8-2013

An Analysis of a Missing Design Concept for Sustainable Buildings: Addressing the Safety and Health of the Construction Worker

Christopher Almond
Clemson University, calmond@vt.edu

AN ANALYSIS OF A MISSING DESIGN CONCEPT FOR SUSTAINABLE BUILDINGS: ADDRESSING THE SAFETY AND HEALTH OF THE CONSTRUCTION WORKERS

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Masters of Science
Civil Engineering

---

by
Christopher Almond
August 2013

Accepted by:
Dr. Leidy Klotz, Committee Chair
Dr. Kalyan Piratla
Dr. Brandon Ross

ABSTRACT

Construction work is inherently dangerous. The 2010 U.S. Bureau of Labor Statistics show the construction industry had the most fatal injuries of all industry sectors, 17%. U.S. regulations place the responsibility for construction safety on the construction contractor. However, owners and designers have the potential to affect the safety of the construction workforce. Owners have gotten more involved in promoting the safety and health of construction workers in recent years; however, studies show that the safety and health of the construction workforce is not typically considered by designers.

The Naval Facilities Engineering Command (NAVFAC) – the U.S. Navy's systems command for facility engineering – has initiated several practices to improve construction safety on its projects and has pursued a zero-injury objective for many years, but the efforts focus on the construction contractor. This study's objective was to provide a analysis to present to NAVFAC to consider implementing a program to make construction safety a factor in design decisions. This analysis provides justification, influence factors, and application methods by answering the following questions regarding NAVFAC using the design phase to reduce, or eliminate, construction safety hazards : (1) why, (2) what influences exist, and (3) how will NAVFAC implement?

A *systematic literature review* was used to perform this study. Three reasons were identified to justify NAVFAC to use the design phase to advance this concept: (1) the viability of another approach, (2) design decisions affect construction safety, and (3) a moral obligation exists. The influences identified for designers to consider construction safety were: (1) designers are resistant, (2) owners influence safety, and (3) project delivery methods. Three stages to apply the concept of using the design phase to consider construction safety were discussed: (1) cultural shift, (2) design suggestions and standards, and (3) systematic methods.

This study contributes to knowledge by providing a panoramic analysis of the concept to consider the safety of the construction worker. Provided this panoramic analysis, the intended audience of this study, NAVFAC, can decide to further develop an implementation plan to have their designers consider the safety and health of the construction workers.

ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Leidy Klotz, for guiding me through the research process and always eager to assist. Thanks to the rest of the members on the committee, Dr. Kalyan Piratla and Dr. Brandon Ross. I appreciate your interest in my study. Thank you for taking the time to provide valuable feedback. Also, thanks to the ESSo research group, I learned a lot from listening to the other research and what was involved in the academic research process.

I have been influenced by many great people within the Navy; thank to many Civil Engineer Corps officers and the NAVFAC civilians who have provided leadership and spent the time to mentor me.

And most of all, thanks to my wife, Amanda. Your love and support was invaluable as I worked on this study.

TABLE OF CONTENTS

Table of Contents (Continued)

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE: INTRODUCTION

The construction industry has a reputation for being one of the most dangerous industry sectors for its workers. In 2010, 774 fatal workplace injuries occurred to workers within the construction industry; shown in Figure 1-1. This represents 17% across all industry sectors for work-related fatalities – more than any other industry (U.S. Bureau of Labor Statistics, 2012).

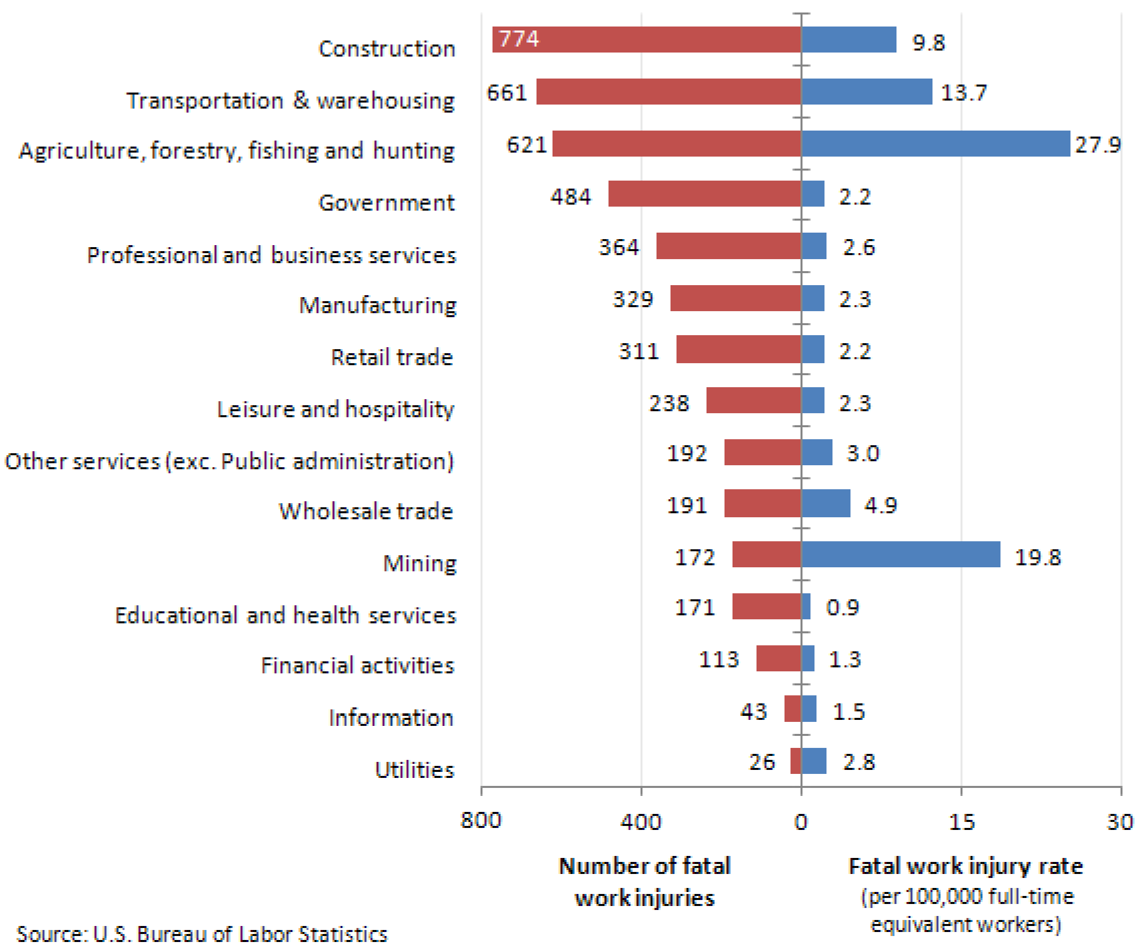


Figure 1-1: Number and rate of fatal occupational injuries in 2010, by industry sector (U.S. Bureau of Labor Statistics, 2012)

After growing concerns over occupational safety, Congress passed the Occupational Safety and Health (OSH) Act of 1970 that was signed by President Nixon. This greatly improved occupational safety, including construction. Multiple initiatives have been made to improve the safety of the construction workers; however, construction industry still 'leads' other industry sectors in occupational fatalities and has been the subject of multiple studies.

1.1 Context

1.1.1 Sustainable development includes construction safety

The United Nations' Brundtland Commission on Environment and Development defines sustainable development as: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). According to the Brundtland Commission, three fundamental components must be addressed for sustainability to exist: (1) environmental protection, (2) economic growth, and (3) social equity. Sustainable development requires that all three components are present. Therefore, in order for a facility, or building, to be considered sustainable, the safety and health of the construction workers must be considered. Construction worker safety is considered as one of four conceptual areas of social equity, and true sustainable design should consider "under-represented groups" such as construction workers (Valdes-Vasquez & Klotz, 2013). Considering the safety and health of the construction workers is part of sustainable development. However, construction worker safety is often left out of the U.S. federal government's policies for sustainable construction and the industry's sustainable rating systems.

1.1.2 Sustainability rating systems do not include construction safety

As the awareness of the need for sustainable design and construction practices has risen, rating systems have been developed by third-parties that can provide a sustainability certification for a facility. When a building receives a sustainability certification, it is often referenced as a green building. Numerous rating systems exist across the world, and some of the most popular in the United States are: the U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED), the Green Building Initiative's (GBI) Green Globes, and the Institute for Sustainable Infrastructure's (ISI) EnVision. The USGBC, GBI, and ISI are all non-profit organizations who claim to support sustainable building or infrastructure design. It is important to note that the U.S. government's Environmental Protection Agency (EPA) has an Energy Star certification program for buildings. However, the EPA claims this certification is only for energy-efficiency in order to reduce greenhouse gas emissions. It is surprising that with the increased awareness of sustainable development that buildings designed and constructed for the current sustainable certifications – either by USGBC, GBI or ISI – do not consider the safety and health of the construction workers. Valdes-Vasquez & Klotz (2013) recommend that the LEED rating system should be modified to include points for construction worker safety. While the design and construction industry is pursuing sustainable certification for their facilities, the social dimension is not completed considered for the certifications (Valdes-Vasquez & Klotz, 2013).

1.1.3 The U.S. Navy's sustainability goals

President Bush signed Executive Order (EO) 13423 – Strengthening Federal Environment, Energy, and Transportation Management – in 2007, which set goals in the areas of energy efficiency, acquisition, renewable energy, toxics reductions, recycling, renewable energy, sustainable buildings, electronics stewardship, fleets, and water conversation. EO 13423 included the requirement for all federal new construction and major renovation projects comply with the 2006 Federal Leadership in High Performance and Sustainable Buildings (FLHPSB) Memorandum of Understanding (MOU), which did not address the safety and health of the construction worker. As a result of EO 13423, the Department of Defense, and subsequently the Department of Navy, directed that all new construction be designed and constructed to a minimum of USGBC's LEED Silver certification.

1.1.4 The U.S. Navy's investment in construction safety and zero-injury objective

The Naval Facilities Engineering Command (NAVFAC) builds and maintains the facilities for all U.S. Navy installations, worldwide, as well as manages the construction on U.S. Marine Corps installations and select U.S. Air Force bases. NAVFAC has emphasized the importance of construction safety for the past several decades. NAVFAC adopted a zero-injury goal for their in-house and contractor workforce. This effort is concurrent with owners in the private industry due to the multiple benefits recognized since the 1990s (Hinze & Wilson, 2000). The obvious benefit to zero injuries is that everyone leaves work in the same condition that they arrived; there are multiple business advantages in having a safe construction site. Low insurance premiums provide incentive for construction companies to maintain a good safety record, reducing the workers compensation claims. Marketability is another incentive for a construction company since some owners – to include NAVFAC – use a safety record as a selection factor (Hinze, Bren, & Piepho, 1995). NAVFAC recognizes the economic and social benefits as it strives for the zero-injury goal.

1.1.5 NAVFAC's initiatives to improve construction safety

To achieve the zero-injury objective, NAVFAC: (1) includes stringent safety regulations within the specifications for the construction contract, (2) considers a construction company's safety record during the selection process, and (3) monitors a construction company's safety program to ensure its effectiveness throughout construction.

In addition to the safety requirements of OSHA's Safety and Health Regulations for Construction (29 CFR 1926), NAVFAC specifies their contractors comply with the United States Corps of Engineer (USACE) Safety and Health Requirements Manual (EM 385-1-1). For any discrepancy between the two regulations, NAVFAC dictates in their construction contracts that the Contractor must adhere to the strictest standard. In addition to specifying adherence to the 29 CFR 1926 and EM 385-1-1, NAVFAC specifies additional safety requirements in their contracts.[1]

Safety has been considered during the source selections for many NAVFAC projects for years; and in 2011, to standardize the process, NAVFAC issued guidance to

[1] Located in the Unified Facilities Guide Specifications 01 35 26, found at http://www.wbdg.org.

include safety as an evaluation factor for the source selection process for construction contractors (2011). For the NAVFAC command that covers the southeast region of the U.S., a pilot initiative specifies that a construction contractor's sub-contractors must meet a minimum Experience Modification Rate (EMR), which is a metric used by insurance companies to determine the premium (Naval Facilities Engineering Command Southeast, 2012). The EMR is explained further in Chapter 2.

To monitor a company's safety program, NAVFAC has multiple items listed in the contract specification that require the attention of the construction contractor staff and NAVFAC field personnel. Prior to any construction, NAVFAC must review and accept the contractor's Accident Prevention Plan (APP). The APP is to be site specific and guidance is found in the U.S. Army Corps of Engineers' Safety and Health Requirements Manual (EM-385-1-1).The APP includes Accident Hazard Analysis (AHA) worksheets for every expected Definable Feature Of Work (DFOW) that are later reviewed with the work crew personnel before they begin work on the DFOW. NAVFAC also specifies the number of safety personnel required for the project; and mishap notifications and required reporting to NAVFAC, in addition to OSHA.

1.2 Scope

The ability to influence safety of a construction project is greatest at the beginning of a project, during the design – either the conceptual or detailed engineering phases, shown in **Error! Reference source not found.** (Szymberski, 1997). There are three primary stakeholders for any construction project: (1) owner, (2) designer, and (3) construction contractor. Many efforts are being made to improve construction safety, but the majority of these efforts place additional requirements on the construction contractor and the workers. Yet, construction safety is also affected by the decisions made by the designer (Hinze & Wiegand, 1992). Having designers consider the safety of construction workers is a paradigm shift from the normal design practice. This study investigates the concept where the design phase is used to reduce, or eliminate, hazards from the construction workers who are considered the "the first tenants" of a project (Szymberski, 1997).

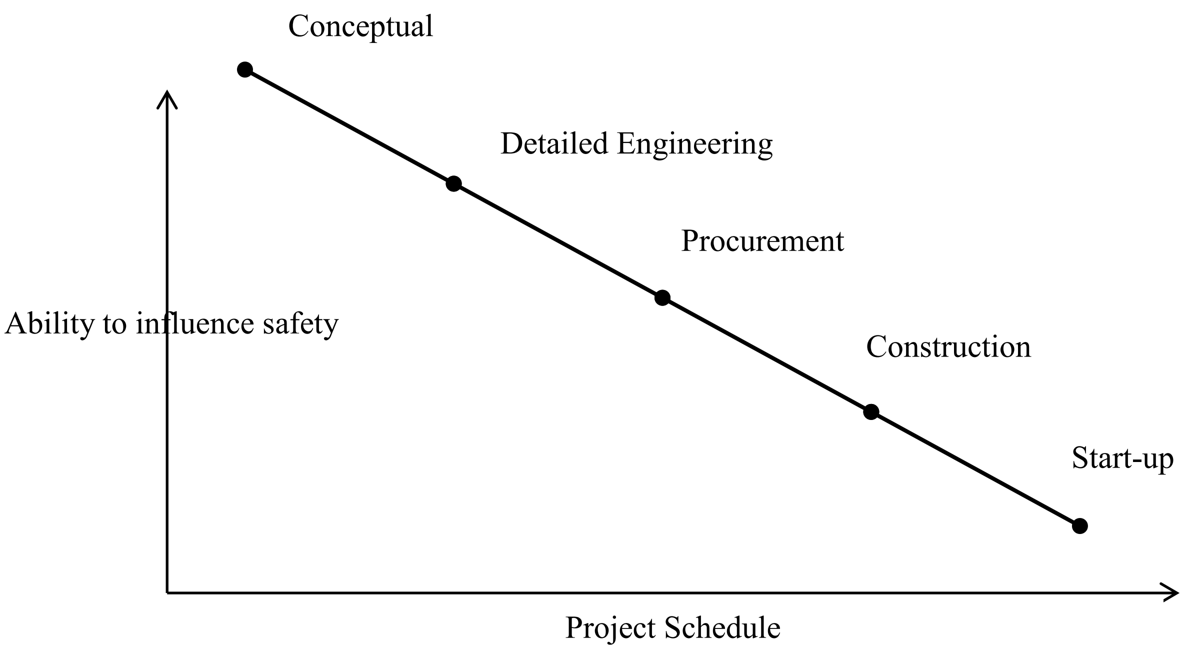


Figure 1-2: Time/safety influence curve (Szymberski, 1997)

1.3 Problem statement

NAVFAC recognizes that the construction industry is hazardous, and has initiated several programs ranging from contract specifications, contractor selection procedures to include safety records as a selection factor, and several management techniques to monitor a contractor's safety program throughout construction. But there is very relatively little emphasis placed on the elimination or reduction of construction hazards in the design phase. Yet, NAVFAC prescribes sustainable designs in their design contracts, but these "sustainable designs" do not include the social equity of construction workers and their safety.

1.4 Research goals

The purpose of this study is examine the existing literature on using the design phase to improve construction worker safety to determine if this concept could be implemented by NAVFAC to improve construction safety for their construction projects. The goals of this research are:

1. Improve construction safety by using the design to reduce, or eliminate, hazards;
2. Outline approaches designers can use to positively influence construction safety; and
3. Identify methods for NAVFAC to have their designers positively influence construction safety.

While the first goal is considered a personal goal as defined by Maxwell (2005) as it is what motivated me to perform this study, it is a commonly shared goal by others. NAVFAC has adopted a zero-mishaps philosophy for several years now, and I know that my desire to improve construction safety has come from my experience – through supervisors and witnessing the dangers inherent to construction.

The second goal is more of intellectual goal in that it seeks to understand the concept of using the design to improve construction safety (Maxwell, 2005). Through understanding the concept, my desire is to achieve my third goal. I want this study to be applicable to industry – specifically to NAVFAC in their objective for zero-mishaps.

1.5 Research approach

To accomplish the goals of this study, the research approach must be discussed. There are two common referenced research approaches – *qualitative* and *quantitative* – that represent the ends of a continuum and the middle of the continuum is labeled as a *mixed-methods* approach (Creswell, 2013). Creswell (2013) states that the ends of the research approach continuum, *qualitative* and *quantitative*, are not distinguished by the use of words or numbers, or open-ended or close-ended methods; but it is based upon three components: (1) philosophical assumptions the researcher possesses, i.e. a philosophical worldview or paradigm; (2) research design; and (3) research methods.

From the four philosophical worldviews discussed by Creswell, shown in Figure 1-3, I identified with the *pragmatism* worldview the most. Since I am a U.S. Navy Civil Engineer Corps officer who has experience with NAVFAC, my problem statement and goals of this research show that I wanted to attempt to improve construction safety through a project's design; i.e. this research is problem centered and real-world practice oriented. Researchers who possess the *pragmatism* worldview focus on the application with little regard to the methods, which leads the researcher to a *mixed methods* approach (Creswell, 2013).

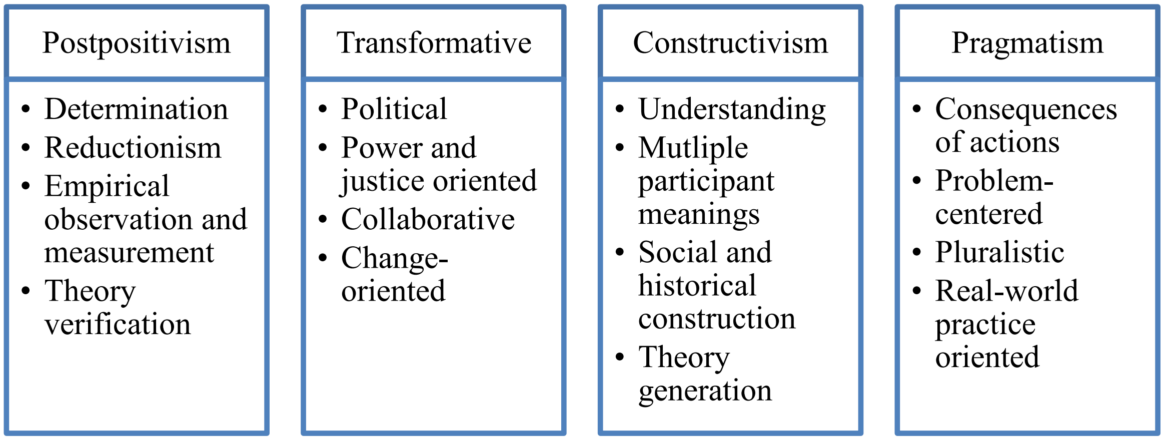


Figure 1-3: Four philosophical worldviews (Creswell, 2013)

The research approach must include a research design type; the design types discussed by Creswell (2013) are shown in Figure 1-4. For this study, I used a *convergent parallel mixed-methods* design. The *convergent parallel mixed-methods* design involves merging qualitative and quantitative data concurrently to develop a summary of available research on the topic (Creswell, 2013, p. 15).

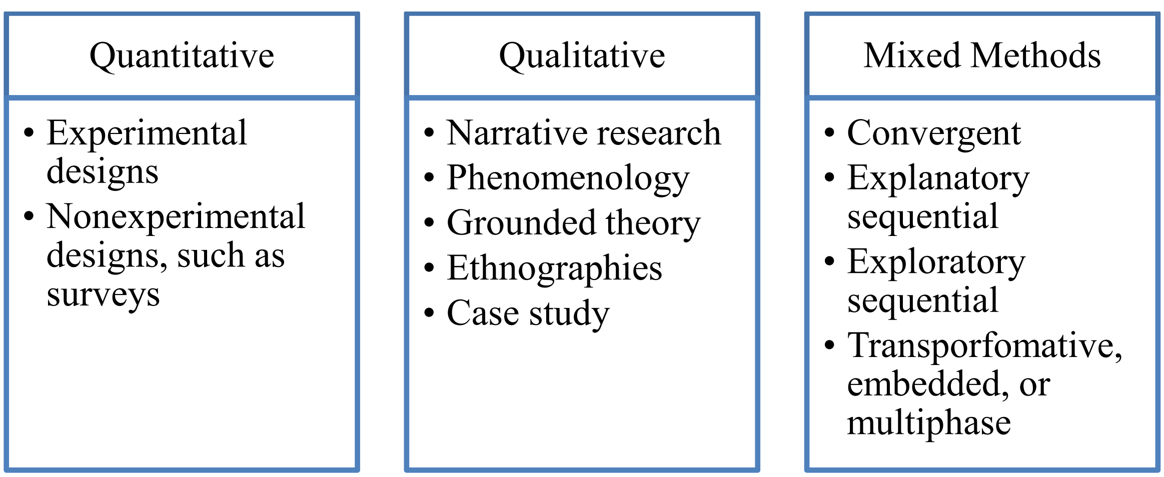


Figure 1-4: List of research designs (Creswell, 2013)

Methods mentioned by Creswell (2013) in Figure 1-5 where the comparisons can be seen between the different approaches – *quantitative*, *mixed-methods*, and *qualitative*.

Combining my research goals; philosophical worldview – *pragmatism*; and research design type – *convergent parallel mixed-methods* – I used the mixed-methods approach to summarize the current research on the concept to consider the safety of the construction workers during the design phase for NAVFAC's review and to consider possible implementation.

Quantitative Methods	**Mixed Methods**	**Qualitative Methods**
Pre-determined	Both predetermined and emerging methods	Emerging methods
Instrument based questions	Both open- and closed- ended questions	Open-ended questions
Performance data, attitude data, observational data, and census data	Multiple forms of data drawing on all possibilities	Interview data, observation data, document data, and audiovisual data
Statistical analysis	Statistical and text analysis	Text and image analysis
Statistical interpretation	Across database interpretation	Themes, patterns interpretation

Figure 1-5: Comparison of research methods (Creswell, 2013)

This study will contribute to knowledge by providing a current summary and analysis of the subject using existing research and my personal experience, as shown in Figure 1-6. Multiple variables exist for construction research – e.g. delivery method, project types and size, geographic location, source selection criteria, and more – that require quantitative and qualitative approaches to understand and present an analysis that considers the "full picture" on the topic of study. Therefore, I plan to use a *mixed-methods approach* to provide a panoramic summary and analysis on the topic of considering the construction workers during the design. In addition to the existing research, I bring my personal experience as a U.S. Navy Civil Engineer Corps officer who has worked for NAVFAC. From my experience with NAVFAC, I can provide some of the limitations to which they can implement the study's subject, e.g. funding resources, federal acquisition regulations, and diverse geographic locations, etc.

Figure 1-6: My contribution to knowledge

1.6 Report structure

To further my research approach, I used the research model presented by Maxwell (2005), as shown in Figure 1-7.

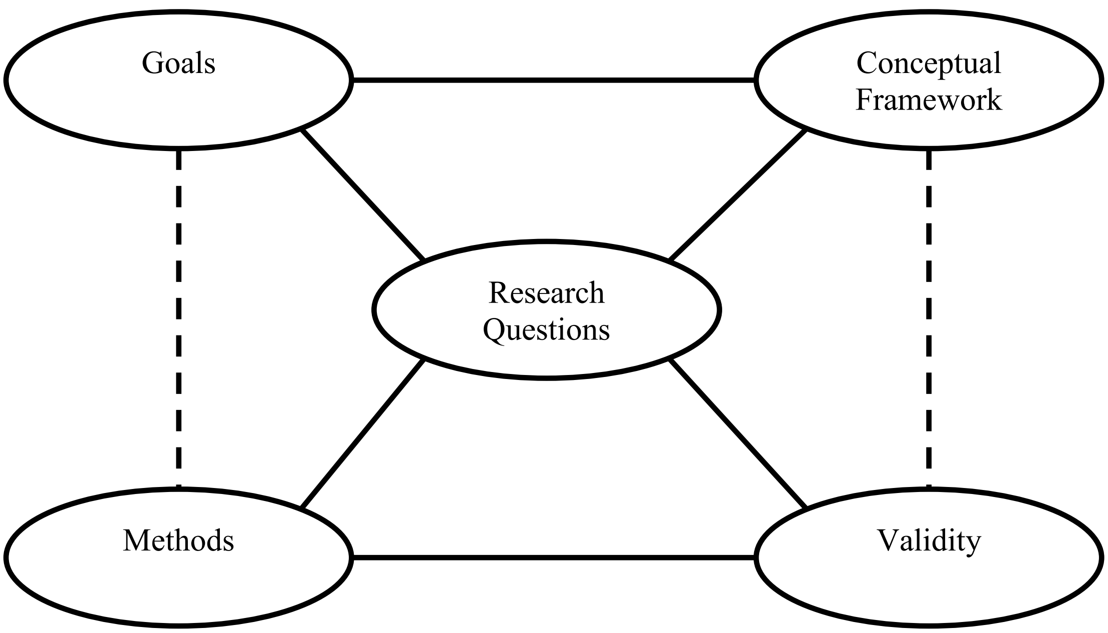


Figure 1-7: Research model (Maxwell, 2005)

The goals explain why I am performing this study; the conceptual framework describe the theories I used – whether grounded or not – to develop the remainder of the study; the research questions describe in detail what I plan to accomplish from this study; methods are the detailed plans in what I do for this study; and validity explores how I might be wrong (Maxwell, 2005). Defined earlier in the chapter, *goals* influence the entire study, and are closely related to the *conceptual framework* and *research questions*, which are both discussed in Chapter 2. The *methods* are explained in Chapter 3 and are connected to the *research questions*, influenced by the *goals*. Chapter 4 outlines the results and analysis of the study, and Chapter 5 is the summary and conclusions of the study where the *validity* is described.

CHAPTER TWO: BACKGROUND, CONCEPTUAL FRAMEWORK AND RESEARCH QUESTIONS

The objective of this chapter to provide background information and to present the conceptual framework used to develop the research questions for this study. The conceptual framework is a system of concepts that was developed through my personal experience and preliminary research that provides organization to my study. From the conceptual framework, the research questions are developed, which are listed at this chapter's conclusion.

2.1 Background

2.1.1 Safety organizations

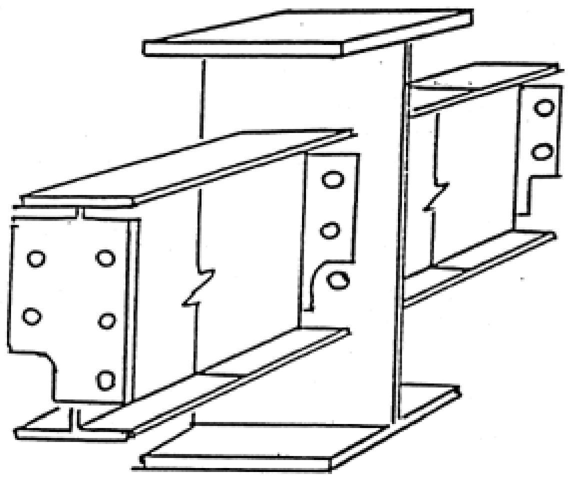
Three safety organizations are referenced in my study. Two organizations are under the federal government. The **Occupational Safety and Health Administration (OSHA)** and the **National Institute for Occupational Safety and Health (NIOSH)** were formed when Congress passed the Occupational Safety and Health (OSH) Act of 1970. OSHA has the authority to establish and enforce occupational safety regulations, and NIOSH is a safety research institute. The **Construction Industry Institute (CII)** is based at The University of Texas at Austin and is a partnership of academic and industry professionals who seek to improve the construction industry through research, initiatives, and best practices (Construction Industry Institute, 2013a).

As part of the U.S. Department of Labor, OSHA is charged with setting and enforcing safety standards and regulations, which are found under Title 29 of the Code of Federal Regulations (29 CFR) (Occupational Safety and Health Administration, n.d.a).

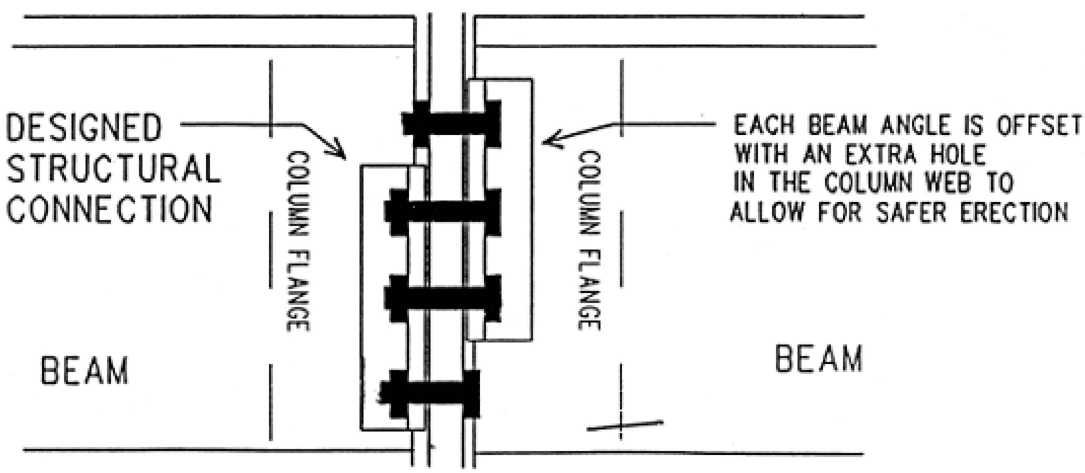
Per the OSH Act, employers are "responsible for providing a safe and healthful workplace;" and "must comply with the General Duty Clause of the OSH Act, which requires employers to keep their workplace free of serious recognized hazards"; Table 2-1 lists the applicable OSHA safety standards and regulations to the construction industry (Occupational Safety and Health Administration, n.d.b). For this study, it is important to note that the majority of the OSHA standards and regulations focus on the construction means and methods. However, some safety standards do apply to designers. Examples of such regulation are requirements set forth in OSHA standard 1926.756 for the steel erection of beams and columns. Figure 2-1, shows the non-mandatory guidelines to comply with standard 1956.756(c)(1) – double connections at columns and/or at beam webs over a column.

Table 2-1: OSHA safety standards and regulations applicable to the construction industry

Standard	**Title**	**Purpose**
Part 1904	Recording and Reporting Occupational Injuries and Illnesses	Requires employers to record and report work-related fatalities, injuries, and illnesses.
Part 1910	Occupational Safety and Health Standards	Contains OSH standards
Part 1926	Safety and Health Regulations for Construction	Contains OSH standards



Clipped end connections are connection material on the end of a structural member which has a notch at the bottom and/or top to allow the bolt(s) of the first member placed on the opposite side of the central member to remain in place. The notch(es) fits around the nut or bolt head of the opposing member to allow the second member to be bolted up without removing the bolt(s) holding the first member.



Staggered connections are connection material on a structural member in which all of the bolt holes in the common member web are not shared by the two incoming members in the final connection. The extra hole in the column web allows the erector to maintain at least a one bolt connection at all times while making the double connection.

Figure 2-1: Double Connections – Illustration of a Clipped End Connection and a Staggered Connection (OSHA, n.d.)

NIOSH is part of the Centers for Disease Control and Prevention within the U.S. Department of Health and Human Services and performs research to identify methods to prevent workplace illness and injury. Two NIOSH programs referenced in this study are the: (1) Fatality Assessment and Control Evaluation (FACE), and (2) Prevention through Design (PtD) programs.

NIOSH established the Fatality Assessment and Control Evaluation (FACE) program in 1982 to have a database of fatal injury investigations to study (Centers for Disease Control and Prevention, 2012a). Personal information is removed in the investigations since they are never intended to determine fault or blame, but only to develop “lessons learned” and identify trends in an attempt to avoid a future recurrence (Centers for Disease Control and Prevention, 2012a).

NIOSH established the PtD program to “prevent or reduce occupational injuries, illnesses, and fatalities through the inclusion of prevention considerations in all designs that impact workers” (Centers for Disease Control and Prevention, 2012b). The PtD National Initiative was launched in 2007 at the first PtD workshop where industry stakeholders discussed the four functional areas – research, education, practice, and policy – as they developed the strategic plan for implementing the goal to “prevent or reduce occupational injuries, illness, and fatalities,” as shown in Figure 2-2 (National Institute for Occupational Safety and Health, 2010).

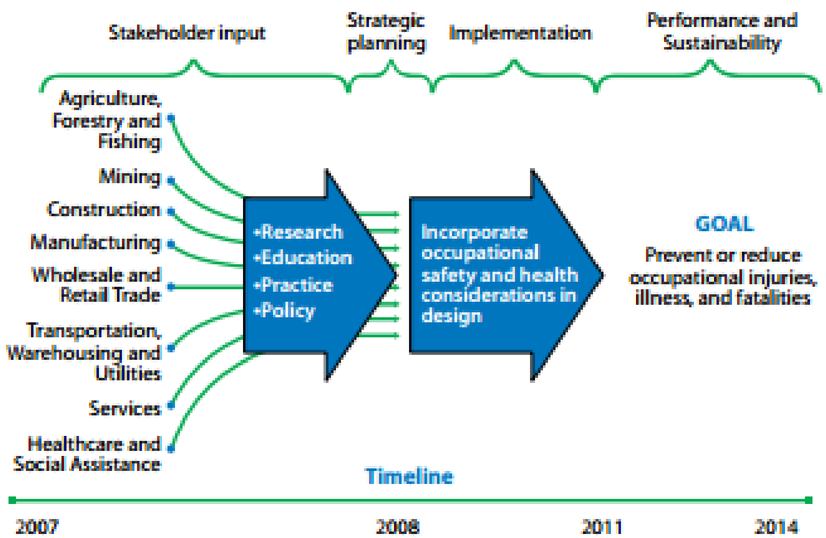


Figure 2-2: PtD National Initiative Timeline (PtD National Initiative Plan)

CII possesses knowledge that has been obtained through years of research that is divided among 14 knowledge areas; one knowledge area is *Safety, Health and Environment*, which contains products under the CII practices for *Design for Safety (DfS)*, listed in Table 2-2 (Construction Industry Institute, 2013b).

Table 2-2: CII Design for Safety Products (CII, 2013b)

Product Name	**Description**
Design for Construction Safety Toolbox, Version 2.0	"…software tool provides a means… to address construction worker safety in [the] design."
Design for Construction Worker Safety	"Web seminar reviews barriers and enablers to designing for construction worker safety and introduces…the *Design for Construction Safety ToolBox*."
Design for Safety	"Highlights the benefits of using the *Design for Safety ToolBox…*"
Addressing Construction Worker Safety in the Project Design	"…identification of design suggestions, or "best practices" …"

Product Name	Description
A Multi-Media Design Aid for Project Hazard Identification & Remediation, Part I	"…describes the background, functional capabilities and design of the *Design for Safety ToolBox* software…"

2.1.2 Construction safety measurement terms

Two safety terms referenced later in this study common in construction industry need to be defined: (1) incident rates, (2) experience modification rate. Both rates can be used to measure a company's safety performance.

The incident rate is defined by OSHA, and companies required, per Part 1904, to submit their rates to OSHA. The two incident rates referenced in this study are: (1) the Recordable Incident Rate (RIR), and (2) the Lost Time Case Rate (LTCR). RIR encompasses all recordable injuries, and LCTR are only those that involve lost workdays. The equations are:

$$RIR = \frac{Total\ recordable\ number\ of\ injuries\ and\ illnesses \times 200{,}000}{Number\ of\ hours\ worked\ by\ all\ employees}$$

$$LCTR = \frac{Total\ number\ of\ injuries\ and\ illnesses\ resulting\ in\ lost\ workday(s) \times 200{,}000}{Number\ of\ hours\ worked\ by\ all\ employees}$$

The Experience Modification Rate (EMR) is calculated for each company to evaluate their safety performance for use by their insurance company. An EMR of 1.0 is industry average. So an EMR greater than 1.0 shows that a company's insurance provider has paid worker compensation claims above the industry average. An EMR less than 1.0 shows that the company's insurance provider has paid less than industry average.

There are several factors that are part of the EMR calculation. An EMR is affected by a company's size, and is not always an "apples-to-apples" comparison (Hinze et al., 1995).

2.2 Conceptual Framework

Maxwell (2005, p. 33) states that a conceptual framework "includes actual and beliefs that [the researcher holds] about the phenomena studied," and proposes four main sources for its development: (1) experiential knowledge, (2) existing theory and research (3) pilot and exploratory research, and (4) thought experiments. For this study's conceptual framework, I used experiential knowledge and existing theory and research.

The following concepts and theories are explored in this section using mainly experiential knowledge and the existing theory and research from Hinze and Wiegand (1992), Gambatese and Hinze (1999), and Hallowell (2013):

- Construction safety is the responsibility of the construction contractor.
- So designers in the U.S. commonly avoid construction safety due to liability concerns and lack of knowledge.
- Ethical codes do not compel a designer to consider the safety of the construction worker.
- However, construction safety can often be a priority of the owner.
- The relationship among the owner, designer, and construction contractor is defined by the project delivery method, which influences the designer's consideration of construction safety.
- Examples exist of design that considers construction safety through research, e.g. NIOSH's PtD and CII's DfS; and from other countries.

2.2.1 Construction safety effects on the stakeholders

The trouble is that promoting construction safety controls is difficult due to the lack of quantifiable benefits. No one can ever be certain if an implemented safety control protected a worker's health and safety. But when safety controls are limited, or almost non-existent, one of two results occur. Either the workforce gets lucky and nothing happens or a safety mishap occurs. Depending on the severity of a safety mishap, the affected parties are, in decreasing order: the injured worker(s) and family; the workers' employer; the prime contractor; sometimes the owner, depending on their involvement; but rarely the designer.

Of course, the injured worker is affected by a safety mishap. As the goal of any construction safety controls is to protect this individual from any type of harm. It is unfortunate that some construction workers leave the construction sites with reduced capabilities, whether it is muscular-skeletal injury, abrasion, contusion, loss of digit or limb, or a loss of life. Obviously, the injured worker's family feels the effect of the injury.

The injured worker's employer feels the effect of the injury. First, they have lost valuable man-hours due to the injury, and may lose more depending on the severity of the injury. Second, their workers compensation rates may be affected by a later date depending on the frequency and severity of other injuries that have occurred. Third, again depending on the severity, fines may be imposed by OSHA, if regulations were violated. Fourth, this affects their safety record, which may make it difficult to obtain work. And fifth, again depending on the severity, there is a possibility of litigation.

Whether or not the injured worker was a direct employee of the prime contractor, the prime contractor feels the effect. A construction mishap involves lost productivity for the majority of the project, if not all; can bring safety investigators to the site, exposing the prime contractor to possible fines for violations, not even related to the mishap; exposes the prime contractor to possible litigation; and provides a poor public relations image for the company and the project. Then based on the owner's involvement, as specified in the contract, the prime contractor may have to provide the owner with an explanation on what happened and their corrective action.

Since the project's productivity is affected by a construction mishap, the owner feels the impact, especially if the prime contractor cannot increase their productivity to regain the lost time, and the project is completed late. Regardless if liquidated damages were incurred, the owner was affected by the late delivery. The owner too can face a poor public relations image and even possible litigation. While the owner has the flexibility to define their role in the project's safety program, more owners are becoming involved due to the increased number of litigations (Huang & Hinze, 2006).

The only project stakeholder left is the designer. From my experience, the designer feels minimal impact from a construction safety mishap. The only reason the designer may get involved is if the designer was determined to be negligent in their design – known as designer liability. Yet, the design phase is where a project can be influenced the most.

2.2.2 Construction safety is the responsibility of the construction contractor

Designing to reduce, or eliminate, construction hazards is a relatively unheard of concept in the U.S. OSHA regulations have placed the responsibility of a safe workplace on the employer through the General Duty Clause; this means construction worker safety is the responsibility of their employer – the construction contractor.

2.2.3 Designers avoid construction safety due to liability concerns and lack of knowledge

Since construction safety responsibility is placed on the construction contractor, designers lack motivation to consider it. Designers separate themselves from the construction means and methods since that is the responsibility of the construction contractor; two common reasons explain this separation: (1) fear of liability, and (2) lack of knowledge (Hinze & Wiegand, 1992). These two reasons build off of each other so the separation between the designer and the construction methods has increased over time. While a designer may observe, at times, their project's construction, their focus is on compliance with the design specifications, with little concern over the construction means and methods.

2.2.4 Ethical codes do not compel a designer to consider the safety of the construction worker

The Code of Ethics for the American Institute of Architects (2012) states that the public safety is of the "finished product". This disregards consideration of the construction worker. However, the Code of Ethics (2007) for the National Society of Professional Engineers references the "safety, health, and welfare of the general public" in the first canon and first rule of practice. So there is more motivation for a Professional Engineer to consider the safety of the construction worker; however, the question is whether a construction worker is considered of the "general public."

2.2.5 Owners can influence designers to consider construction safety

Often attempts to improve construction safety become a business issue due to the many variables inherent to construction, e.g. project delivery method, project type, required completion date, environmental factors, available workforce and equipment, funding statutes, et cetera (Hallowell, 2013). Therefore, the owner has influence since they are the stakeholder funding the project product and determine whether the designers are to reduce, or eliminate, construction hazards from the construction workers. Owners have considerable influence over the designers in their consideration of construction worker safety (Hinze & Wiegand, 1992).

2.2.6 Project delivery method influences the use of safety controls during the design phase

The project delivery method defines the relationship among the three key stakeholders – owner, designer, and construction contractor – and has a large influence on the designer's consideration for the safety of the construction worker. According to the American Institute of Architects and the Associated General Contractors (AGC) of America (2011), four project delivery methods exist: (1) design-bid-build (D-B-B), (2) design-build (D-B), (3) construction management at-risk (CMA-R), and (4) integrated project delivery (IPD). Even though construction safety is the legal responsibility of the construction contractor – through the OSH Act General Duty Clause – considering the construction worker during the design phase is the action of the designer. Subsequently, the designer is influenced by the owner and possibly, the construction contractor, depending on the project delivery method.

For the D-B-B method, the only influence for the designer to consider the safety of the construction worker is the owner. The construction contractor will not be selected until the designer finalizes the design. Only after a final design is produced will the owner be able to solicit and select a construction contractor.

The D-B method involves only one contract with the owner. It is between the owner and the construction contractor, and the construction contractor has a partnership with the designer. Since the construction contractor is already chosen for the project, the designer can be influenced by the construction contractor to consider the safety of the construction workers. Often for D-B projects, the construction contractor has the contract with the owner, and the contract has the designer subordinate to the construction contractor. In addition to the construction contractor, the owner still has influence on the designer to consider construction worker safety.

Similar to the D-B-B method, the owner has two separate contracts for the CMA-R method. One is between the designer and owner, and the second is between the construction management agency and owner. The construction management agency is responsible for hiring the construction contractor, and ensures the owner a guaranteed maximum price specified in their contract. Unlike the D-B-B method, the construction management agency is typically involved during the design phase. This allows the construction management agency to provide feedback on the design before it is final. So while the designer's main influence to construction worker safety comes from the owner, the construction management agency can also influence the designer to consider construction safety. However, since a construction management agency usually hires companies to perform the construction, they never are the employer of the construction workers so they lack the legal responsibility to invest into the construction workers' safety and health.

The IPD is a relatively new delivery method that defines itself as a collaborative approach. There is a multi-party arrangement of all project stakeholders who are present at the beginning of a project. Due to the collaborative approach, it seems that designer could be influenced to consider construction safety by the owner and construction contractor, provided it is included into the initial agreement.

2.2.7 Examples of affecting construction safety using design

Unlike the U.S., other countries have safety regulations that share the responsibility for construction safety with the designers. In 1992, Europe passed the Temporary and Mobile Construction Sites Directive placing some responsibility for construction safety on to the designers that resulted in the United Kingdom passing the Construction (Design and Management) Regulations (CDM) in 1994 (J. Gambatese & Hinze, 1999), later issuing a revised CDM in 2007 (Health and Safety Executive, n.d.). According to CDM 2007, designers are required to: (1) eliminate hazards and risks during design, and (2) provide information about remaining risks.

As a result of CDM, the Royal Institute of British Architects has provided multiple sources to assist architects in designing for construction safety that can be located on the internet. In addition, Hinze and Wiegand (1992) and Gambatese and Hinze (1999) offer the several design suggestions that consider the safety of the construction worker in their study. The following are design suggestions provided by Hinze and Wiegand (1992):

- Design trenches at minimum feasible depths.
- Detail methods to be used in trenches.
- Avoid high fill and embankment heights.
- Specify temporary decking to be installed as soon as possible to prevent injury from falling.
- Substitute hazardous materials with less hazardous materials for chemical cleaning, paints, and castings.
- Specify natural gas to be purged from manholes.
- Detail the methods for polychlorinated biphenyl (PCB) removal.
- Specify rigging procedures and crane placement for larger lifts.
- Design trench requirements to match shoring systems.
- Consider noise emissions from installed equipment.
- Use three-dimensional computer-assisted design (CAD) programs to plan safe work sequencing and to identify and mediate hazards before construction begins.
- Conduct a hazard assessment for construction during design.

- Valve stems and motor operators on valves are examined during design to determine if they will protrude into walkway areas, and are rotated so as to provide safe passage on stairs and platforms.
- Permanent stairways and walkways are designed to be constructed first, so that the use of temporary scaffolding is minimized.
- Permanent stairs and walkways are designed as integral components of piping and structural steel assemblies.
- Design permanent stairs to be constructed first, and verify that all component assemblies are modified suitably to accommodate the required access for installation with the stairs in place. (pp. 679-680)

2.3 Research Questions

Research questions provide the link for a study's components as shown in Figure 1-7; and they consider why I am performing this study – the goals – and the tentative and existing theories on the subject – the conceptual framework (Maxwell, 2005).

To accomplish this study's goals, the research questions should fit within the following stages: (1) owner's justification, (2) influence factors, and (3) application methods. From experience, presenting any new and unique approach to a problem, justification must be provided to answer the question "why?" Second, factors that influence the proposed approach should be identified, whether they are positive or negative, to address the multiple questions that start with "what…?" And finally, examples of applications need to be presented to address the "how" questions. Based on these stages identified from this study's goals and the conceptual framework discussed earlier in the chapter concepts to explore in this study are shown in Figure 2-3.

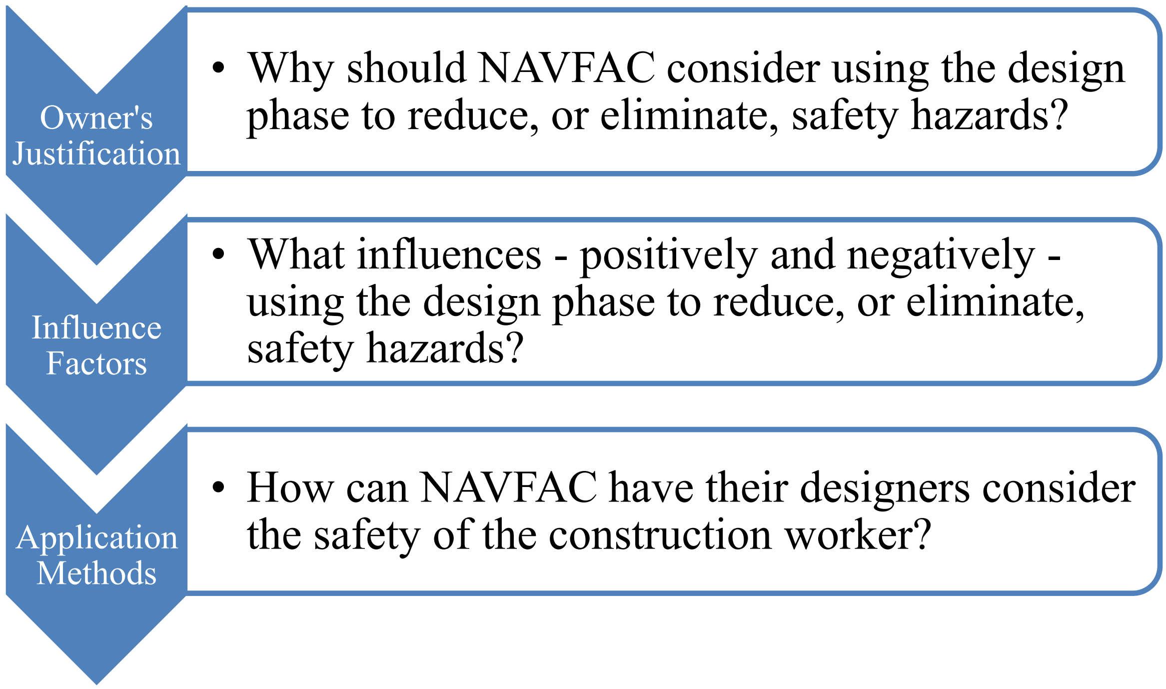


Figure 2-3: Research Questions

CHAPTER THREE: RESEARCH METHODS

This chapter outlines the research method I used to provide a panoramic analysis to achieve this study's goals and answer the research questions. Based upon the research approach discussed in Chapter 1, an accepted approach was needed to identify, review, and synthesize available studies. While no systematic research method exists specific to construction research, I selected the *systematic literature review* method developed for the software engineering domain, developed by Kitchenham (2004). Kitchenham (2004) developed the *systematic literature review* method by evaluating the systematic methods that were accepted for medical research and tailored them towards software engineering. Kitchenham (2004) presented this method at the 2004 International Conference on software Engineering where it was widely accepted.

Kitchenham (2004) states that while multiple reasons exist to use this *systematic literature review* method, the three most common are:

- Summarize existing evidence on a topic;
- Identify any research gaps to suggest areas for improvement; and
- Provide a framework for any new research.

The reason I chose to use the Kitchenham (2004) *systematic literature review* is that I wanted to provide a panoramic analysis of the existing studies that address this study's research questions, i.e. summarize existing evidence.

The Kitchenham (2004) *systematic literature review* involves a pre-defined protocol so it requires a greater effort than a routine literature review. *Primary studies* are those that are identified, reviewed, and synthesized into the *secondary study*. A *secondary study* contributes to knowledge because of its increased validity as it has examined the validity for the *primary studies,* exposing false assumptions, bias, or both (Kitchenham, 2004).

Kitchenham's (2004) *systematic literature review* consists of three main phases: (1) planning the review, (2) conducting the review, and (3) reporting the review as shown in Figure 3-1. The remainder of this chapter discusses the application of the first two phases of this study. The third phase, *reporting the review*, is discussed in Chapter 4.

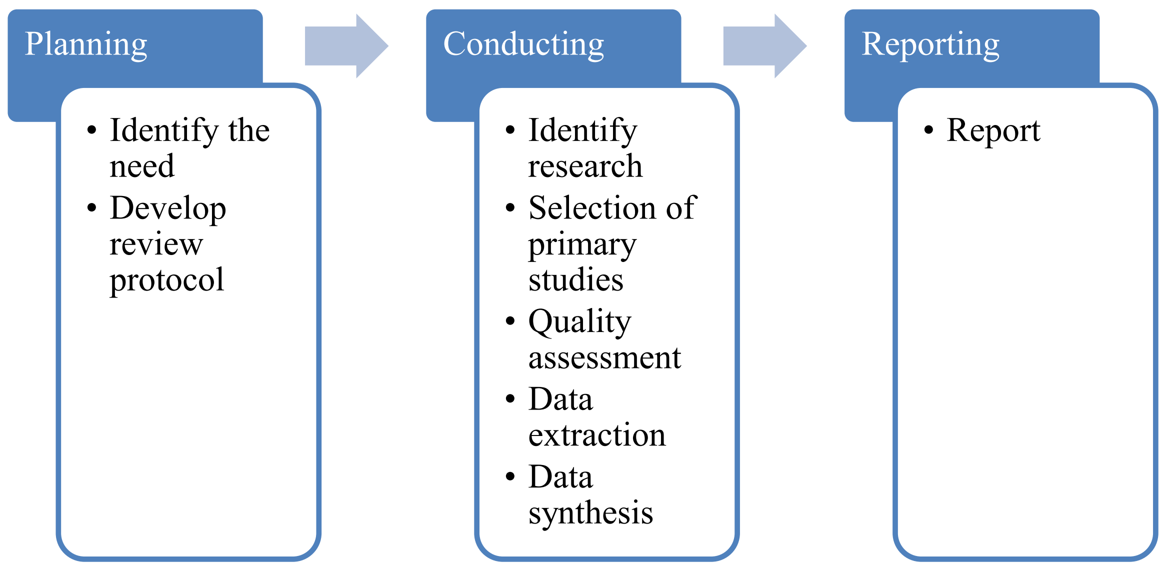


Figure 3-1: Systematic Literature Review Process (Kitchenham, 2004)

3.1 Planning the review

For the first phase, *planning the review*, the need for a systematic review was identified, and a review protocol developed.

The need for this *review* comes from the research goals defined in Chapter 1 and the research questions developed in Chapter 2. Protocol for this *review* can be found in

Appendix A and was developed according to following principles outlined by Kitchenham (2004):

- Background and rationale for the *review*;
- Research questions, to be answered;
- Search strategy, to include search terms, databases, and mediums;
- Selection criteria and procedures used to filter and obtain only relevant studies;
- Quality assessment criteria;
- Data extraction strategy;
- Synthesis strategy; and
- Project timetable.

The **background and rationale** for the review is based on the need for the review. The **research questions** developed and listed in Chapter 2 were used. For the **search strategy**, search terms were taken from the terms used by the large organizations that have funded research on this study's subject – CII (Design for Construction Safety [DfCS]) and NIOSH (Prevention through Design [PtD]). Since Hinze and Wiegand (1992) are attributed to popularizing the DfCS and PtD (for construction) concepts found during preliminary research (Behm, 2005), the date for the search was from 1992 to the present. The medium was only for journal articles and conference proceedings based on the assumption that books are published only after a concept has been thoroughly researched with multiple journal articles published; information gathered in books would probably be redundant from the information gathered in the journal articles. The Compendex database was used as it is a very comprehensive database, and contains several respectable sources, e.g. journals from the American Society of Civil Engineers and Elsevier. The **study selection criteria** focused on selection of articles that could answer the research questions, and all articles were to be gathered, regardless of how generic or specific its application. The **quality assessment criteria** used was not intended to completely disregard a journal article, but only to provide some level of validation. Since the data sources gathered were expected to be electronic, the defined **data extraction strategy** included the use of bibliographic software, i.e. RefWorks, which would make the data extraction simple. A **project timetable** was defined to guide this study and ensure adequate time was given to the *review,* yet accomplished in reasonable time period.

3.2 Conducting the review

To *conduct the review*, I performed the following steps in accordance with the protocol: (1) identified the initial research, (2) selected the primary studies, (3) performed the quality assessment, (4) extracted data, and (5) synthesized the data.

Using the search strategy defined in the protocol, I **identified the initial research**. Table 3-1 displays the date of the search, medium, search terms, and the number of results. While Table 3-1 shows a total of 78 results, 13 were found to be duplicates; so the number of research studies identified was 65.

Table 3-1: Systematic Literature Review Search Results Documentation

Search Date Performed	Medium	Term	Number of Results
6-Jun-13	Journal Articles	“design for construction safety”	3
6-Jun-13		“prevention through design”	16
6-Jun-13		“construction safety” and “design"	21
6-Jun-13		“construction safety” and “sustainability”	3
6-Jun-13	Conference Articles	“design for construction safety”	2
6-Jun-13		“prevention through design”	8
6-Jun-13		“construction safety” and “design”	20
6-Jun-13		“construction safety” and “sustainability”	5
6-Jun-13	Article in Press	“design for construction safety”	0
6-Jun-13		“prevention through design”	0
6-Jun-13		“construction safety” and “design phase”	0
6-Jun-13		“construction safety” and “sustainability”	0

I **selected the primary studies** based on whether the research addressed the concept of using the design phase to eliminate, or reduce, construction hazards for the workers for commercial buildings, per the protocol. Three common reasons existed that excluded articles; the article focused on: (1) residential construction, not commercial; (2) designing for the construction stage, e.g. ensuring structural stability during the construction stage; and (3) practices outside the U.S. Table B-2 lists the research articles that were not selected as primary studies with the reason for exclusion noted. A total of 26 journal articles and conference proceedings were selected as *primary studies* and are listed in Table 3-2 and Table 3-3, respectively.

Table 3-2: Journal articles used as primary studies

Authors	Title	Periodical	Year	Volume	Issue
Behm, Michael	Linking construction fatalities to the design for construction safety concept	Safety Science	2005	43	8
Behm, Michael	Safe design suggestions for vegetated roofs	Journal of Construction Engineering and Management	2012	138	8
Coble, Richard J.; Blatter Jr.,Robert L.	Concerns with safety in design/build process	Journal of Architectural Engineering	1999	5	2
Dewlaney, Katie Shawn; Hallowell, Matthew	Prevention through design and construction safety management strategies for high performance sustainable building construction	Construction Management and Economics	2012	30	2
Gambatese, John A.	Research Issues in Prevention through Design	Journal of Safety Research	2008	39	2
Gambatese, John A.	Liability in designing for construction worker safety	Journal of Architectural Engineering	1998	4	3
Gambatese,John A.; Behm,Michael; Rajendran,Sathyanarayanan	Design's role in construction accident causality and prevention: Perspectives from an expert panel	Safety Science	2008	46	4
Gambatese, John A.; Hinze, Jimmie W.; Haas, Carl T.	Tool to design for construction worker safety	Journal of Architectural Engineering	1997	3	1
Hallowell, Matthew R.; Gambatese, John A.	Construction safety risk mitigation	Journal of Construction Engineering and Management	2009	135	12

Authors	**Title**	**Periodical**	**Year**	**Volume**	**Issue**
Landis Floyd,H.	Prevention through design	IEEE Industry Applications Magazine	2010	16	3
Landis Floyd,H.; Liggett, Danny P.	Hazard mitigation through design	IEEE Industry Applications Magazine	2010	16	3
Manuele, Fred A.	Prevention through Design (PtD): History and Future	Journal of Safety Research	2008	39	2
Mitropoulos, Panagiotis; Cupido, Gerardo; Namboodiri, Manoj	Cognitive approach to construction safety: Task demand-capability model	Journal of Construction Engineering and Management	2009	135	9
Rajendran, Sathyanarayanan; Gambatese, John	Risk and financial impacts of prevention through design solutions	Practice Periodical on Structural Design and Construction	2013	18	1
Rajendran, Sathyanarayanan; Gambatese, John A.	Development and initial validation of sustainable construction safety and health rating system	Journal of Construction Engineering and Management	2009	135	10
Toole,T. M.; Gambatese, John	The Trajectories of Prevention through Design in Construction	Journal of Safety Research	2008	39	2
Zhang, Sijie; Teizer, Jochen; Lee, Jin-Kook; Eastman, Charles M.; Venugopal, Manu	Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules	Automation in Construction	2013	29	

Table 3-3: Conference proceedings used as primary studies

Authors	Title	Conference Proceeding
Dharmapalan, Vineeth; Gambatese, John A.	Comparison of design risk factors of multistory commercial office buildings	Construction Research Congress 2012: Construction Challenges in a Flat World, May 21, 2012 - May 23
Floyd,H. L.; Liggett, Danny P.	The NIOSH "prevention through design" initiative applied to electrical hazards in construction	2008 55th IEEE Petroleum and Chemical Industry Technical Conference, PCIC 2008, September 22, 2008 - September 24
Gambatese, John A.	Safety constructability: Designer involvement in construction site safety	Construction Congress VI: Building Together for a Better Tomorrow in an Increasingly Complex World, February 20, 2000 - February 22
Hinze, Jimmie	The need for academia to address construction site safety through design	Construction Congress VI: Building Together for a Better Tomorrow in an Increasingly Complex World, February 20, 2000 - February 22
Kasirossafar, Mohammad; Shahbodaghlou, Farzad	Application of visualization technologies to design for safety concept	6th Congress on Forensic Engineering 2012: Gateway to a Better Tomorrow, October 31, 2012 - November 3
Qi, Jia; Issa, R. R. A.; Hinze, J.; Olbina, S.	Integration of safety in design through the use of building information modeling	2011 ASCE International Workshop on Computing in Civil Engineering, June 19, 2011 - June 22
Taiebat, M.; Ku, K.	Design and planning for safety (DPfS); A factor modeling approach to find the best response to hazard	AEI 2011: Building Integrated Solutions, March 30, 2011 - April 2
Toole, T. M.; Carpenter, Gabrielle	Prevention through design: An important aspect of social sustainability	International Conference on Sustainable Design and Construction 2011: Integrating Sustainability Practices in the Construction Industry, ICSDC 2011, March 23, 2011 - March 25
Zhang, Sijie; Lee, Jin-Kook; Venugopal, Manu; Teizer, Jochen; Eastman, Charles M.	A framework for automatic safety checking of Building Information Models	Construction Research Congress 2012: Construction Challenges in a Flat World, May 21, 2012 - May 23

In accordance with the protocol, I performed the **quality assessment** of the *primary studies*, which is shown in Table B-3. No studies were disregarded because of the quality assessment, but the quality assessment procedure is required to provide a level of validity. The reference type was noted along with the peer review. The number of times the *primary studies* was cited in Google Scholar was noted. The type of study was stated along with any issues, or discrepancies, found from quantitative data referenced from previous studies. Per the Kitchenham (2004), examination for publication bias was performed, but no studies showed signs of significant publication bias. No major issues for quality were discovered for the *primary studies.*

Data extraction involved reading all *primary studies* and gathering all theories with appropriate level of data for the study. Some of the conference proceedings were found to reference the same study found in journal article that had been gathered so consideration was made to evaluate only one of the *primary sources*. Then I synthesized the data to fit into one of the three stages – owner's justification, influence factors, and application methods.

CHAPTER FOUR: RESULTS AND ANALYSIS

The results from the *systematic literature review* were organized into the three stages that were discussed in developing the research questions in Chapter 2. The first stage provides **justification** for an owner to consider construction safety in the design process. The second stage describes the **influences** on designing for the safety of the construction worker. The third stage focuses on the **application methods** of reducing the number of construction hazards during design.

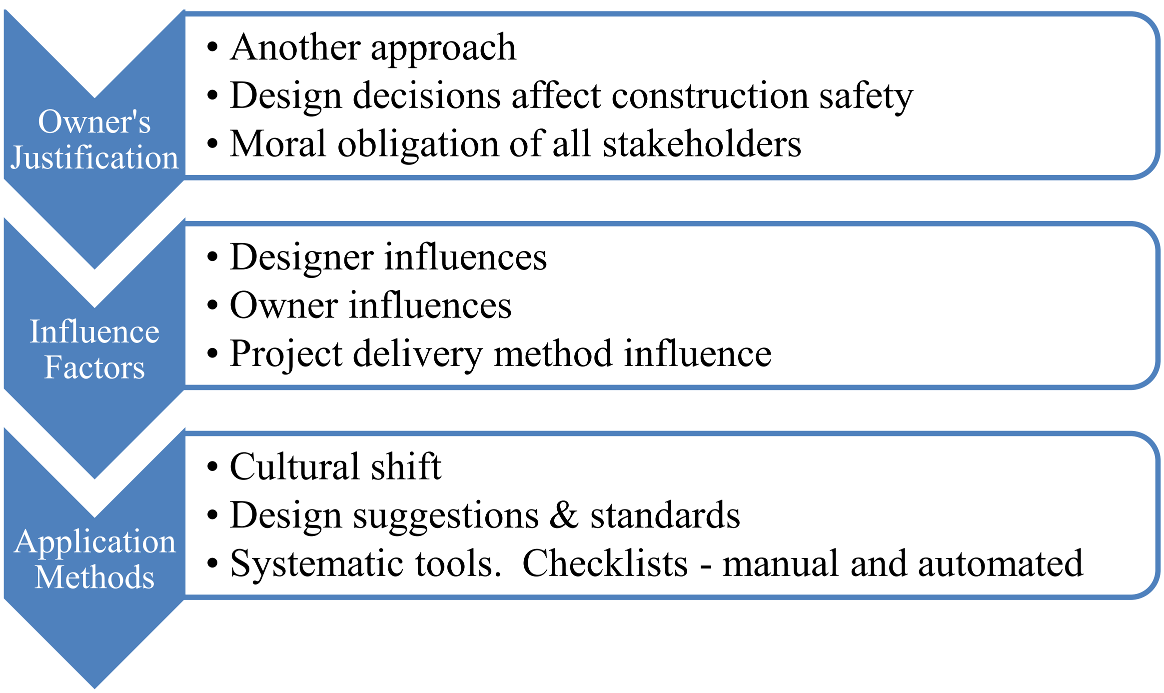


Figure 4-1: Summary of results

4.1 Justification for the owner

Three reasons exist for why owners should consider the design phase to reduce, if not eliminate, construction hazards. First, using the design phase is **another approach** to reducing construction hazards, i.e. a shift in paradigm. Second, a **connection** is shown between design and construction worker safety. Finally, ethical reasons exist, but are somewhat ill-defined for designers to consider construction safety for project.

4.1.1 Another approach to construction safety

Mitropoulos, Cupido, and Namboodiri (2009) explain that three paradigms exist in construction safety: (1) normative, (2) error-based, and (3) cognitive engineering. Most efforts to improve construction safety are from the normative paradigm, which is based on enforcing safety rules and regulation. Using a cognitive engineering approach, safety program elements focus on adjusting the factors that affect the task demands (e.g. production factors) and the applied capabilities (e.g. workload, resources and design). Mitropoulos et al. (2009) list three key factors in construction safety: (1) production, (2) teamwork, and (3) the task-capability interface (TCI) model. Mitropoulos et al. (2009) adopted the TCI model from Fuller (2005), shown in Figure 4-2. According Fuller (2005) and Mitropoulos et al. (2009), a *loss of control* occurs when the task demand is greater than the capability; and a *loss of control* results in either a *lucky escape* or *collision*. Decisions made in the design phase affect the *task demands* of this model, affecting the chance of a *loss of control* (Mitropoulos et al., 2009).

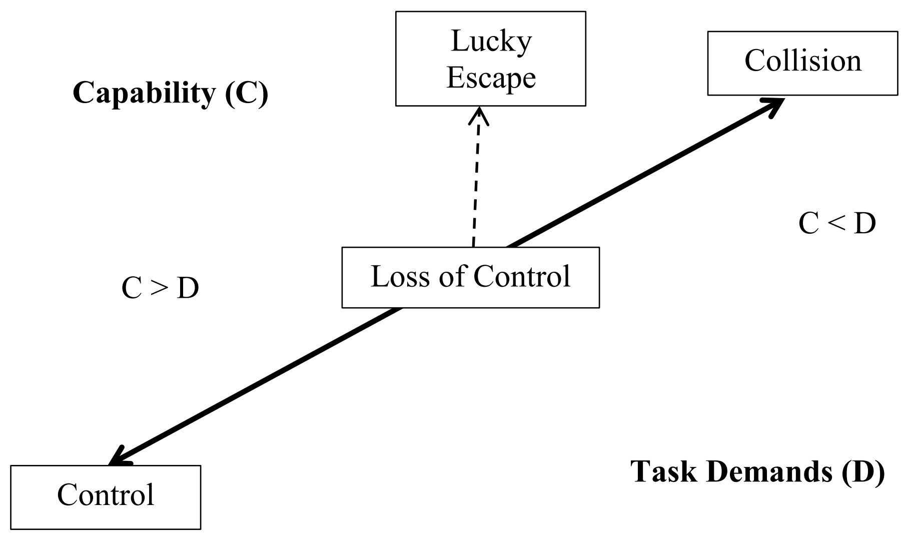


Figure 4-2: Outcomes of the dynamic interface between task demand and capability (Fuller, 2005)

While it appears that Hinze and Wiegand (1992) prompted research for the topic of using the design phase to improve construction safety – through the CII, NIOSH, and others – the National Safety Council's 1955 Accident Prevention Manual suggested this approach (Toole & Carpenter, 2012). Addressing construction safety during the design phase is a "proactive life-cycle approach" to address a project's construction safety (Toole & Carpenter, 2012, p. 187).

4.1.2 Design decisions affect construction safety

To understand the relationship between design decisions and fatal occupational injuries in the construction industry, Behm (2005) reviewed investigations from 224 fatal injuries contained within NIOSH FACE database. In addition, to the main hypothesis, to relate the design decisions to the fatal injuries, Behm (2005) established five additional hypotheses to investigate if there was any relationship between the fatal injury and the construction: (1) nature (i.e. new construction, renovation, and demolition), (2) type (i.e.

commercial, residential, and industrial), (3) design element according to the 16-division specification standard[2], (4) contractor's Standard Industrial Classification (SIC) code[3], and (5) designer's discipline. The results from Behm (2005) study are:

- 42% of the cases reviewed could have been prevented in the design phase;
- New construction and renovations were equally represented for the design's impact on the fatal injuries, only 3% of the projects were demolition so they were disregarded in the analysis;
- All construction types were equally represented for design's impact on the fatal injuries;
- The combined thermal moisture and doors divisions and metal divisions[4] had the most links to fatal injuries;
- Roofing and structural steel construction companies showed the highest correlation between the design decisions and the fatal injuries; and
- Architecture was determined to have the most influence on reducing, or eliminating, construction hazards in the design phase, compared to civil[5], mechanical, and electrical engineering.

Behm (2005) lists design guidelines, both existing at the time and those that were developed from the research, that were not followed and resulted in one, or more, of the

---

[2] From the Construction Specification Institute (CSI)'s MasterFormat 1995 Edition.
[3] Four digit code used by the government to classify industry areas.
[4] The fatal injuries for the metal divisions were primarily falls from structural steel.
[5] Civil/structural engineers are involved in multiple aspects, not just designing structural steel, which was a significant contributor to the number of fatal injuries.

224 fatal injuries investigated in this research and additional design suggestions that developed from the research.

Gambatese, Behm, and Rajendran (2008) performed a study to validate Behm (2005) by selecting an expert panel to review ten of the 224 cases. There was a 71% agreement rate on Behm (2005) results (J. A. Gambatese et al., 2008).

Even though it has been shown construction safety can be influenced by design phase; designing for construction safety is only one element of construction safety (Behm, 2005; J. A. Gambatese et al., 2008). Construction safety is multi-faceted, and many variables affect the effectiveness of designing for safety. Yet, to increase the effectiveness of designing for safety, relationships need to be made for specific design features and construction workers' safety (J. A. Gambatese, 2008).

4.1.3 A level of moral obligation exists

Hinze (2000) states it is debatable whether there is a moral obligation for a designer to consider construction safety during the design phase. Using the designers' code of ethics, Hinze (2000, p. 1189) states the dilemma of the moral obligation is "most clear for members of the National Society of Professional Engineers (NSPE) and less so for members of the American Institute of Architects (AIA.)" This dilemma is given for the differences of the ethical codes between the AIA and NSPE, as mentioned in the conceptual framework in Chapter 2. Therefore, the moral obligation to construction safety during the design phase is still open to interpretation.

4.2 Influences on considering construction safety during the design phase

The two principal influences on the use of DfCS/PtD are the **designer** and the **owner**. Their relationship, defined by the **project delivery method**, also affects the consideration of construction worker safety in the design phase.

4.2.1 Designers are resistant

Resistance by design professionals is one of the greatest challenges for consideration of construction worker safety during the design phase (Toole & Carpenter, 2012). Multiple priorities – either from the designer and sometimes the owner – consume the designer's focus, making it difficult to consider designing for safety, which is a cultural shift from the normal process (J. A. Gambatese, 2008). Designers remain reluctant to design for construction safety for two main reasons: (1) lack of construction knowledge and (2) liability concerns.

Designers must understand construction processes in order to design for safety (Coble & Blatter Jr., 1999), and any lack of construction knowledge is a barrier for designers to consider construction safety in their design (Toole & Carpenter, 2012). The lack of knowledge is perpetuated by the lack of consideration of safety in design standards. For example musculoskeletal injuries are common in construction, mainly due to working limited areas; yet, designers have limited capability to improve this on their design since no standard clearances are published, expect for steel erection (Toole & Gambatese, 2008).

Liability concern is another issue for designers considering construction safety during the design phase. A study performed by Gambatese (1998) investigates the issue of designer liability as it relates to construction safety using past legal cases. First, Gambatese (1998) discusses the responsibility of a professional, which is outlined in a code of ethics. The NSPE Code of Ethics has an all-inclusive statement that engineers shall: "Hold paramount the safety, health, and welfare of the public" (2007); the AIA Code of Ethics is more specific that architects shall consider safety for the "finished product" (2012). Despite the difference between the ethical codes for architects and engineers, Gambatese (1998) makes reference to cases that a design professional would be exposed to liability only to a party to which there was a contractual agreement; however, Gambatese (1998) mentions that recent legal cases show that third parties (i.e. injured worker) may be able to bring forth claims based on negligence in the future. Gambatese (1998) highlights that designers involved in liability cases are often questioned if they were operating within the profession's standard of practice. In the relationship to designing for construction safety, the legal cases Gambatese (1998) reviewed for design-bid-build projects show that if safety knowledge was implemented, the design professional was not held liable; however, the design professional was held liable if safety knowledge was not implemented. Figure 4-3 summarizes the conclusions for Gambatese (1998).

	Safety Knowledge Implemented	Safety Knowledge Not Implemented
Not Standard Practice	Not Liable	Liable
Standard Practice	Not Liable	Liable

Figure 4-3: Designer Liability for Worker Injuries or Fatalities (Gambatese, 2008)

4.2.2 *Owners influence safety*

An owner can make construction safety a priority for a project, greatly influencing it (Coble & Blatter Jr., 1999). From my observation, in recent years, many owners are including past safety performance as a selection factor for projects. Construction contractors have noticed that future work depends on their safety performance, and are implementing aggressive construction safety programs.

Hallowell and Gambatese (2009) compiled a list of the most effective safety program elements, and used the Delphi method to narrow the most effective elements to include ‘upper management support’ and ‘subcontractor selection and management.’ Due to the rise of safety interest for owners, many construction contractors’ upper management place safety as a priority. Thus the ‘upper management support’ referenced by Hallowell and Gambatese (2009) as an effective safety program element could be attributed to the owners’ influence.

According to a case study performed by Rajendran and Gambatese (2013), cost was perceived to be a major barrier for construction PtD solutions. It is known that designers will charge more if they need to consider construction safety during the design phase. However, some researchers mention that by considering the safety and health of the construction worker during the design, construction costs may decrease due to fewer temporary safety controls and decreased risk to the workers, lowering worker compensation and insurance premiums. Gambatese (2008) claims “cost shifting” occurs when consideration is not made for the construction worker’s safety during the design – i.e. shifting safety control costs from the designer to the construction contractor. The owner may prefer higher design fees to avoid injury-related costs of construction and possible litigations (J. A. Gambatese, 1998), and a solution to help prioritize construction safety during the design phase is to educate owners that this approach may decrease a project's total cost (Toole & Carpenter, 2012). My observation is that while claims exist that "cost shifting" occurs, it is difficult to quantify, given the variety of projects and other factors involved. This is consistent with Gambatese (2008) who recognizes more research is needed to investigate the costs of designing for construction safety and the specific safety controls implemented. Costs should consider people, the environment, and social equity, e.g. construction safety.

4.2.3 Designing for safety favors the Design-Build and Integrated Project Delivery methods

After the decline of the master-builder concept, divisions have grown over time among the three project stakeholders: owner, designer, and construction contractor (Coble & Blatter Jr., 1999). This division created confusion over construction safety, which became the sole legal responsibility of the construction contractor (Coble & Blatter Jr., 1999; J. A. Gambatese, 1998). The traditional D-B-B method provides little motivation for designers to consider construction safety (Toole & Carpenter, 2012). While all project stakeholders benefit from considering the safety and health of the construction worker during the design phase, only the owner and/or designer can implement this approach; the construction contractor cannot unless they have influence on the designer (Behm, 2005). If owners want to have construction safety considered during the design, the better project delivery methods are D-B and IPD, which promotes collaboration and provides incentives for designers to consider construction safety in their decisions (Coble & Blatter Jr., 1999; Toole & Gambatese, 2008). Since a D-B firm is one entity – who performs the design and construction – this project delivery method overcomes the division among the stakeholders because the designer is more involved in the constructability (Coble & Blatter Jr., 1999).

Because of the increased use of the D-B project delivery method in recent years, designers are likely to become more involved in construction engineering, which they can perform efficiently since they have a detailed understand of the structure; provided they gain knowledge of construction processes (Toole & Gambatese, 2008). A designer with construction engineering capabilities could become the expectation for a D-B firm who seeks to consider construction worker safety in their design decisions (Toole & Gambatese, 2008). And if D-B-B becomes less prevalent then designers will have to change to provide a more efficient design for D-B firms (Hinze, 2000).

A downside mentioned for D-B method is that it requires the owner to have experience with construction projects (Coble & Blatter Jr., 1999). For the D-B method, there is only one contract between the owner and the D-B firm; the construction contractor and designer are joined by a separate contract that the owner is not privy to. This is unlike the D-B-B arrangement where the owner has two contracts – one for design and one for construction – where the designer can provide the owner input on whether the construction contractor is performing per the design specifications. For the D-B method, the owner must have enough construction project experience to ensure the design specifications are being followed, e.g. have a quality assurance program.

4.3 Application

Based on a cognitive engineering approach, construction safety can be improved by increasing the Capabilities and decreasing the Task Demands, as shown in the task-capability interface (TCI) model, Figure 4-2 (Mitropoulos et al., 2009). Since the most significant factor for Task Demands is design, this requires the attention of the designers to consider the safety and health of the construction workers in their designs, which is considered a paradigm shift by Mitropoulos et al. (2009). Changing a culture takes time and requires a cycle of continuous change. My thought is that as this approach – to consider construction worker safety during the design phase – gains popularity, each stage will increase the following stage. Figure 4-4 shows the stages on how I organized the application methods that came from the *systematic literature review*.

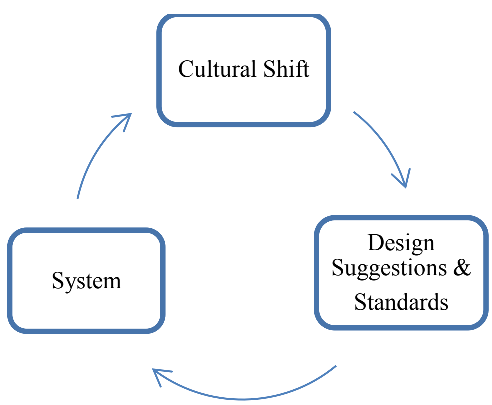


Figure 4-4: Application stages to consider construction worker safety in the design phase

4.3.1 Cultural shift

Several articles have been written in response to NIOSH PtD campaign to promote awareness and bring CII DfS concepts to the construction industry. Articles found in the study focus on bringing awareness by addressing the need for: (1) **training**, (2) more **research**, and (3) the concept that designers should base some of their design decisions to reduce, or eliminate, construction hazards from the workers through **education**.

Floyd and Liggett (2008; 2010) address that OSHA 1910.332 already requires electrical safety training for designers and electrical engineers; however, this is often overlooked. My review of OSHA 1910.322 showed a disclaimer that electrical engineers who: do not go into the field, face the risk of electrocution, or who do not have subordinates who do are required to obtain the electrical safety training. This disclaimer covers many design electrical engineers.

More research is needed for specific PtD and DfS applications in order to effectively promote designing for construction safety and overcome the resistance common among the design industry (J. A. Gambatese, 2008; Rajendran & Gambatese, 2013). Gambatese (2008) says that PtD and DfS applications uncovered through research need to be popularized. And case studies of projects designed to reduce construction hazards are needed to advance the concept (Manuele, 2008).

Owners can influence the awareness and promotion to consider construction safety during the design phase by budgeting for information technology tools that encourage collaboration among designers and construction industry to obtain additional design suggestions (Toole & Gambatese, 2008).

4.3.2 Design suggestions, alternatives, and standards

After showing that design decisions influence safety, designers will recognize their decisions impact the safety and health of the construction workers, changing a designer's approach to construction safety. To overcome the obstacles that influence designers not to consider construction safety, **design suggestions** must be developed. These suggestions should lead to **alternative designs**. Then **industry trends** could develop resulting in revised **design standards**.

From the preliminary research, Hinze and Wiegand (1992) initiated a movement to gather **design suggestions** that was later funded by CII. The *systematic literature review* shows that generic building **design suggestions** have been developed by Behm (2005) and Toole and Gambatese (2008). Dewlaney and Hallowell (2012) present **design suggestions** for "green" buildings – i.e. buildings designed and constructed for certification under a sustainable rating system, e.g. LEED; and Behm (2012) developed "safe-design techniques" to install a vegetated roof.

Behm (2005) lists several **design suggestions** that cover multiple disciplines and trades that existed prior to the study and **design suggestions** that resulted from the study. Toole and Gambatese (2008) suggest that designs include utility layouts, requiring designers to investigate the site conditions more; concurrent with ASCE's vision 2025 calling civil engineers: "master innovators and integrators."

Rajendran, Gambatese, and Behm (2009) suggested safety incidences increased for "green" projects; yet, its results were only suggestive, not conclusive. In a follow-up study to Rajendran et al. (2009) – Fortunato III, Hallowell, Behm, and Dewlaney (2012)

– identified and evaluated the safety risks for “green” projects through case studies. Fortunato III et al. (2012) showed that 16 LEED credits contributed to increased safety risk for the construction workers. Dewlaney and Hallowell (2012) identified at least one **design suggestion** for each of the 14 LEED credits that presented a greater risk to construction safety identified by Fortunato III et al. (2012). Dewlaney and Hallowell (2012) wrote their article before the study by Fortunato III et al. (2012) was published, which is why their study refers to 14 LEED credits and the other 16. Dewlaney and Hallowell (2012) conclude that **design alternatives** exist for each of the LEED credits that reduced the safety and health risks to the construction workers. Through observation research for a feature found on “green” buildings, Behm (2012) recognized two safety issues for the installation of vegetated roofs – (1) access, and (2) fall protection. A total of seven (7) “safe-design techniques” from Behm (2012) were developed; two (2) addressed the access issue, and five (5) addressed fall protection.

Rajendran and Gambatese (2013) compare two **alternative designs** for a roof: a parapet to a roof anchor system. A parapet that meets the OSHA required height to protect construction and maintenance workers is a common example of a design suggestion that considers the safety and health of the construction workers. Rajendran and Gambatese (2013) conducted interviews to understand the advantages and disadvantages of specifying a parapet for a roof compared to a roof anchor system and conclude that: (1) a parapet system is more expensive; (2) a parapet is a safer alternative than a roof anchor system, (3) a roof anchor system requires more risk since either a personal fall protection system is required or a temporary guardrail is erected and later removed, which involves considerable risk; (4) a roof anchor system reduces productivity by 15%, compared to a parapet system; and (5) neither system affected the quality of a product. Rajendran and Gambatese (2013) recommend that more **alternative design** comparisons should be developed to provide the owners and designers a thorough review of the alternatives.

Dharmapalan and Gambatese (2012) used risk factors for all construction activities required for the construction of a multistory commercial building – developed by Dharmapalan in a previous study – to compare **alternative designs**. They conclude that the following were safer to construct versus their alternative: (1) steel stud framing versus concrete masonry unit blocks for exterior backup walls and interior partitions, (2) resilient and carpet flooring versus stone panel, terrazzo, and raised access flooring, and (3) suspended acoustical ceilings versus gypsum ceilings (Dharmapalan & Gambatese, 2012).

Building materials better for the environment are becoming readily available because designers are specifying them as a result of the "green" building movement; Toole and Gambatese (2008) claim that if it becomes standard for designers to consider the safety and health of the construction workers, **industry trends** will follow – e.g. prefabrication. Prefabrication processes are already increasing due to cost effectiveness, but they will increase more if more designers would consider construction safety in their decisions (Toole & Gambatese, 2008). Prefabrication would allow construction activities that are not conducive to worker safety because of the multiple variables that exist (e.g.

weather and site conditions) to become manufacturing processes (Toole & Gambatese, 2008).

In response to the NIOSH PtD campaign for electrical design, Floyd and Liggett (2008) state that the NFPA 70E – Standard for Electrical Safety in the Workplace – and NFPA 70 – National Electric Code – already focuses on the control measures that "include design requirements that reflect the intent of PtD." Floyd (2010) recommends revision of the electrical **design standards**, e.g. NFPA 70, 70E, IEEE 902 Yellow Book; and the adoption of a new ANSI standard. Electrical **design standards** should be updated to include additional hazard control measures such as: (1) elimination of the hazard, (2) substitution of less-hazardous equipment and materials, and (3) engineering controls to reduce exposure and severity (Landis Floyd & Liggett, 2010).

4.3.3 Tools for implementation

Four tools were identified through the literature review: (1) Design for Construction Safety Toolbox, (2) safety constructability reviews, (3) Sustainable Construction Safety and Health Rating System, and (4) model checking software that works through the Building Information Model (BIM). These tools rely on design suggestions that have been developed over the years. The "Design for Construction Safety Toolbox" software is a database where designers access design suggestions. Safety constructability reviews, the SCSH rating system, and model checking software are used as reviews to check the design to identify any potential construction hazards so that the design could be modified.

Beginning in 1994, CII sponsored research to gather design suggestions to improve construction safety; Gambatese, Hinze, and Haas (1997) gathered over 400 design suggestions from 1994 to 1997 that formed the basis of the **"Design for Construction Safety Toolbox"** software, and it was later updated in 2007 by Marini and Hinze (Qi, Issa, Hinze, & Olbina, 2011). This tool can present appropriate design suggestions based on a project type and designer discipline providing ideas to the designers how to eliminate, or reduce, the hazards from the construction worker (J. A. Gambatese et al., 1997). Sources, design disciplines, project components, construction site hazards, and project systems addressed by the design suggestions for the original software, developed in 1997, are listed in Gambatese et al. (1997).

Gambatese (2000) recommends the performance of **safety constructability reviews** at specified milestones during the design phase, e.g. a maximum of five reviews held at the following design reviews: Planning Review, Preliminary Design Review, 30% Design Review, 60% Design Review, and 90% Design Review.

Rajendran and Gambatese (2009) developed and validated the **Sustainable Construction Safety and Health (SCSH) rating system** as a tool to measure the efforts during the design and construction to considering construction worker safety. The SCSH rating system was developed in response to the lack of construction worker safety consideration in the current LEED rating system; it is organized in a similar manner and has 50 elements (Rajendran & Gambatese, 2009). There are few design elements included in the SCSH as it is more focused on the construction. Rajendran and Gambatese (2009) admit their SCSH rating system focuses more on the construction phase; so they recommend the development of a rating system for the consideration of construction worker safety during the design phase.

Three *primary studies* addressed **model checking software** as a tool to check for construction safety and address them during the design: (1) Qi, Issa, Hinze, Olbina (2011) , (2) Kasirossafar and Shahbodaghlou (2013), and (3) Zhang, Teizer, Lee, Eastman, & Venugopal (2013).

According to a survey from Kasirossafar and Shahbodaghlou (2013), the two most influential measures in using BIM to address construction safety during design are: (1) incorporate construction material, equipment, and workers into BIM; and (2) consider safety hazards using a database to the model. These measures require the use of a **model checking software**. Both Qi et al. (2011) and Zhang et al. (2013) developed **model checking software** that used a dictionary and constraint model that provided an automated rule-based safety checking framework. Incorporating design criteria – e.g. design suggestions from the Design for Construction Safety ToolBox database, user input, or both – the model checking software interacts with the model, i.e. BIM, and shop drawings to check for possible construction hazards. Running the model checking software produces two sets of results: (1) all non-compliances are identified in the drawings along with suggestions for better consideration of construction safety for the worker, and (2) the three-dimensional view presents hazards that the user can decide to eliminate, or reduce, through changing the design (Qi et al., 2011). Qi et al. (2011) explains that using either the D-B or IPD project delivery methods better support the use of the **model checking software** and BIM to identify and eliminate construction hazards during the design phase.

CHAPTER FIVE: SUMMARY AND CONCLUSIONS

5.1 Summary

The safety and health for construction workers is an important topic to research; in 2010, the construction sector had the most fatal injuries out of all industry – 17% - according to the U.S. Bureau of Labor Statistics (2010). Even though U.S. regulations place construction safety on the construction contractors, owners have gotten more involved to promote safe construction projects. NAVFAC has implemented multiple programs and has adopted a zero-injury objective common among other safety-conscious owners. The most common approach in addressing construction safety is during the construction phase. This study investigated the application of implementing controls during the design phase. The theory is that many construction hazards can be reduced, if not eliminated, by changing the permanent features of the project during the design.

The objective of this research was to develop a panoramic analysis of the concept – using the design phase to reduce, or eliminate, construction hazards. The analysis was categorized into three stages: (1) justification for the owner, (2) influences on the concepts use, and (3) application of the concept. Each stage had a corresponding research question, which were:

- Why should NAVFAC consider using the design phase to reduce, or eliminate, construction safety hazards?
- What influences this concept – to use the design phase to reduce, or eliminate, safety hazards?
- What application tools, or methods, exist that NAVFAC could adopt for their use?

To provide a panoramic analysis that answers the research questions, I used a *systematic literature review* as the research method. The three primary reasons to perform a *systematic literature review* are to: (1) summarize existing evidence on a topic, (2) identify any research gaps to suggest areas for improvement, and (3) provide a framework for any new research. I performed the *systematic literature review* primarily to summarize existing evidence on this topic.

The results of the *systematic literature review* were categorized into one of the three stages addressed by research question. **Justification for the owner** to use the design phase to reduce, or eliminate, construction hazards to the workers include:

- It is another approach to address construction safety that could be very effective.
- Design decisions affect construction worker safety. Correlation was made between design decisions and fatal injury investigations.
- A level of moral obligation exists. This could be debated depending on the Code of Ethics referenced, but there is a level of moral obligation present.

Influences on this concept – to use the design phase to consider construction safety were:

- Designers are resistant. Fear of liability and a lack of construction knowledge were cited as the primary reasons.
- Owners influence construction safety on their projects. Evidence has shown that owners influence construction safety since they establish the priorities for the project – shown through selection of the project delivery method and contractors and their overall involvement.

- The project delivery method affects the consideration of the construction worker safety in the design phase since it defines the relationship between all stakeholders.

To **apply** the concept – using the design phase to reduce, or eliminate construction hazards, - three stages were discussed: (1) cultural shift; (2) design suggestions, alternatives, and standards; and (3) implementation tools. The knowledge base within each of these stages will build on each other as the concept gains popularity. Under each stage, more specific applications and methods were shown through the *systematic literature review* results. The results provide NAVFAC a panoramic summary of the existing research on the topic of using the design phase to reduce, eliminate, construction hazards.

5.2 Implications

This study contributes to knowledge by providing a panoramic analysis of the concept to consider the safety and health of construction workers in the design phase. The intended audience of this research is NAVFAC, but any interested owner can benefit from it. While not an objective of this study, gaps in knowledge were revealed by using a *systematic literature review*.

The research questions and the objective of this research were developed to provide an objective summary for NAVFAC to decide whether or not to pursue an implementing a plan to adopt this concept. Using this analysis, NAVFAC leaders can be better educated on what this concept is and how it can be implemented.

This analysis remains broad in nature; therefore, it can be adapted for use by anyone who seeks to understand this shift in approach to construction safety. Any owner who seeks to investigate this approach to construction safety could use this analysis.

By summarizing the existing studies on this subject, research gaps were revealed. A *primary study* considering the safety and health of the construction workforce that could benefit owners and designers is one that compares design alternatives, i.e. parapet versus roof anchor system; however, there was only one study to that level of detail. I think a study of this nature would be beneficial to the owner, designer, or both in order to make an informed design decision. More research should be performed to examine additional design alternatives. Another research gap shown is that no case studies exist for a project where the design phase was used to reduce, or eliminate, construction hazards for the workers. Since no *primary study* from the *systematic literature review* contained a case study, I contacted another researcher who mentioned that there are owners who are pursuing this approach to construction safety, and Intel is one of the most aggressive (J.W. Hinze, personal communication, June 26, 2013).

5.3 Limitations

The following limitations should be considered when evaluating the results and conclusions:

- Lack of diverse research studies. Several of the *primary studies* were more editorial in nature than research-based. The same authors were observed in multiple *primary studies* raising concerns for validity since several of the *primary studies* lacked multiple perspectives, i.e. authorship. For future studies, I recommend that the researchers develop a diverse focus group, consisting of owners, designers, and construction contractors to gather additional information on the subject

- Data extraction. Since I was the only person who extracted the data, a concept or theory could have been excluded during the extraction process. It would have been preferable to have multiple researchers extract the data and synthesize it. For future studies, I recommend a research group extract the data and compile.

5.4 Future research

To further develop this study's concept, future research should focus on:

- Validation of this study. I recommend that a *systematic literature review* be performed on recurring basis to provide a synthesis of the latest research to the industry for application and to assist researchers to develop and publish relevant and applicable research.
- Developing practical ways for owners to consider the safety and health of construction workers during the design phase. I recommend a focus group, case study, or both. The focus group should be composed of representatives of owners who have pursued and implemented methods that consider safety and health of a construction worker. The case study should be of a project where the owner has influenced the designer to consider construction worker safety in the design phase.
- Duplicating the survey performed by Hinze and Wiegand (1992) to evaluate whether the design culture has changed and if a shift has occurred.

- Examining the education curriculum for designers, i.e. architects and engineers, to understand the availability and requirement of construction method courses of instruction.
- Examining the legal aspect of designers considering construction safety during the design phase. The fear of liability is a major obstacle for a designer to consider construction safety so it would be beneficial to examine just the legal aspect of this concept. Gambatese (1998) was the only *primary source* gathered that discussed the liability concern in detail. More studies should be developed to examine the legal aspect.

5.5 Final remarks

Numerous U.S. Federal government policies exist for sustainable development and the reduction of life-cycle costs of Federal buildings. Theoretically, this should include the consideration of the safety and health of the construction workforce; however, the Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding, dated January 2006, does not include the topic of construction safety in its Guiding Principles. In addition to efforts to promote energy-efficiency and environmental stewardship, an opportunity exists for a large owner, e.g. NAVFAC, to work with their designers to include consideration of the safety and health of the construction worker just like they have been doing to develop energy-efficient and environmentally-preferred facilities.

This study developed a panoramic analysis of the concept to consider construction worker safety in the design, which is a cultural shift for most designers. The analysis was developed through the review of existing research and studies that discussed and examined this concept. The results from this study provide the justification that should encourage NAVFAC to: (1) develop their acquisition strategy so that the designers are influenced to consider construction safety in their design and (2) train their workforce to look for ways to improve the safety and health of the construction workers before construction even begins.

REFERENCES

American Institute of Architects. (2012). *2012 code of ethics and professional conduct*. Retrieved June 13, 2013, from http://www.aia.org/aiaucmp/groups/aia/documents/pdf/aiap074122.pdf

American Institute of Architects, Associated General Contractors of America. (2011). *Primer on project delivery (Second ed.)*. Retrieved June 13, 2013, http://www.aia.org/aiaucmp/groups/aia/documents/pdf/aiab093116.pdf

Behm, M. (2005). Linking construction fatalities to the design for construction safety concept. *Safety Science, 43*(8), 589-611. doi:10.1016/j.ssci.2005.04.002

Behm, M. (2012). Safe design suggestions for vegetated roofs. *Journal of Construction Engineering and Management, 138*(8), 999-1003. doi:10.1061/(ASCE)CO.1943-7862.0000500

Centers for Disease Control and Prevention. (2012). NIOSH: Fatality assessment and control evaluation (FACE) program. Retrieved May 13, 2013, from http://www.cdc.gov/niosh/face/

Centers for Disease Control and Prevention. (2012). NIOSH: Prevention through design. Retrieved May 13, 2013, from http://www.cdc.gov/niosh/programs/ptdesign/default.html

Coble, R. J., & Blatter Jr., R. L. (1999). Concerns with safety in design/build process. *Journal of Architectural Engineering, 5*(2), 44-48. doi:10.1061/(ASCE)1076-0431(1999)5:2(44)

Construction Industry Institute. (2013). *CII at a glance*. Retrieved May 13, 2013, from https://www.construction-institute.org/scriptcontent/basics.cfm?section=aboutcii

Construction Industry Institute. (2013). *CII knowledge structure*. Retrieved June 15, 2013, from https://www.construction-institute.org/source/Orders/CII_Matrix.cfm?section=Orders&OrdersSection=Matrix

Creswell, J. W. (2013). *Research design: Qualitative, quantitative, and mixed methods approaches.* Thousand Oaks, CA: Sage Publications, Incorporated.

Dewlaney, K. S., Hallowell, M. R., & Fortunato III, B. R. (2012). Safety risk quantification for high performance sustainable building construction. *Journal of Construction Engineering and Management, 138*(8), 964-971. doi:10.1061/(ASCE)CO.1943-7862.0000504

Dewlaney, K. S., & Hallowell, M. (2012). Prevention through design and construction safety management strategies for high performance sustainable building construction. *Construction Management and Economics, 30*(2), 165-177. doi:10.1080/01446193.2011.654232

Dharmapalan, V., & Gambatese, J. A. (2012). *Comparison of design risk factors of multistory commercial office buildings*. Paper presented at the Construction Research Congress 2012: Construction Challenges in a Flat World, May 21, 2012 - May 23, 299-309. doi:10.1061/9780784412329.031

Floyd, H. L., & Liggett, D. P. (2008). *The NIOSH "prevention through design" initiative applied to electrical hazards in construction*. Paper presented at the 2008 55th IEEE Petroleum and Chemical Industry Technical Conference, PCIC 2008, September 22, 2008 - September 24. doi:10.1109/PCICON.2008.4663967

Fortunato III, B. R., Hallowell, M. R., Behm, M., & Dewlaney, K. (2012). Identification of safety risks for high-performance sustainable construction projects. *Journal of Construction Engineering and Management, 138*(4), 499-508. doi:10.1061/(ASCE)CO.1943-7862.0000446

Fuller, R. (2005). Towards a general theory of driver behaviour. *Accident Analysis & Prevention, 37*(3), 461-472. doi: 10.1016/j.aap.2004.11.003

Gambatese, J., & Hinze, J. (1999). Addressing construction worker safety in the design phase designing for construction worker safety. *Automation in Construction, 8*(6), 643-649. doi:10.1016/S0926-5805(98)00109-5

Gambatese, J. A. (1998). Liability in designing for construction worker safety. *Journal of Architectural Engineering, 4*(3), 107-112. doi:10.1061/(ASCE)1076-0431(1998)4:3(107)

Gambatese, J. A. (2000). *Safety constructability: Designer involvement in construction site safety*. Paper presented at the Construction Congress VI: Building Together for a Better Tomorrow in an Increasingly Complex World, February 20, 2000 - February 22, 650-660. doi:10.1061/40475(278)70

Gambatese, J. A. (2008). Research issues in prevention through design. *Journal of Safety Research, 39*(2), 153-156. doi:10.1016/j.jsr.2008.02.012

Gambatese, J. A., Behm, M., & Hinze, J. W. (2005). Viability of designing for construction worker safety. *Journal of Construction Engineering and Management, 131*(9), 1029-1036. doi:10.1061/(ASCE)0733-9364(2005)131:9(1029)

Gambatese, J. A., Behm, M., & Rajendran, S. (2008). Design's role in construction accident causality and prevention: Perspectives from an expert panel. *Safety Science, 46*(4), 675-691. doi:10.1016/j.ssci.2007.06.010

Gambatese, J. A., Hinze, J. W., & Haas, C. T. (1997). Tool to design for construction worker safety. *Journal of Architectural Engineering, 3*(1), 32-41. doi:10.1061/(ASCE)1076-0431(1997)3:1(32)

Ghaderi, R., & Kasirossafar, M. (2011). *Construction safety in design process*. Paper presented at the AEI 2011: Building Integrated Solutions, March 30, 2011 - April 2, 464-471. doi:10.1061/41168(399)54

Hallowell, M. R., & Gambatese, J. A. (2009). Construction safety risk mitigation. *Journal of Construction Engineering and Management, 135*(12), 1316-1323. doi:10.1061/(ASCE)CO.1943-7862.0000107

Haslam, R. A., Hide, S. A., Gibb, A. G. F., Gyi, D. E., Pavitt, T., Atkinson, S., & Duff, A. R. (2005). Contributing factors in construction accidents. *Applied Ergonomics, 36*(4), 401-415. doi:10.1016/j.apergo.2004.12.002

Health and Safety Executive. (n.d.). *Construction design and management*. Retrieved April 24, 2013, from http://www.hse.gov.uk/construction/cdm.htm

Hinze, J., Bren, D. C., & Piepho, N. (1995). Experience modification rating as measure of safety performance. *Journal of Construction Engineering and Management, 121*(4), 455-458. doi:10.1061/(ASCE)0733-9364(1995)121:4(455)

Hinze, J., & Bren, K. (1996). Identifying OSHA paragraphs of particular interest. *Journal of Construction Engineering and Management, 122*(1), 98-100. doi:10.1061/(ASCE)0733-9364(1996)122:1(98)

Hinze, J., Godfrey, R., & Sullivan, J. (2013). Integration of construction worker safety and health in assessment of sustainable construction. *Journal of Construction Engineering and Management, 139*(6), 594-600. doi:10.1061/(ASCE)CO.1943-7862.0000651

Hinze, J., & Wiegand, F. (1992). Role of designers in construction worker safety. *Journal of Construction Engineering and Management, 118*(4), 677-684. doi:10.1061/(ASCE)0733-9364(1992)118:4(677)

Hinze, J. (2000). *The need for academia to address construction site safety through design*. Paper presented at the Construction Congress VI: Building Together for a

Better Tomorrow in an Increasingly Complex World, February 20, 2000 - February 22, 2000, 278 1189-1195. doi:10.1061/40475(278)128

Hinze, J., Devenport, J. N., & Giang, G. (2006). Analysis of construction worker injuries that do not result in lost time. *Journal of Construction Engineering and Management, 132*(3), 321-326. doi:10.1061/(ASCE)0733-9364(2006)132:3(321)

Hinze, J., & Gambatese, J. (2003). Factors that influence safety performance of specialty contractors. *Journal of Construction Engineering and Management, 129*(2), 159-164. doi:10.1061/(ASCE)0733-9364(2003)129:2(159)

Hinze, J., Huang, X., & Terry, L. (2005). The nature of struck-by accidents. *Journal of Construction Engineering and Management, 131*(2), 262-268. doi:10.1061/(ASCE)0733-9364(2005)131:2(262)

Hinze, J., & Wilson, G. (2000). Moving toward a zero injury objective. *Journal of Construction Engineering and Management, 126*(5), 399-403. doi:10.1061/(ASCE)0733-9364(2000)126:5(399)

Huang, X., & Hinze, J. (2003). Analysis of construction worker fall accidents. *Journal of Construction Engineering and Management, 129*(3), 262-271. doi:10.1061/(ASCE)0733-9364(2003)129:3(262)

Huang, X., & Hinze, J. (2006). Owner's role in construction safety. *Journal of Construction Engineering and Management, 132*(2), 164-173. doi:10.1061/(ASCE)0733-9364(2006)132:2(164)

Huang, X., & Hinze, J. (2006). Owner's role in construction safety: Guidance model. *Journal of Construction Engineering and Management, 132*(2), 174-181. doi:10.1061/(ASCE)0733-9364(2006)132:2(174)

Kasirossafar, M., & Shahbodaghlou, F. (2013). *Application of visualization technologies to design for safety concept*. Paper presented at the 6th Congress on Forensic Engineering 2012: Gateway to a Better Tomorrow, October 31, 2012 - November 3, 370-377. doi:10.1061/9780784412640.040

Kitchenham, B. (2004). Procedures for performing systematic reviews. *Keele, UK, Keele University, 33*, 2004.

Landis Floyd, H. (2010). Prevention through design. *IEEE Industry Applications Magazine, 16*(3), 14-16. doi:10.1109/MIAS.2010.936115

Landis Floyd, H., & Liggett, D. P. (2010). Hazard mitigation through design. *IEEE Industry Applications Magazine, 16*(3), 17-22. doi:10.1109/MIAS.2010.936122

Manuele, F. A. (2008). Prevention through design (PtD): History and future. *Journal of Safety Research, 39*(2), 127-130. doi:10.1016/j.jsr.2008.02.019

Maxwell, J. A. (2005). *Qualitative research design: An interactive approach* (2nd ed.) . Thousand Oaks, CA: Sage Publications, Incorporated.

Mitropoulos, P., Cupido, G., & Namboodiri, M. (2009). Cognitive approach to construction safety: Task demand-capability model. *Journal of Construction Engineering and Management, 135*(9), 881-889. doi:10.1061/(ASCE)CO.1943-7862.0000060

National Institute for Occupational Safety and Health. (2010). *Prevention through design: Plan for the national initiative*. (DHHS (NIOSH) No. 2011-121). NIOSH.

National Society of Professional Engineers. (2007). Code of ethics for engineers. Retrieved June 13, 2013, from http://www.nspe.org/resources/pdfs/Ethics/CodeofEthics/Code-2007-July.pdf

Naval Facilities Engineering Command. (2011). *Safety as and evaluation factor in source selections* (Naval Engineering Training and Operating Procedure and Standard No. 23). NAVFAC.

Naval Facilities Engineering Command Southeast. (2012). *Governmental safety requirements NAVFAC SE version*. Retrieved April 13, 2013, from https://portal.navfac.navy.mil/portal/page/portal/navfac/navfac_ww_pp/navfac_southeast_pp/dbb/pdff/1/01%2035%2026.00%2025.pdf

Occupational Safety and Health Administration. (n.d.). *About OSHA*. Retrieved May 13, 2013, from http://www.osha.gov/about.html

Occupational Safety and Health Administration. (n.d.). *OSHA law & regulations*. Retrieved May 13, 2013, from http://www.osha.gov/law-regs.html

Qi, J., Issa, R. R. A., Hinze, J., & Olbina, S. (2011). *Integration of safety in design through the use of building information modeling*. Paper presented at the 2011 ASCE International Workshop on Computing in Civil Engineering, June 19, 2011 - June 22, 698-705. doi:10.1061/41182(416)86

Rajendran, S., & Gambatese, J. (2013). Risk and financial impacts of prevention through design solutions. *Practice Periodical on Structural Design and Construction, 18*(1), 67-72. doi:10.1061/(ASCE)SC.1943-5576.0000129

Rajendran, S., & Gambatese, J. A. (2009). Development and initial validation of sustainable construction safety and health rating system. *Journal of Construction Engineering and Management, 135*(10), 1067-1075. doi:10.1061/(ASCE)0733-9364(2009)135:10(1067)

Rajendran, S., & Gambatese, J. A. (2009). Development and initial validation of sustainable construction safety and health rating system. *Journal of Construction Engineering and Management, 135*(10), 1067-1075. doi:10.1061/(ASCE)0733-9364(2009)135:10(1067)

Rajendran, S., Gambatese, J. A., & Behm, M. G. (2009). Impact of green building design and construction on worker safety and health. *Journal of Construction Engineering and Management, 135*(10), 1058-1066. doi:10.1061/(ASCE)0733-9364(2009)135:10(1058)

Szymberski, R. (1997). Construction project safety planning. *Tappi Journal, 80*(11), 69-74.

Taiebat, M., & Ku, K. (2011). *Design and planning for safety (DPfS): A factor modeling approach to find the best response to hazard*. Paper presented at the AEI 2011: Building Integrated Solutions, March 30, 2011 - April 2, 437-447. doi:10.1061/41168(399)51

Toole, T. M., & Carpenter, G. (2012). *Prevention through design: An important aspect of social sustainability*. Paper presented at the International Conference on Sustainable Design and Construction 2011: Integrating Sustainability Practices in the Construction Industry, ICSDC 2011, March 23, 2011 - March 25, 187-195. doi:10.1061/41204(426)25

Toole, T. M., & Gambatese, J. (2008). The trajectories of prevention through design in construction. *Journal of Safety Research, 39*(2), 225-230. doi:10.1016/j.jsr.2008.02.026

United States Bureau of Labor Statistics. (2012). *Injuries, illnesses, and fatalities*. Retrieved May 13, 2013, from http://www.bls.gov/iif/oshwc/cfoi/worker_memorial.htm

Valdes-Vasquez, R., & Klotz, L. E. (2013). Social sustainability considerations during planning and design: Framework of processes for construction projects. *Journal of Construction Engineering & Management, 139*(1), 67-76. doi:10.1061/(ASCE)CO.1943-7862.0000566

World Commission on Environment and Development. (1987). Towards sustainable development. In *Our common future: Report of the world commission on environment and development* (2). Retrieved April 14, 2013, from http://www.un-documents.net/ocf-02.htm

Zhang, S., Lee, J., Venugopal, M., Teizer, J., & Eastman, C. M. (2012). *A framework for automatic safety checking of building information models*. Paper presented at the Construction Research Congress 2012: Construction Challenges in a Flat World, May 21, 2012 - May 23, 574-581. doi:10.1061/9780784412329.058

APPENDICES

APPENDIX A: SYSTEMATIC LITERATURE REVIEW PROTOCOL

Background

Construction safety has remained a topic of interest among the field of construction engineering and management. While there are legal responsibilities, many consider it an ethical and moral obligation to promote the safety and health of construction workers. In the U.S., responsibility for construction safety falls to a worker's employer, the construction contractor. This report investigates how the designer can influence safety, which is commonly called the Design for Construction Safety Concept (DfCS). Its target is the owner - how can an owner influence the designer to design for construction safety? This literature review plans to synthesize previous studies on this topic to provide an objective summary that can provide an owner justification whether or not to implement DfCS principles.

NIOSH has initiated a campaign, called Prevention through Design (PtD), which is an attempt to reduce occupational injuries through the design. Construction is only part of this campaign.

Research Questions

- Are "green buildings" safer?
- What project delivery method has the most influence for designers to use DfCS?
- What are some methods being used by designers to increase the amount of construction safety?
- What correlations exist that show that having designers including safety controls will help improve construction safety?

Search Strategy

Search Medium

- Journal articles
- Conference proceedings
- Articles in Press

Search Terms

The following terms are to be searched for within the Title/Subject/Abstract:

- "design for construction safety"
- "prevention through design"
- "construction safety" and "design phase"
- "construction safety" and "sustainability"

Database

The Compendex database will be used to search for journal articles, conference proceedings, and articles in the press. Since the topic of construction safety in the design phase has only been around for the past three decades, most journal articles should be in the electronic database. In addition, the Compendex database contains numerous civil engineering and construction publications. Most notable is the American Society of Civil Engineers' (ASCE) Journal of Construction Engineering and Management (CEM), which was discovered to have a lot of relevant articles during my preliminary research.

Constraints

- Country of origin – should be limited to the United States. This is due to the problem being within the United States. While the U.S. Navy operates around the world, it is limited by U.S regulations and practices. During the preliminary research, articles from the United States did reference other countries and how they address construction safety during the design phase.
- Date of publication – should be limited from 1987 to the present. 1987 was when the Brundtland Commission defined sustainability. During my preliminary research, very few articles on this subject were found prior to 1987. In the fact, the journal article that has been referenced as initiating the topic was published in 1992 – Hinze and Wiegand in ASCE's Journal of CEM.

Documenting

For each search, the results will be exported as detailed records into a bibliographic software using – ie. RefWorks. In addition, the following table will be populated to quantify the number of results found using this protocol.

Selection Criteria and Process

Study Selection Criteria

Based upon this study's focus - improving construction safety through the design - and the target audience -an owner, below are the selection criteria to be used to identify the studies for this systematic literature review.

The studies must:

- Address construction safety for the site and/or workers;
- Address commercial building construction;
- Discuss at least one of the following:
    - Construction safety as part of social sustainability;
    - The project delivery method's effect on construction safety;
    - Roles and responsibilities of the designer for construction safety;
    - Examples of design that increased construction safety for the site and/or workers; or
    - Effectiveness of designing for construction safety.
- Address policy, if references are made to a country outside the United States.

Study Selection Process

1. Identify primary sources through search strategies using established search terms.
2. Read the title, abstract, and key words to see if it is applicable to answering the research questions.
3. If applicable, read the conclusion to see if it is applicable to answering the research questions.
4. Use selection criteria to determine if article should be included.
5. Read full article to extract data.

Quality Assessment Process

After primary sources are identified in accordance with selection criteria, the sources must be evaluated for quality. Due to the expected low numbers of studies to be found, no hierarchies will be used for the types of studies selected as no quality thresholds will be set.

All primary sources will be evaluated for bias. Any bias will be noted, but the article will still be search for applicable data. Because of the note, the bias will be discussed in the results of the primary study. This requires investigation of any study that references a previous study's data.

To help identify any bias, any primary studies that reference "recent" or "prior" studies will be investigated. Attempts will be made to locate and "recent" or "prior" studies to ensure its conclusions are consistent with the claims stated in the primary study under investigation.

Data Extraction Strategy

Data collection forms will be used. A source's title, author, publication, and abstract will be transferred into the data collection form verbatim. Any other results or key principles will be summarized and included into the form as well as any notes noted during the quality assessment process.

Synthesis of Extracted Data

The principles extracted will be categorized into the conceptual framework developed in this study and will be coded. These principles will then be applied to answering the research questions.

Project Timetable

April – May 2013:	Preliminary Review of Available Sources
May – June 2013:	Development of Conceptual Framework
June 2013:	Search and Selection of Primary Sources
June – July 2013:	Synthesize Data
July 2013:	Draw Conclusions

Table A-1: Format to report number of search results using the Compendex database

Search Date Performed	Medium	Term	Number of Results
	Journal Articles	“design for construction safety”	
		“prevention through design”	
		“construction safety” and “design phase”	
		“construction safety” and “sustainability”	
	Conference Proceedings	“design for construction safety”	
		“prevention through design”	
		“construction safety” and “design phase”	
		“construction safety” and “sustainability”	
	Article in Press	“design for construction safety”	
		“prevention through design”	
		“construction safety” and “design phase”	
		“construction safety” and “sustainability”	

APPENDIX B: CONDUCTING THE SYSTEMATIC LITERATURE REVIEW

Table B-2: Excluded studies and articles with the reason

Study	Reasons for excluding
Al-Humaidi, H., & Hadipriono Tan, F. (2009). Construction safety management accidents, laws and practices in kuwait. Paper presented at the 3rd International Conference on Safety and Security Engineering, SAFE 2009, July 1, 2009 - July 3, , 108 399-408. doi:10.2495/SAFE090371	Does not involve design for construction safety in the U.S.
Al-Humaidi, H., & Tan, F. H. (2010). Construction safety in kuwait. Journal of Performance of Constructed Facilities, 24(1), 70-77. doi:10.1061/(ASCE)CF.1943-5509.0000055	Does not involve design for construction safety in the U.S.
Averill, J. D., Mileti, D., Peacock, R., Kuligowski, E., Groner, N., Proulx, G., . . . Nelson, H. (2012). Federal investigation of the evacuation of the world trade center on september 11, 2001. Paper presented at the Special Issue on Human Behaviour in Fire, , 36(5-6) 472-480. doi:10.1002/fam.2162	Focuses on the WTC, not construction safety.
Chapman, L. J., Newenhouse, A. C., Pereira, K. M., Karsh, B., Meyer, R. M., Brunette, C. M., & Ehlers, J. J. (2008). Evaluation of a four year intervention to reduce musculoskeletal hazards among berry growers. Journal of Safety Research, 39(2), 215-224. doi:10.1016/j.jsr.2008.02.025	Focus is on berry growers, not construction workers.
Chi, S., & Caldas, C. H. (2012). Design of a preliminary error impact analysis model for spatial safety assessment of earthmoving operations. Paper presented at the , 22 212-222. doi:10.1016/j.autcon.2011.06.019	Does not involve design for construction safety in the U.S.
Corotis, R. B., Ellingwood, B., & Scanlon, A. (1989). Reliability bases for codes for design of reinforced concrete structures. Paper presented at the Proceedings of ICOSSAR '89, the 5th International Conference on Structural Safety and Reliability, Part III, August 7, 1989 - August 11, 2035-2042.	Focus was not the safety of the construction worker. Mentioned designing for the construction stage.
Domitrovich, T. A., Floyd, A. H. L., & Smail, T. (2012). Methods to influence change in home safety. Paper presented at the19th Annual Conference on IEEE IAS Electrical Safety Workshop: Changing the Electrical Safety Culture, ESW 2012, January 31, 2012 - February 3, 39-46. doi:10.1109/ESW.2012.6165534	Does not involve design for construction safety in the U.S.
Duthinh, D., McGrattan, K., & Khaskia, A. (2008). Recent advances in fire-structure analysis. Fire Safety Journal, 43(2), 161-167. doi:10.1016/j.firesaf.2007.06.006	Does not address construction safety.
Fisher, J. M. (2008). Healthcare and social assistance sector. Journal of Safety Research, 39(2), 179-181. doi:10.1016/j.jsr.2008.02.006	Does not address construction safety.
Gatti, U., Scharrer, A., Migliaccio, G. C., & Bogus, S. M. (2012). Using the workforce's physiological strain monitoring to enhance social sustainability of construction. Paper presented at the International Conference on Sustainable Design and Construction 2011: Integrating Sustainability Practices in the Construction Industry, ICSDC 2011, March 23, 2011 - March 25, 180-186. doi:10.1061/41204(426)24	Focused on PSMs, not Design for Construction Safety.

Study	Reasons for excluding
Hadipriono, F. C. (1992). Expert system for construction safety. II: Knowledge base. Journal of Performance of Constructed Facilities, 6(4), 261-274.	Did not focus on design for construction safety. More focused on the FTES-FALL.
Hayden, C. S., & Zechmann, E. (2008). Product noise control as a public health issue. Paper presented at the 23rd National Conference on Noise Control Engineering, NOISE-CON 2008 and 3rd Sound Quality Symposium, SQS 2008, July 28, 2008 - July 31, , 2 1047-1051.	Does address construction safety.
Jia, B., Kim, S., & Nussbaum, M. A. (2011). An EMG-based model to estimate lumbar muscle forces and spinal loads during complex, high-effort tasks: Development and application to residential construction using prefabricated walls.International Journal of Industrial Ergonomics, 41(5), 437-446. doi:10.1016/j.ergon.2011.03.004	Discusses PtD solution for residential, not commercial.
Johnson, J. V. (2008). Services sector. Journal of Safety Research, 39(2), 191-194. doi:10.1016/j.jsr.2008.02.003	Does not address the safety of construction workers, only service workers.
Jung, K., Kim, K., Sim, C., & Kim, J. J. (2011). Verification of incremental launching construction safety for the ilsun bridge, the world's longest and widest prestressed concrete box girder with corrugated steel web section. Journal of Bridge Engineering, 16(3), 453-460. doi:10.1061/(ASCE)BE.1943-5592.0000165	Focus was on the construction stage design, not the safety of the construction worker.
Kartam, N. A., Flood, I., & Koushki, P. (2000). Construction safety in kuwait: Issues, procedures, problems, and recommendations. Safety Science, 36(3), 163-184. doi:10.1016/S0925-7535(00)00041-2	Does not involve design for construction safety in the U.S.
Kaskutas, V., Dale, A. M., Lipscomb, H., & Evanoff, B. (2013). Erratum: Fall prevention and safety communication training for foremen: Report of a pilot project designed to improve residential construction safety (journal of safety research (2013) 44 (111-118)). Journal of Safety Research, 45, 153. doi:10.1016/j.jsr.2013.03.006	References residential construction.
Kaskutas, V., Dale, A. M., Lipscomb, H., & Evanoff, B. (2013). Fall prevention and safety communication training for foremen: Report of a pilot project designed to improve residential construction safety. Paper presented at the , 44(1) 111-118. doi:10.1016/j.jsr.2012.08.020	References residential construction.
Khudeira, S. (2009). Scaffolding on high-rise buildings. Practice Periodical on Structural Design and Construction, 14(1), 11-13. doi:10.1061/(ASCE)1084-0680(2009)14:1(11)	Focused on scaffolding safety, not as applied to construction worker safety.
Kim, S., Nussbaum, M. A., & Jia, B. (2011). Low back injury risks during construction with prefabricated (panelised) walls: Effects of task and design factors. Ergonomics, 54(1), 60-71. doi:10.1080/00140139.2010.535024	Mentions residential construction, not commerical construction.

Study	Reasons for excluding
Kim, S., Seol, H., Ikuma, L. H., & Nussbaum, M. A. (2008). Knowledge and opinions of designers of industrialized wall panels regarding incorporating ergonomics in design. International Journal of Industrial Ergonomics, 38(2), 150-157. doi:10.1016/j.ergon.2007.08.009	Referenced residential construction.
Lin, K. (2009). The development of a sustainable e-learning model - using construction safety and health education as an example. Paper presented at the 2009 ASCE International Workshop on Computing in Civil Engineering, June 24, 2009 - June 27, , 346 593-602. doi:10.1061/41052(346)59	Does not involve design for construction safety in the U.S.
Lin, K., Son, J. W., & Rojas, E. M. (2011). A pilot study of a 3D game environment for construction safety education.Electronic Journal of Information Technology in Construction, 16, 69-83.	Focus was more on the game developed than construction safety principles.
Lin, M. (2008). Practice issues in prevention through design. Journal of Safety Research, 39(2), 157-159. doi:10.1016/j.jsr.2008.02.011	No mention of construction or design of buildings. All about the"product."
Lincoln, J. M., Lucas, D. L., McKibbin, R. W., Woodward, C. C., & Bevan, J. E. (2008). Reducing commercial fishing deck hazards with engineering solutions for winch design. Journal of Safety Research, 39(2), 231-235. doi:10.1016/j.jsr.2008.02.027	Abstract talks about safety of fishmerman, not construction workers.
Mander, T. J., Henley, M. D., Scott, R. M., Head, M. H., Mander, J. B., & Trejo, D. (2009). Experimental investigation of full-depth precast overhang panels for concrete bridge decks. Paper presented at the 2009 Structures Congress - Don't Mess with Structural Engineers: Expanding our Role, April 30, 2009 - may 2, 1030-1038. doi:10.1061/41031(341)114	Did not focus on construction worker safety. More focused on designing for the construction stage.
McGurl, M. P., & Johnston, D. W. (2012). Spreadsheet analysis of load distribution in shoring and reshoring systems. Paper presented at the Concrete Construction and Structural Evaluation: A Symposium Honoring Dov Kaminetzky at the ACI Fall 2010 Convention, October 24, 2010 - October 28, (285) 25-43.	Focused more on the design for the construction stage. Not designing for construction safety.
Mitropoulos, P., & Namboodiri, M. (2011). New method for measuring the safety risk of construction activities: Task demand assessment. Journal of Construction Engineering and Management, 137(1), 30-38. doi:10.1061/(ASCE)CO.1943-7862.0000246	Focused on the TDA. Not design for construction safety.
Morse, J. S., & Batzer, S. A. (2010). Prevention through design - an idea whose time has come. Paper presented at theASME 2009 International Mechanical Engineering Congress and Exposition, IMECE2009, November 13, 2009 - November 19, , 13 213-221.	Focuses on consumer products applications, not construction.
Overby, C. M. (1991). QFD taguchi for the entire life cycle. Paper presented at the 45th Annual Quality Congress Transactions, may 20, 1991 - may 22, , 45 433-438.	Does not involve construction safety.

Study	Reasons for excluding
Savonis, M. J., Burkett, V. R., Potter, J. R., Kafalenos, R., Hyman, R., & Leonard, K. (2009). The impact of climate change on transportation in the gulf coast. Paper presented at the 2009 ASCE Technical Council on Lifeline Earthquake Engineering Conference, TCLEE 2009: Lifeline Earthquake Engineering in a Multihazard Environment, June 28, 2009 - July 1, , 357 64. doi:10.1061/41050(357)64	Focused on climate change, not construction safety.
Son, J., Lin, K., & Rojas, E. M. (2011). Developing and testing a 3D video game for construction safety education. Paper presented at the 2011 ASCE International Workshop on Computing in Civil Engineering, June 19, 2011 - June 22, 867-874. doi:10.1061/41182(416)107	Focus is on the education of construction safety through a video game developed.
Stemp, B. A., & Walewski, J. (2011). Lampson transi-lift mobile crane: Concept, design, and use. Paper presented at the , 137(10) 785-792. doi:10.1061/(ASCE)CO.1943-7862.0000380	Crane discussed is more of the focus, not construction safety.
Stewart, E., Heidel, D., & Quinn, M. (2009). Prevention through design in the health care sector. Paper presented at the5th International Conference on the Impact of Environmental Factors on Health, EHR'09, September 21, 2009 - September 23, , 14 187-194. doi:10.2495/EHR090191	Does not address construction safety, only workplace safety for the medical profession.
Tiss, K. J. (2012). Developing construction management educators: Is instructional design, development and evaluation the key? Paper presented at the 119th ASEE Annual Conference and Exposition, June 10, 2012 - June 13,	Does not focus on construction safety. "Construction safety" is the name of the course in the case study.
Toole, T. M. (2011). Internal impediments to ASCE's vision 2025. Leadership and Management in Engineering, 11(2), 197-207. doi:10.1061/(ASCE)LM.1943-5630.0000120	Focus was not on construction safety. It was on a vision statement from ASCE.
Ungar, L. Y. (2008). The economics of harm prevention through design for testability. Paper presented at the IEEE Autotestcon 2008, September 8, 2008 - September 11, 80-87. doi:10.1109/AUTEST.2008.4662589	Does not involve construction safety.
Wilkins, J. R. (2011). Construction workers' perceptions of health and safety training programmes. Construction Management and Economics, 29(10), 1017-1026.	Focused on training programs. Not design for safety.
Zhao, Q., Yu, B., & Burdette, E. G. (2010). Effects of cross-frame on stability of double I-girder system under erection. Transportation Research Record, (2152), 57-62. doi:10.3141/2152-07	Based on the articles focus on construction stage safety, not construction site or worker safety.

Table B-3: Quality assessment of primary sources

Primary Source	**Reference Type**	**Peer Reviewed**	**Number of Citations in Google Scholar**	**Method**	**Issues found from referenced or previous studies**
Behm, M. (2005). Linking construction fatalities to the design for construction safety concept. Safety Science, 43(8), 589-611. doi:10.1016/j.ssci.2005.04.002	Journal Article	Yes	141	Quantitative - linked construction fatalities to DfCS concept	
Behm, M. (2012). Safe design suggestions for vegetated roofs. Journal of Construction Engineering and Management, 138(8), 999-1003. doi:10.1061/(ASCE)CO.1943-7862.0000500	Journal Article	Yes	1	Observational research. Developed design suggestions.	
Coble, R. J., & Blatter Jr., R. L. (1999). Concerns with safety in design/build process. Journal of Architectural Engineering, 5(2), 44-48. doi:10.1061/(ASCE)1076-0431(1999)5:2(44)	Journal Article	Yes	19	Editorial	

Primary Source	**Reference Type**	**Peer Reviewed**	**Number of Citations in Google Scholar**	**Method**	**Issues found from referenced or previous studies**
Dewlaney, K. S., & Hallowell, M. (2012). Prevention through design and construction safety management strategies for high performance sustainable building construction. Construction Management and Economics, 30(2), 165-177. doi:10.1080/01446193.2011.654232	Journal Article	Yes	1	Interviews to develop risk mitigation strategies	Made liberal assumptions from the conclusion of a previous study referenced. But the assumption just provided justification on why the study was performed.
Dharmapalan, V., & Gambatese, J. A. (2012). Comparison of design risk factors of multistory commercial office buildings. Paper presented at the Construction Research Congress 2012: Construction Challenges in a Flat World, May 21, 2012 - May 23,299-309. doi:10.1061/9780784412329.031	Conference Proceedings	Yes	0	Interviews to develop risk factors. "Field survey-analytical research."	

Primary Source	Reference Type	Peer Reviewed	Number of Citations in Google Scholar	Method	Issues found from referenced or previous studies
Floyd, H. L., & Liggett, D. P. (2008). The NIOSH "prevention through design" initiative applied to electrical hazards in construction. Paper presented at the 2008 55th IEEE Petroleum and Chemical Industry Technical Conference, PCIC 2008, September 22, 2008 - September 24, doi:10.1109/PCICON.2008.4663967	Conference Proceedings	Yes	1	Editorial	
Gambatese, J. A. (1998). Liability in designing for construction worker safety. Journal of Architectural Engineering, 4(3), 107-112. doi:10.1061/(ASCE)1076-0431(1998)4:3(107)	Journal Article	Yes	42	Editorial	
Gambatese, J. A. (2000). Safety constructability: Designer involvement in construction site safety. Paper presented at the Construction Congress VI: Building Together for a Better Tomorrow in an Increasingly Complex World, February 20, 2000 - February 22, , 278 650-660. doi:10.1061/40475(278)70	Conference Proceedings	Yes	18	Editorial	

Primary Source	**Reference Type**	**Peer Reviewed**	**Number of Citations in Google Scholar**	**Method**	**Issues found from referenced or previous studies**
Gambatese, J. A. (2008). Research issues in prevention through design. Journal of Safety Research, 39(2), 153-156. doi:10.1016/j.jsr.2008.02.012	Journal Article	Yes	18	Editorial	
Gambatese, J. A., Behm, M., & Rajendran, S. (2008). Design's role in construction accident causality and prevention: Perspectives from an expert panel. Safety Science, 46(4), 675-691. doi:10.1016/j.ssci.2007.06.010	Journal Article	Yes	75	Expert Panel to validate Behm (2005)	
Gambatese, J. A., Hinze, J. W., & Haas, C. T. (1997). Tool to design for construction worker safety. Journal of Architectural Engineering, 3(1), 32-41. doi:10.1061/(ASCE)1076-0431(1997)3:1(32)	Journal Article	Yes	91	Best practices	
Hallowell, M. R., & Gambatese, J. A. (2009). Construction safety risk mitigation. Journal of Construction Engineering and Management, 135(12), 1316-1323. doi:10.1061/(ASCE)CO.1943-7862.0000107	Journal Article	Yes	27	Delphi process	

Primary Source	Reference Type	Peer Reviewed	Number of Citations in Google Scholar	Method	Issues found from referenced or previous studies
Hinze, J. (2000). The need for academia to address construction site safety through design. Paper presented at the Construction Congress VI: Building Together for a Better Tomorrow in an Increasingly Complex World, February 20, 2000 - February 22, , 278 1189-1195. doi:10.1061/40475(278)128	Conference Proceedings	Yes	5	Editorial	
Kasirossafar, M., & Shahbodaghlou, F. (2013). Application of visualization technologies to design for safety concept. Paper presented at the 6th Congress on Forensic Engineering 2012: Gateway to a Better Tomorrow, October 31, 2012 - November 3,370-377. doi:10.1061/9780784412640.040	Conference Proceedings	Yes	1	Survey to gain best practices	
Landis Floyd, H. (2010). Prevention through design. IEEE Industry Applications Magazine, 16(3), 14-16. doi:10.1109/MIAS.2010.936115	Journal Article	Yes	0	Editorial	
Landis Floyd, H., & Liggett, D. P. (2010). Hazard mitigation through design. IEEE Industry Applications Magazine, 16(3), 17-22. doi:10.1109/MIAS.2010.936122	Journal Article	Yes	1	Editorial	

Primary Source	Reference Type	Peer Reviewed	Number of Citations in Google Scholar	Method	Issues found from referenced or previous studies
Manuele, F. A. (2008). Prevention through design (PtD): History and future. Journal of Safety Research, 39(2), 127-130. doi:10.1016/j.jsr.2008.02.019	Journal Article	Yes	11	Editorial	
Mitropoulos, P., Cupido, G., & Namboodiri, M. (2009). Cognitive approach to construction safety: Task demand-capability model. Journal of Construction Engineering and Management, 135(9), 881-889. doi:10.1061/(ASCE)CO.1943-7862.0000060	Journal Article	Yes	14	Cognitive model is developed. Good literature review.	
Qi, J., Issa, R. R. A., Hinze, J., & Olbina, S. (2011). Integration of safety in design through the use of building information modeling. Paper presented at the 2011 ASCE International Workshop on Computing in Civil Engineering, June 19, 2011 - June 22,698-705. doi:10.1061/41182(416)86	Conference Proceedings	Yes	3	Computer model developed	
Rajendran, S., & Gambatese, J. (2013). Risk and financial impacts of prevention through design solutions. Practice Periodical on Structural Design and Construction, 18(1), 67-72. doi:10.1061/(ASCE)SC.1943-5576.0000129	Journal Article	Yes	0	Case study	

Primary Source	**Reference Type**	**Peer Reviewed**	**Number of Citations in Google Scholar**	**Method**	**Issues found from referenced or previous studies**
Rajendran, S., & Gambatese, J. A. (2009). Development and initial validation of sustainable construction safety and health rating system. Journal of Construction Engineering and Management, 135(10), 1067-1075. doi:10.1061/(ASCE)0733-9364(2009)135:10(1067)	Journal Article	Yes	23	Delphi survey	
Taiebat, M., & Ku, K. (2011). Design and planning for safety (DPfS); A factor modeling approach to find the best response to hazard. Paper presented at the AEI 2011: Building Integrated Solutions, March 30, 2011 - April 2, 437-447. doi:10.1061/41168(399)51	Conference Proceedings	Yes	0	Framework developed. Maybe concept mapping.	
Toole, T. M., & Carpenter, G. (2012). Prevention through design: An important aspect of social sustainability. Paper presented at the International Conference on Sustainable Design and Construction 2011: Integrating Sustainability Practices in the Construction Industry, ICSDC 2011, March 23, 2011 - March 25, 187-195. doi:10.1061/41204(426)25	Conference Proceedings	Yes	2	Provides overview of PtD	

Primary Source	**Reference Type**	**Peer Reviewed**	**Number of Citations in Google Scholar**	**Method**	**Issues found from referenced or previous studies**
Toole, T. M., & Gambatese, J. (2008). The trajectories of prevention through design in construction. Journal of Safety Research, 39(2), 225-230. doi:10.1016/j.jsr.2008.02.026	Journal Article	Yes	36	Existing literature to evaluated concept over the next couple decades	
Zhang, S., Lee, J., Venugopal, M., Teizer, J., & Eastman, C. M. (2012). A framework for automatic safety checking of building information models. Paper presented at the Construction Research Congress 2012: Construction Challenges in a Flat World, may 21, 2012 - may 23, 574-581. doi:10.1061/9780784412329.058	Conference Proceedings	Yes	1	Constructed Framework for BIM	
Zhang, S., Teizer, J., Lee, J., Eastman, C. M., & Venugopal, M. (2013). Building information modeling (BIM) and safety: Automatic safety checking of construction models and schedules. Automation in Construction, 29, 183-195. doi:10.1016/j.autcon.2012.05.006	Journal Article	Yes	10	Constructed Framework for BIM	

Table B-4: Data extraction and synthesis organized according to stage

Primary Source	Owner Jusification	Influence Factors	Application Methods
Behm, M. (2005)	X	X	
Behm, M. (2012)			X
Coble, R. J., & Blatter Jr., R. L. (1999)	X	X	
Dewlaney, K. S., & Hallowell, M. (2012)			X
Dharmapalan, V., & Gambatese, J. A. (2012)			X
Floyd, H. L., & Liggett, D. P. (2008)			X
Gambatese, J. A. (1998)	X	X	
Gambatese, J. A. (2000)			X
Gambatese, J. A. (2008)	X	X	X
Gambatese, J. A., Behm, M., & Rajendran, S. (2008)	X		
Gambatese, J. A., Hinze, J. W., & Haas, C. T. (1997)			X
Hallowell, M. R., & Gambatese, J. A. (2009)	X		
Hinze, J. (2000)	X	X	
Kasirossafar, M., & Shahbodaghlou, F. (2013)			X
Landis Floyd, H. (2010)			X
Landis Floyd, H., & Liggett, D. P. (2010)			X
Manuele, F. A. (2008)			X
Mitropoulos, P., Cupido, G., & Namboodiri, M. (2009)	X		
Qi, J., Issa, R. R. A., Hinze, J., & Olbina, S. (2011)			X
Rajendran, S., & Gambatese, J. (2013)		X	X
Rajendran, S., & Gambatese, J. A. (2009)			X
Taiebat, M., & Ku, K. (2011)	X		X
Toole, T. M., & Carpenter, G. (2012)	X	X	
Toole, T. M., & Gambatese, J. (2008)		X	X
Zhang, S., Lee, J., Venugopal, M., Teizer, J., & Eastman, C. M. (2012)			X
Zhang, S., Teizer, J., Lee, J., Eastman, C. M., & Venugopal, M. (2013)			X