs. He was tied off to the tank and could not break free until Employee #3 finally unhooked his lanyard and got him to the water jump tank. Employee #1 suffered serious chemical burns. Employees #2 and #3 were also exposed to the phosphorus solution, and all three employees were hospitalized. Citations were issued for inadequate personal protective equipment, inadequate training, and inadequate means to notify employees of an imminent hazard.		
203	Plumbing Engineer	Piping System Placement	Preliminary Design	3A	Minimize the need for hot work permits by providing adequate buffer from existing piping systems.	[Accident: 882225]: Four subcontractors were working at a compressor station of a natural gas plant. Two employees were welding 6 inch steel pipe in an excavation. Employees #1 and #2 were 21 feet away in another excavation. Employee #1 was outside of the excavation and Employee #2 was cutting a 4 inch dump line with pipe cutters when the pipe released a condensate mixture. The liquid and the vapors came in contact with the arc welding electrodes and ignited, burning Employees #1 and #2. The other two workers were not injured.		

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204	Plumbing Engineer	System Design	Design Development	3A	Design piping systems which feed tanks, chests, and large walk-in type equipment to prevent inadvertent system activation.	[Accident: 201271103]: At approximately 7:00 p.m. on June 12, 2000, Employees #1 through #5 were working on the third shift in the casting department when the chlorine rupture disc in the chlorine mixing station building activated. Approximately 240 lb of vaporized chlorine was released through an open piping system to the outside of the building and was carried by the wind approximately 75 ft to the casting department. The chlorine went unnoticed until Employees #1 through #5 smelled it, after which the gas activated the monitors at the drop area for aluminum ingots, near the furnace. These monitors at the furnaces were used for detecting chlorine leaks in the chlorine piping system for fluxing the pots and drops. The hazmat team manually turned off the valve on the one-ton chlorine cylinder, preventing its entire contents from being released. Employees #1 through #5 were exposed to the chlorine vapor and were transported to the hospital. Employees #1 through #3 were admitted for observation; Employees #4 and #5 were treated and released. This incident was likely caused by a malfunctioning argon heater and a bad chlorine regulator. The malfunctioning equipment probably caused the temperature and pressure of the chlorine in the line to rise, rupturing the rupture disc.		
205	Plumbing Engineer	Piping System Placement	Design Development	3A	Route pump seal water in a manner to avoid wet slippery surfaces around the equipment.	[Accident: 14549299]: At approximately 7:30 am on August 21, 1986, Employee #1 was walking on a wet concrete floor. He slipped and fell, striking his head on the floor. He suffered a severe head injury. Death resulted from complications caused by a blood clot in the brain. He died at 10:45 am on August 25, 1986.		
206	Plumbing Engineer	Piping System Placement	Design Development	3A	Route piping lines below electrical/instrumentation cable trays to prevent the chance of electrical shock due to leaking pipes.	[Accident: 170579189]: An employee was picking up a metal tool from the floor. The tool was lying in water from a leaking pool. A ground fault in some electric machinery had energized a nearby cable tray. The employee, who had his hand on the cable tray when he touched the metal tool, received an electric shock. He was hospitalized for his injury.		

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207	Plumbing Engineer	Relief Valves	Design Development	3A	Direct safety relief valve exhausts away from passageways and work areas.	[Accident: 170572457]: At approximately 4:00 p.m. on February 22, 1998, Employee #3, a chemical operator, added the wrong catalyst for a reaction, causing overpressurization of the vessel. The safety relief valve opened, releasing vapors and liquid that settled to the ground near a roll-up door. Employees #4 through #12, contractors doing pipe fitting work on an adjacent reactor, were exposed to the vapors as they left the area. Employee #1 was exposed during clean-up and Employee #2 was performing housekeeping duties near the roll-up doors. Employees #1 through #12 were transported to the hospital complaining of nausea, dizziness, and chest tightness—all symptoms of acute chemical exposure. They were treated and released. The employer was cited for violations of T8CCR 1910.119, T8CCR 1910.120, and T8CCR 1910.1200.		
208	Plumbing Engineer	Piping System Placement	Construction Documents	3A	Design covers over sumps and drains to be flush with the finished floor to eliminate these features as tripping hazards.	[Accident: 200801702]: On January 6, 2007, an employee and coworkers were erecting walls on the third story of a commercial building. The employee was carrying 2-ft by 6-ft panels for other coworkers to erect the walls. The employee and coworkers had the second wall section on the north side of the building finished and ready for installation. The foreman for the company was on the phone with the owner and noticed the employee walking towards the edge of the unguarded floor edge. He then saw him trip and fall over the side of the building. The employee fell 36 feet and suffered a collapsed lung, a broken pelvis, and broken ribs. He was hospitalized.		
209	Plumbing Engineer	System Design	Design Development	4B	Design process/effluent sewer systems to vent gases to the outside of buildings or other project work areas.	[Accident: 170197230]: At 10:30 a.m. on May 5, 1991, Employees #1 and #2 and five coworkers at the Sym-Tet chlorine plant were exposed to vapor releases of chlorine and carbon tetrachloride. Employees #1 and #2 were hospitalized in the intensive care unit; the five coworkers were checked and released. A system overpressure release valve had opened, exposing the employees to the chemicals.	Designers' lack of safety expertise	Engage outside safety experts to review designs; Utilize designers with formal safety training

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210	Plumbing Engineer	Relief Valves	Design Development	4B	Provide relief valves between each pair of sectionalizing valves on lines containing liquids and subject to being both isolated and heated, such as heat exchangers, liquefied gas piping, etc.	[Accident: 14495006]: Employer #1 was using a boiler and heat exchanger to heat contaminated water at a hazardous waste site. In the piping between the boiler and heat exchanger were two valves and a strainer which were made of class 125 b cast iron. The boiler was operating at 200 psig to 225 psig. The cast iron equipment was rated at a maximum of 145 psig. Employee #1 was standing beside the strainer when it ruptured, spraying steam heated to about 380 degrees onto him. He died from the severe burns he received. The equipment should not have been subjected to pressure above its capacity, or a suitable relief valve should have been installed. The boiler was a portable tractor trailer mounted type.	Designers' lack of safety expertise; Absence of designer interest and motivation	Engage outside safety experts to review designs; Utilize designers with formal safety training; Identify alternative design measure to address the associated safety hazards
211	Plumbing Engineer	System Design	Design Development	4A	Prevent water hammer by providing air vents, surge valves, surge chambers, or delayed or timed valve operation.	[Accident: 200271096]: On May 25, 2002, Employee #1 and his supervisor were slowly opening a 30-psi manual steam valve on a 30-in. steam line during plant start up procedures. When they heard what they believed to be a water hammer occurring in the line, they attempted to close the valve. The valve blew apart, the line separated, and Employee #1 was burned over 80 to 90 percent of his body. He died from his injuries on July 30, 2002.		
212	Plumbing Engineer	Piping System Placement	Design Development	4B	Route piping drains and overflows to trench drains so that floors remain dry.	[Accident: 14549299]: At approximately 7:30 am on August 21, 1986, Employee #1 was walking on a wet concrete floor. He slipped and fell, striking his head on the floor. He suffered a severe head injury. Death resulted from complications caused by a blood clot in the brain. He died at 10:45 am on August 25, 1986.	Exposure to Liability	Revised contract language; Revised insurance policy

## **Appendix K:          Certification of IRB Approval of Research**

### **Carnegie Mellon University**

#### **Institutional Review Board**

Federalwide Assurance No: FWA00004206

IRB Registration No: IRB00000603

#### **Research Regulatory Compliance**

Warner Hall, Fourth Floor

Pittsburgh PA 15213

412-268-1901

[lrb-review@andrew.cmu.edu](mailto:lrb-review@andrew.cmu.edu)

### **Certification of IRB Approval**

**IRB Protocol Number:** HS11-162  
**Title:** Minimizing Impediments to Design for Construction Safety (DFCS)  
Implementation on Capital Projects  
**Investigator(s):** Mustapha Bello, Omer Akin  
**Department(s):** Architecture  
**Date:** May 10, 2011

Carnegie Mellon University Institutional Review Board (IRB) reviewed the above referenced research protocol in accordance with the requirements of Public Law 99-158 as implemented by 45 CFR 46 and CMU's Federalwide Assurance. The research protocol has been given **APPROVAL as Exempt by the IRB on May 10, 2011 in accordance with 45 CFR 46.101(b)(2).**

This approval does not expire. However, if you wish to make modifications to this protocol, please contact the IRB regarding these changes prior to their implementation to ensure compliance with this designation.

The Investigator(s) listed above in conducting this protocol agree(s) to follow the recommendations of the IRB and the Office of the Provost of any conditions to or changes in procedure subsequent to this review. In undertaking the execution of the protocol, the investigator(s) further agree(s) to abide by all CMU research policies including, but not limited to the policies on responsible conduct research and conflict of interest.

Please call the Research Regulatory Compliance Office at 412-268-5460 if you have any questions regarding this certification. Thank you.



David Danks, Ph.D., Chair