DESIGNING FOR CONSTRUCTION WORKER SAFETY: A SOFTWARE TOOL FOR DESIGNERS

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
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To my lovely wife, Alison and to my mother, Dottie.

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This paper is for the women in my life without whom I would not be half the man I am today. It is for my amazing wife, Alison, who, at every step of the way, has been my inspiration with her unselfish love for me and her ability to teach me to be a better man with every moment that passes. And, it is for my mother, Dottie, who has sacrificed so much so that I might enjoy the life associated with a higher level of education. The stanza that follows is from “A Woman’s Question,” a poem written by my grandfather, Robert Woolsey, and I hope that it will remind us all to appreciate the women in our lives.

> Do you know you have asked for the costliest thing
> Ever made by the hand above--
> A woman’s heart and a woman’s life,
> And a woman’s wonderful love

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Safety in the construction industry continues to be an industry-wide concern. Accidents happen on construction projects for many reasons such as unsafe conditions, carelessness on the part of workers, and other inherent dangers. However, many firms recognize that the dangers associated with construction work can be reduced by placing more emphasis on construction worker safety in the design phase. That is, design professionals, such as architects and engineers, can play an instrumental role in reducing the risks of construction workers by incorporating certain elements into their plans and specifications. Reluctance on the part of designers to embrace the concept of designing for construction worker safety stems, in part, from their lack of knowledge about how projects can be designed with worker safety in mind.

The intention of the software tool developed through this research was to make hundreds of construction worker safety design suggestions accessible to design professionals. A previously developed tool with similar intentions was found to be difficult to use, update and deliver. By using the latest software development tools; researching, devising and compiling the latest list of design suggestions; and using the original software as a basis, the new software performs the tasks intended in a much more user-friendly and modern interface. Other improvements in the new software include an updatable, text-based database, help sections, a tour of the software, and

several report-generation methods. It is expected that these improvements will greatly increase the number of design professionals willing to use such a design tool. If the software is embraced and used, the practice of worker safety-in-design may continue to gain acceptance in the minds of design professionals and the construction industry in general. It will then follow that construction-related injury rates will decrease due to the proven correlation between decisions that influence project design elements and construction worker safety.

CHAPTER 1
INTRODUCTION

Safety in the construction industry continues to be a concern of many construction firms. In the quest for zero injuries, many firms recognize that the inherent dangers associated with construction work can be reduced by creating plans and specifications that put more emphasis on construction worker safety. Architects and engineers consider safety when they make design decisions, but they usually consider only the safety of the end user i.e., the contractors are expected to determine the best way in which to construct the project safely. Sadly, few designers consciously make design decisions for the safety of the construction worker. According to one study, “the lack of designers' involvement in worker safety is attributed to their minimal education and experience in addressing safety on the construction site, and their attempt to minimize their liability exposure” (Gambatese et al. 1997).

The lack of safety training for designers in the area of safety has contributed to a culture where the safety of construction workers is largely ignored. Past research developed many different worker safety-in-design suggestions but designers may easily become overwhelmed with these ideas. In fact, The Construction Industry Institute (CII) has developed well over 400 design suggestions that could be useful for design professionals. This thesis is focused on the development of a software tool created to aid designers in the daunting task of making construction projects safer for workers by making design decisions with construction worker safety in mind. By implementing the design for construction worker safety suggestions that have been developed, designers could significantly decrease the number of injuries incurred on projects. A software tool that provides easy access to these design ideas would be an effective means by which designers could quickly become familiar with the concept of designing for construction worker safety.

History of Existing Software

Using a software tool as a design aid for professionals wishing to incorporate design for construction worker safety suggestions into their projects is not a new idea. Recognizing that an increasing number of designers were addressing construction worker safety, the Construction Industry Institute (CII) funded a research project in 1996 to develop a software tool to assist designers in designing for construction worker safety. It was developed by John Gambatese, under the guidance of Dr. Jimmie Hinze. That software, entitled "Design for Construction Safety Toolbox," was fully functional, but it was quickly found to be cumbersome, hard to update, and hard to use because of the limitations of the authoring software at the time. As a result, the tool has not been used by designers to the extent that was anticipated and CII expressed a desire to have a newer version created which utilizes the most current authoring software to display the most updated list of design suggestions in an easily updatable, user friendly environment.

Objective: The New Software

The objective of this research is to develop software built specifically to give design professionals the ability to quickly and easily access and select from hundreds of compiled design for construction worker safety suggestions for use in their projects via the Web or a compact disc. In essence, the software is to provide easy access to design for construction worker safety suggestions. The software is to generate a printable report of only the CII approved design suggestions which the user has chosen thus limiting the vast amount of data to only those suggestions which are relevant to the project. For example, a user might be constructing a building which utilizes structural steel framing and therefore has no need to delve into the design ideas associated with wood, masonry or concrete framing. With the proposed software, the user could bypass the data which are not applicable to a specific project, thus limiting the amount of information that has to be entered to access a suitable report of the suggestions relevant to their

project. It is the goal of this thesis to create a software tool that will aid designers in making decisions that could ultimately reduce injury and death on construction projects by providing them with design suggestions in an easy to update, user friendly environment.

CHAPTER 2
LITERATURE REVIEW

What is Designing for Construction Worker Safety?

"The construction industry has the most fatalities of any other industry sector" (Bureau of Labor Statistics, 2005). There have been numerous studies to explain the reason for this statistic. The primary reason is that, simply put, construction work is inherently dangerous. Employers can take many steps to improve their safety performance. In fact, every party involved in the construction process can have an impact on construction safety. This is also true of designers. If action is taken in the design phase, it stands to reason that some of the inherent dangers can be minimized if not eliminated completely. In fact, "research studies have identified the design aspect of projects as being a significant contributing factor to construction site accidents" (Gambatese et al. 2005). Designing for construction worker safety requires a unique thought process where the designer must consider the people who construct the project, not just the end users, e.g. designing parapet walls to be tall enough to serve as guard rails to protect workers from falls. It entails utilizing modern technology, previous construction experience, common sense and other means necessary to explicitly design for construction worker safety.

History of Designing for Construction Worker Safety

In 1992, the first documented design for construction worker safety research was conducted by Dr. Jimmie Hinze and Francis Wiegand concerning the role that designers play with regard to construction worker safety. They contended that "despite the obvious reasons for placing the primary responsibility on the contractor, the safety performance on a project may well be dictated to a large extent by decisions made by the designer" (Hinze and Wiegand, 1992). With that research, a well-formed concept of designing for construction worker safety

was born despite the existing culture which dictated that designers simply had no responsibility for a project being constructed safely.

Unfortunately, standard industry practice continues to place the responsibility of the safety of construction workers on the contractor alone. Besides the widely accepted idea that contractors are responsible for worker safety, AIA documents clearly reinforce this by stating that the responsibility of worker safety does not fall on the designer. According to AIA201 (Section 3.3.1),

> The Contractor shall supervise and direct the Work, using the Contractor's best skill and attention. The Contractor shall be solely responsible for and have control over construction means, methods, techniques, sequences and procedures and for coordinating all portions of the Work under the Contract . . .

While the above statement does not explicitly place the responsibility of worker safety on the contractor, it does not imply in any way that designers have a responsibility to produce construction documents which promote worker safety. This is more explicitly stated in the AIA code of ethics which states quite clearly that the architect's role in terms of safety is limited to "the safety to the public of the finished project" (AIA, 2004). Even the commentary of the code of ethics states that the "rule applies only to the safety of the finished project, an obligation coextensive with the usual undertaking of an architect" (AIA, 2004).

Two other issues that tend to deter designers who would otherwise be willing to aid in decreasing injuries and fatalities on construction projects by designing for construction worker safety are liability and a lack of knowledge. John Gambatese summed it up well when he commented on designers avoiding the issue of designing for construction worker safety. He said "the lack of designers' involvement in worker safety is attributed to their minimal education and experience in addressing safety on the construction site, and their attempt to minimize their

liability exposure" (Gambatese et al. 1997). While steps have been taken to minimize these issues, they continue to be the major reasons given for the unwillingness of design firms to take on the endeavor of making their projects safer for the people who actually construct them.

Despite the many obstacles to having worker safety-in-design become a widely accepted practice, there has been an increasing amount of research and interest in designing for construction worker safety since the initial research in 1992. Researchers and professionals have been working on ways in which to aid designers in taking on the daunting task of creating designs that will decrease the injury and fatality rate in the construction industry. After years of working in an industry culture where the designer assumes little responsibility for the safety of construction workers, it is now becoming apparent that action at the design phase is a very important element which is necessary to reduce the number of injuries and deaths on construction projects.

Why Design for Construction Worker Safety?

"Better design provides a foundation for improved outcomes in the development, use and maintenance of a product like plant and equipment or a building" (Trethewy and Atkinson, 2003). There are several specific reasons why designers should consider worker safety when planning projects. First and foremost, it is becoming increasingly accepted that designing for construction worker safety can reduce the number of injuries and fatalities in one of the most dangerous industries. Secondly, professional designers should recognize that they have a moral, if not legal, responsibility to take every step necessary to ensure that their design ideas aid in minimizing injuries and fatalities on their projects. Also, studies have shown that decreasing the number of accidents in construction can reduce costs, making projects more lucrative to designers as well as builders, and making owners more willing to repeat their business with firms that take widespread precautions to ensure safe construction.

Injuries and fatalities should be avoided on construction sites by any means necessary. According to various studies, scheduling, planning, and designing activities can decrease the risk of incidents on construction projects. In fact, “a study of 100 construction site accidents found that changes in the permanent design elements would have reduced the likelihood of the accident occurring in 47 of the accidents” (Gibb, 2004). There is also evidence that design elements serve to protect the health of construction workers, not just their immediate safety. For example, “50% of the general contractors responding to a survey of the construction community in South Africa identified the design as an aspect or factor that negatively affects health” (Smallwood, 1996). Based on these and other studies, it is becoming increasingly apparent that appropriate design initiatives can significantly reduce injuries in construction and therefore the concept should be put into wider practice.

Another reason why worker safety-in-design should be practiced is based on professional and moral responsibilities of designers. Designers should take steps to avoid the devastating negative impact an ill-conceived design can have on the well-being of others, including construction workers. Unfortunately, “a survey of design engineers, general contractors, and subcontractors indicates there is not uniform agreement on the site safety responsibilities that should be assumed by each of these groups” (Toole, 2002). This statement indicates the lack of formally established responsibilities on construction projects and possibly encourages professional designers to leave the safety of the workers in the hands of the firms responsible for the actual means and methods of construction e.g., general contractors and subcontractors.

Another important reason for utilizing safety-in-design is the concept of investing in safety. That is, constructing projects safely is good for business. According to past safety studies previously mentioned in this paper, safety-in-design can dramatically decrease the number of

injuries incurred on construction sites. Thus, it can be inferred that designing for construction worker safety pays off financially as well. According to a study by Jimmie Hinze which examined the financial costs associated with accidents on construction projects, “the financial commitment in safety makes good business sense” (Hinze, 2000). Not only does it pay off in direct cost savings, but the amount of repeat clients a firm is likely to have can depend on their safety record. Any firm wishing to improve their safety record should incorporate designing for construction worker safety into their projects to achieve the best results.

Development of Past Ideas and Tools

Although the design community has not come very far in terms of implementing worker safety-in-design since 1992, there have been several studies performed, publications written and even tools developed to aid designers in designing for construction worker safety. The main goals of these endeavors have been to increase the awareness of designers to their responsibility for the safety of construction workers and to devise ways in which to provide designers with the knowledge necessary to create safer working conditions on construction sites. As previously stated, designers generally have little knowledge of designing for construction worker safety and are sometimes unwilling to accept this responsibility due to the potential increase in their liability exposure. Therefore, researchers have attempted to address these issues directly, but resistance among designers is strong. Significant changes must occur before the practice becomes widely accepted so that injury and fatality rates on construction projects decline dramatically.

One way in which researchers have attempted to increase designers’ knowledge is by devising suggestions that can be accessed and utilized by design professionals when planning out their projects. The Construction Industry Institute (CII) developed over 400 design suggestions through one of its research projects on construction safety. These ideas were devised using various research methods, including researching existing ideas, interviewing industry personnel

and reviewing safety manuals. This was done with the intention of aiding designers by compiling many useful designing for construction worker safety suggestions, i.e., the design suggestions were provided to expose designers to a different mindset about their designs. The intent was for designers to consider each design suggestion for its viability and that selection of specific design suggestions "should be conducted by the designer as specific project objectives are examined" (Construction Industry Institute, 1996). Thus, the idea was to provide design professionals with the information and tools necessary to make effective design decisions with regard to construction worker safety by providing a wide array of suggestions that may or may not be suitable for a specific project and the decision to use or not use the suggestions is left ultimately to the design professional.

With the development of these many useful worker safety-in-design ideas came another problem. The ideas were available but so abundant that designers could quickly become overwhelmed and not be exposed to potentially applicable ideas. At that point, CII recognized the necessity for a software tool specifically developed to compile the many valuable design for worker safety suggestions and make them easily accessible for design professionals. The first attempt at a software tool was a program called "Design for Construction Safety Toolbox" which was developed by John Gambatese, under the guidance of Dr. Jimmie Hinze, in 1996. However, while that software was fully functional and compiled the list of design for construction worker safety ideas, industry users of the software determined it to be very difficult to use and update, due mostly to the limitations of the authoring software. Therefore CII was not able to get the desired response from the program and it ultimately failed as a useful tool for designers wishing to incorporate worker safety into their designs.

Even as late as 2005, researchers have expressed the importance of tools that can promote the idea of designing for construction worker safety. There is a “compelling need to better understand how to put the safety-in-design concept into practice” (Weinstein et al. 2005). It is for this reason that CII recently expressed a desire to implement a new version of the software which would take advantage of the powerful authoring software available today. The ultimate goal of CII was to develop a tool that could compile the ever-growing list of designing for construction worker safety suggestions in a user-friendly environment. The software tool they have envisioned would promote more interest in designing for worker safety for several reasons. First, it would be easy to use so more design professionals would be willing to actually use it thus exposing more and more designers to the suggestions. Secondly, it would be easy to update as new suggestions were devised. Also, it would be accessible via the Web – a feature not possible with the previously developed software – making worldwide distribution simple and promoting the concept of safety-in-design through exposure to the many design for construction worker safety ideas already devised.

CHAPTER 3
METHODOLOGY

Introduction

The objective of this thesis was to create a tool that would provide designers with quick and easy access to many design for construction worker safety suggestions. This effort was begun by researching many aspects of the history, existing tools and existing ideas related to worker safety-in-design. The research methodology for this study consists of four phases. First, it was necessary to research the existing design for construction worker safety suggestions that had already been developed, especially those previously developed by the Construction Industry Institute (CII). Second, new suggestions were devised to ensure that the most comprehensive list was entered into the new software database. Third, research was conducted to choose the most suitable authoring environment for this type of application. Finally, after an authoring environment was chosen and the design suggestions were compiled into a usable format, the software was designed, coded, tested, modified, and finalized.

Phase 1: Existing Design Suggestions

Since the first documented design for safety research in 1992, many useful design for construction worker safety suggestions have been identified and compiled. The first phase of the research began by compiling the known suggestions on designing for construction worker safety. The existing suggestions were broken down into categories that had been previously developed through research by John Gambatese and Jimmie Hinze in 1996 for the CII. The following list shows how the existing suggestions were sorted:

- Administrative
    - Layout
    - Planning
    - Design
- Sitework
    - Layout

    - Roads and Paving
    - Earthwork
- Foundations
- Roofing
- Structural
    - Steel
    - Concrete
    - Masonry
    - Timber and Wood
- Finishes
    - General
    - Stairs and Railings
    - Ladders
- Doors and Windows
- Mechanical and HVAC
- Electrical
- Industrial Piping
- Tanks and Vessels

The above list was determined to be an appropriate model for organizing the new software database. The list appeared logical in format and the CII design for safety suggestions were already organized according to these categories (i.e., no significant changes were deemed warranted). The CII design for safety suggestions were placed into a spreadsheet using Microsoft Excel so that as additional design suggestions were identified or devised, it was a quick and easy process to ascertained whether or not any suggestions had, in fact, already been listed. This data management approach was necessary because of the large number of suggestions (over 400) that had been devised and collected for the CII research and because this process reduced the chance of duplicating ideas that were already listed.

Phase 2: Collecting and Devising New Suggestions

The second phase of the research was important since one of the issues with the original CII software was the difficulty involved in updating its database. Since additional design suggestions had been identified and developed since the 1996 CII research, it was essential that these ideas be added to the database. New ideas were collected and devised in this phase through

research of new ideas (developed since 1996), graduate student participation, and simple observations of construction sites by this researcher. The suggestions were then evaluated and logged for possible inclusion in the software database. Upon completion of these three methods, over 100 additional designing for safety suggestions were added to the new program.

The first method used for collecting and devising new design for construction worker safety suggestions was through research of the ideas that were devised since the finalization of the "Design for Construction Worker Safety Toolbox" software created in 1996. Jimmie Hinze, John Gambatese, Michael Behm and many other researchers have been active in devising new suggestions since the original software was developed. In fact, nearly thirty of the new suggestions came from Michael Behm's research in 2005. Many of these suggestions are included in published articles. In addition, several suggestions had been collected by John Gambatese and were provided for use in this research. Since these suggestions have been backed with extensive research, they were included in the new software to ensure an up-to-date database of suggestions. These new ideas were compiled and sorted by the categories used in the first phase of this research. They were then added to the spreadsheet under the proper category (or categories) for ultimate use in the software database. When suggestions were related to more than one category, they were added to more than one category.

New suggestions were also devised through the participation of Rinker School graduate students (enrolled in BCN 5737 and BCN 5715). The BCN 5737 class was given a presentation on designing for construction worker safety and a list of the existing suggestions. The students were then asked to perform the following task:

> Develop and describe at least one design for construction worker safety suggestion. Be sure to examine the existing suggestions to ensure that the suggestion is not already listed. Your suggestion can be an improvement on any suggestions that might already exist. Use sketches or figures if that helps to convey your idea.

The students in the other graduate class (BCN 5715) were simply asked to devise three possible designing for construction worker safety suggestions after receiving a brief explanation of the research being conducted. The suggestions from these two exercises were catalogued using the same method as in the first phase of this research and the ones deemed appropriate for use in the software were added to the spreadsheet under the applicable categories for use in the new software database.

The final method of devising and collecting new design for construction worker safety suggestions was through simple observations. Various construction projects were visited with the intention of identifying potential hazards that could be eliminated if more emphasis had been placed on safety at the design level. These suggestions were compiled and logged in the same fashion as in phase one of this research and were later scrutinized further for their appropriateness in the software.

Phase 3: Research of Authoring Environment

To produce effective and usable applications, software development requires research to choose the best authoring environment before the design and coding of an interface can take place. Since it has become a standard for the development of similar applications, Macromedia Flash 8 Professional (Flash) was chosen as the authoring environment. It was also chosen due to its high level of scalability, usability, accessibility and the powerful nature of Action Scripting (Flash's programming language) which permitted the creation of a database to which new design suggestions could be added in the future by simply editing a text file. Flash applications can be accessed via the Web, a compact disc, hard drive, or any storage device with the necessary file capacity (in this case, the application itself is only about 250 kilobytes). Flash applications do require the use of Flash Player, but "Flash Player is installed on 98% of Internet-enabled desktops worldwide and on a wide range of popular devices" (Adobe Systems Incorporated,

2007). In addition, the player is a free download for anyone with Internet access. The powerful features mentioned above made Flash the best choice for authoring the new designing for construction worker safety software.

Phase 4: Software Development

The fourth and final phase of this research consisted of the actual development of the new designing for construction worker safety application. Under the guidance of Jimmie Hinze, along with direction from a CII liaison, the new software outline began to take shape. Since this researcher had a strong background in both Web and software development, it was not necessary to research the Flash authoring environment in order to develop the software to meet the needs expressed by the CII. In essence, the CII expressed a need for a software tool which would replace the "Design for Construction Worker Safety Toolbox" software tool created in 1996. The primary disadvantages of the 1996 software were that it was cumbersome and nearly impossible to update. Therefore, it was necessary for the new software to be user-friendly and to utilize a database that could easily accommodate future design for construction worker safety suggestions as they are devised.

There are many different elements that play a role in the development of a useful application including design, navigation, features, and the database. The design, consisting of layout, colors, graphics, etc., is important because it keeps users interested in using the software. The design of the new application was created with the weaknesses of the 1996 software in mind. Various design elements were added to increase usability and to decrease the amount of user training necessary to effectively operate the software. The navigation of an application consists of interactive buttons used for getting around within the interface and is important because users should not become frustrated or lost within a virtual environment. Difficult navigation was another weakness of the 1996 "Design for Construction Worker Safety Toolbox."

Therefore, simplicity was the focus of the navigation in the new application to further ensure that it was optimized for ease-of-use, with minimal training requirements. The word features, in this context, refers to help sections, software tours, print functions, etc. In this application, these elements were used as a means by which to increase the ease-of-use of the environment while allowing for a large number of suggestions to be easily accessed. The database of an application is where the main portion of the data is stored and accessed by the interface (in this case, the database consists of design suggestions). Since the other main drawback of the original 1996 CII software was that its database could not be updated, the new database consisted of a simple, external, text-based (XML) file designed specifically to allow for easy updates, most of which can be done even without the use of Flash authoring software.

Since the main function of the new software was to compile design for construction worker safety suggestions for easy access by design professionals, the above elements all focused on attaining that goal. However, in the design process, it was found necessary to exclude some functions that were included in the original software. One example of this is the exclusion of the Save function. The new software was designed for use on a one-session basis. That is, users will not have the ability to save their progress, but they do have the ability to access their report by either printing it or copying and pasting it. Another example of an excluded feature is the inability to edit design suggestions within the interface. If a design suggestion needs to be edited, it would need to be edited in the database and not in the software interface itself. The above limitations exist mainly due to restrictions that were found while attempting to optimize the application for deliverability and ease-of-use. In essence, it was deemed acceptable to trade certain functionality for ease-of-use and software deliverability.

Upon completion of a prototype application, the software was critiqued and tested by more than 50 individuals. This proved to be an effective test of the software's stability, usability, and accessibility. Testing was performed throughout the entire design process but took place more formally in a classroom setting after the software was deemed reasonably functional. The same graduate-level class as mentioned in the second phase of this research (BCN5737) was asked to participate in testing the software. After being given a demo version of the software for review, they were given the following task:

> Review the information in the software being developed on designing for safety. When doing this, comment on the usability of the software itself. That is, describe the strong features and the weak features of the software. Describe features that you feel would be helpful to include in the software as it is developed further.

The information gleaned from the results of this exercise proved invaluable for working out bugs, adding certain features and cleaning up design issues which might otherwise have been overlooked. This extensive testing made for a more stable, user-friendly software application.

CHAPTER 4
RESULTS

Designing For Worker Safety Suggestions

Before this research began, there was a collection of 430 unique designing for construction worker safety suggestions in the 1996 software database. Upon completion of the research, using various methods to collect and devise new suggestions, a total of 555 unique suggestions were included in the new software database. Therefore, the methods used to collect and devise new designing for construction worker safety suggestions allowed an additional 125 suggestions to be added to the new software database (Table 4-1). Since there were many suggestions which had relevancy to more than one category, a total of 807 suggestions can be accessed through the new software database.

New Software Uses

The results of this thesis can best be explained in terms of the design, functionality, and possible industry benefits that the new software tool can provide. Upon completion of this research a fully functional, standalone application had been developed. The application essentially functions as a compiler of designing for construction worker safety ideas intended for use by design professionals such as architects and engineers. This software serves as a tool with which design professionals can easily sort through the many useful suggestions and generate a report of those selected by users. The input consists of selections made by users of various suggestions that are deemed appropriate for a specific project. The output is a generated report of the suggestions which were selected by users. The suggestion database consists of a text file (XML) which is updatable even without the use of the Macromedia Flash 8 Professional authoring software. There are other elements incorporated into the software as well including, illustrations that describe complex suggestions, Help sections, a Tour, and an About section.

Design Elements

The software tool offers substantial improvements not included in the 1996 version. For example, the list of suggestions has been expanded, the software is now much more user-friendly, the software is deliverable by many different means (including via the Web, via compact disc, or hard drive), and the suggestion database can be easily updated. These improvements have been incorporated into a final version of the software that will hopefully be embraced by design professionals as a means by which they can design projects that are safer for construction workers. As more designers realize the effectiveness and ease-of-use of the software tool, it stands to reason that more designers will become exposed to the principle of designing for construction worker safety and be more willing to put it into practice in their designs. The above-mentioned characteristics of the software place primary emphasis on the design, navigation, features and the software database.

The design of the application focused on the effective use of graphics, colors and other elements to optimize the user's experience when using the software. For example, the Start screen (Figure 4-1) is pleasing to the eye and does not visually confuse users. The goal was not to intimidate users with too many elements while keeping the software interesting, and encouraging the user to move on. The graphical elements were also used in order to create an intuitive environment to promote the use of the software. For clarification of complex design suggestions, illustrations were created and added to some suggestions to ensure complete understanding of the design suggestion. The use of the same header throughout a session when using the software gives users a sense of where they are at all times and that all sections are related. To further ensure simplicity of use, the layout was based on only three main screens; The Start screen (Figure 4-1), Step 1 screen (Figure 4-2), and Step 2 screen (Figure 4-3). The Start screen is the launching pad for the software which includes a Take Tour button, Start button, and

an About button. The Step 1 screen is the input screen where users actually choose suggestions which are appropriate for their project. As such, it is on the Step 1 screen where most of the users' time will be spent when reviewing and selecting design for construction worker safety suggestions. The Step 2 screen is an output screen where users can print, copy, or simply view their selected suggestions. This simplistic approach to design proved effective when the software was shown to various individuals for critique of the ease-of-use of the software. It was noted that with a brief introduction to the software that novice users can comprehend and use the software with confidence within about five minutes.

The navigation of the software focused on ease-of use as well. It is straightforward and intuitive and allows users to go to any screen with no more than two mouse clicks from any given point. Start, Step 1 and Step 2 were deemed to be the most appropriate headings for the three main screens and their respective interactivity is limited to only the functions necessary at each of these screens. Once the user clicks the Start button and begins Step 1 of the application, the navigation becomes only slightly more complicated. Along the left side of the screen, the categories mentioned above, such as Administrative: Layout, Administrative: Planning, etc., are listed for quick access. Users also have the ability to move on to the Step 2 screen, or view the Tour (Figure 4-4) and About (Figure 4-5) screens from this step. When users continue to Step 2, the navigation becomes very simplistic. Users have minimal choices on the Step 2 screen. They can go to the step-specific Help screen by clicking on the Help button, they can print the compiled suggestions by clicking on the Print Report button, or they can go back to the Step 1 screen and add or remove suggestions. The latter allows users to read their report and decide if they want to discard suggestions or add suggestions.

The various features in this application were designed to make the software as user-friendly as possible. One feature that was incorporated is the Take Tour feature (Figure 4-4). This feature allows users to preview what they will see when they click the Start Button on the Start screen. It labels the navigational areas and gives hints as to how to use the software effectively. Another feature relates to the step-specific Help sections which appear on the Step 1 (Figure 4-6) and Step 2 (Figure 4-7) screens. These sections were designed to help the user with questions they might have while working in a specific step. Instead of accessing all the help information with one button, the Help buttons are customized for the step that the user is actually viewing at the time that assistance becomes necessary. Another feature is the Print function. Flash has a feature that allows developed applications to work directly with a local or network printer in order to turn the users' input into a hard copy report of project-specific design for construction worker safety suggestions. The text in the Step 2 screen is also selectable allowing users to copy and paste their report into Microsoft Word or any other word-processing application to facilitate the creation of an editable list of project-specific suggestions.

The database (Figure 4-8) designed for this application is very simplistic. The application reads the category suggestions from a simple XML file (which can be edited in Notepad or any similar word processing application). This allows anyone with minimal Information Technology training to update the suggestions that are listed in the software. The XML file is formatted using tags and is labeled throughout for simplistic addition of data. This simple yet powerful marriage of Flash programming and design with a simple text-based database is the main property that makes this software easy to update.

Interface Walkthrough

The input, output, and various features of the new software can more specifically be described by explaining the functionality of each of the three screens (Start, Step 1, and Step 2)

which make up the main interface of the software application. When users launch the software, the Start screen is displayed. At this point there are subsections of the Start screen that might be of particular interest to novice or first-time users, including the Take Tour section and the About section. After exploring those sections (or choosing not to explore them), the user can click on the Start button and be taken to the Step 1 screen. After choosing appropriate suggestions in the Step 1 screen, the user can go directly to the Step 2 screen where they will be provided with a generated report of only the selected suggestions which they deemed appropriate for their particular project. The following is a walkthrough of the software that explains each element of each of the main screens as well as the features associated with them.

The Start Screen

The Start screen (Figure 4-1) is the first screen users see upon launching the software. It is from this screen that the user can take a tour of the software by clicking on the Take Tour button, read various information about the software by clicking on the About button, or simply begin using the software by clicking on the Start button. The Take Tour screen (Figure 4-4) was intended as a means by which users could get an idea of how the software works without actually going to Step 1 in the sequence. It also serves as a familiar tool (incorporated into many applications) that enables users to become familiar with the navigational environment. The About screen (Figure 4-5) is simply an informational screen which displays data about the software such as licensing information, software version, and other pertinent information. The third and final button on the Start screen, the Start button, takes the user directly into Step 1 (input screen) of the sequence.

The Step 1 Screen: Input

Upon clicking on the Start button from the Start screen, the user is taken to the Step 1 screen, the input screen. This is where users can choose the suggestions that are relevant to their

project. The user has the ability to choose from the categories in the category model mentioned in Phase 1 of the research methodology and choose from over 800 suggestions (with an average of over 40 suggestions per category). By default, the suggestions for the first category (Administrative: Layout) are displayed in the center of the screen under their respective heading and the button for that category is highlighted (Figure 4-2). When a user clicks on a different category, that button becomes highlighted and its suggestions are then displayed in the center of the screen along with their respective heading, and so on. When all suggestions for one category cannot be viewed at one time, a scroll bar can be used to view those suggestions not viewable on the default screen.

No more elements change until the user actually selects a suggestion by clicking on its corresponding checkbox. At that point, a checkmark is displayed next to the suggestion which has just been selected. In addition, a checkmark is displayed next to the category button on the left side of the screen which indicates that the user has visited that category and has chosen at least one suggestion from it (Figure 4-9). Both of those checkmarks will remain until the user deselects the suggestion(s) or exits the program. Since some of the design suggestions listed in the database were not intuitive with a verbal description alone, graphics were included under the relative suggestion to ensure that each suggestion would be thoroughly understood by the users (Figure 4-9). Once users have chosen all the suggestions that they deem appropriate, they can click on the Step 2 tab and be taken to the Step 2 screen in the sequence where the report of selected suggestions is generated. Other navigation within the Step 1 screen includes the step-specific Help button which takes the user to a Help screen that will explain what input is needed in order to complete Step 1. The Take Tour button and an About button are also accessible on the Step 1 screen.

The Step 2 Screen: Output

Once users have selected the suggestions that they feel are relevant and have clicked on the Step 2 tab, they proceed to the Step 2 screen (Figure 4-3). This screen is the equivalent of a report page as it compiles only the suggestions that have been selected in Step 1 and places them into an easy-to-read format, sorted by category, for quick reference. Users have several choices in Step 2. They can simply view their report in the interface, they can print their report by clicking on the Print Report button, they can copy and paste their report into Microsoft Word (or any similar word-processing application), they can go to the step-specific Help screen, or they can go back to Step 1 to edit the list of suggestions which appear in the report. Another important addition to this step is the information listed on the left-hand side of the screen. This information provides users with a quick reference as to their choices on the Step 2 screen.

Software Limitations

The major limitations of the software are that there is no Save function, there is no Search function and users do not have the ability to edit design suggestions within the interface. The exclusion of the Save function eliminates the users' ability to stop work in the middle of a session and pick up at a later time. The software was designed in a one-session manner meaning that users must finish selecting suggestions and retrieve their report before exiting the software or all checkboxes will default back to unchecked status when the program is restarted. However, if the user followed a sequential pattern of reviewing the suggestions, a note could be made as to those categories that have been reviewed and for which suggestions have been saved in a Microsoft Word file or printed to hard copy. Users could then do a follow-up session to review the categories not yet examined. The lack of a Search function limits users' ability to find design suggestions with keywords. However, the simplicity of the category organization makes a Search function a convenience rather than a necessity and should not affect the ease-of-use to any great

extent. The final limitation mentioned is that the interface has no built-in means by which users can edit design suggestions. That is, in order to modify the design suggestions that appear in the interface, one must edit the text file that serves as the application's database. However, since the reports have the ability to be copied and pasted, users do have the ability to edit the suggestions at that point if they feel it is necessary for their project.

Advantages and Benefits

The advantages of this software when compared to the 1996 "Design for Construction Worker Safety Toolbox" software include a more simplistic interface, a more modern look and feel, the ability to deliver the software via the Web and perhaps most importantly, the ability to update the design suggestion database with limited Information Technology experience. Since the creation of the original software in 1996, one of the factors that limited its use was that it was cumbersome for users. They quickly became confused while working in the interface and the added features only complicated the main goal of compiling the design suggestions for easy access by design professionals. This new software addresses this issue well by focusing on ease-of-use in its design. Users are able to follow the software and quickly access over 800 design suggestions without getting lost or confused. To be effectively put into use, software must be changed regularly in order for users to stay interested. The look and feel of the software created in 1996 is dated. The new software has a modern look and feel due to its use of graphics, illustrations and the fact that it has been developed with Flash, one of the most popular authoring software tools in the world today. Another powerful advantage of the new software is that it can be accessed via the Web, a compact disc or even a flash memory card with no installation required on most computers, while the 1996 software was difficult to install and distribute. The above three weaknesses of the new software are noted but, perhaps are overshadowed by the most important advantage of the new software, namely its database capabilities. The 1996

software was nearly impossible to update, while the new software uses a simple text file to incorporate design suggestions into the interface with the use of nothing more complex than Microsoft Notepad. These advantages over the original software come together to produce a tool that can potentially affect design practices in the industry, making construction a safer industry in which to work.

Since the new software is user-friendly, easy to deliver, and easy to update, it should be more widely accepted by design professionals as a useful tool than was the case with the 1996 version of the software. If the tool becomes widely distributed and embraced by the design community, not only will more designers be exposed to the suggestions incorporated into the software at the time of this research, there will be increased exposure to the concept of designing for construction worker safety itself. This exposure could prove to be very effective in convincing designers that injuries and fatalities can be reduced if more focus on safety occurs at the design phase of construction. As more designers use the software, more designers may realize that the design suggestions are readily available and that incorporating them into their designs is not difficult. That fact, coupled with the fact that they could potentially be saving lives by using simple design suggestions from a simple software application, could begin to convince designers that the resources and tools are available to them to contribute to construction worker safety in the construction industry.

Table 4-1. Number of Design Suggestions Collected and Devised from Various Sources

Suggestion Source	Approximate Number of Suggestions
Database of original software	430
Suggestions collected since 1996	71
Graduate student suggestions	23
Suggestions devised by researchers	31
Total unique suggestions in database	555
Total number of suggestions in database	807

Figure 4-1. Screenshot of Start screen.

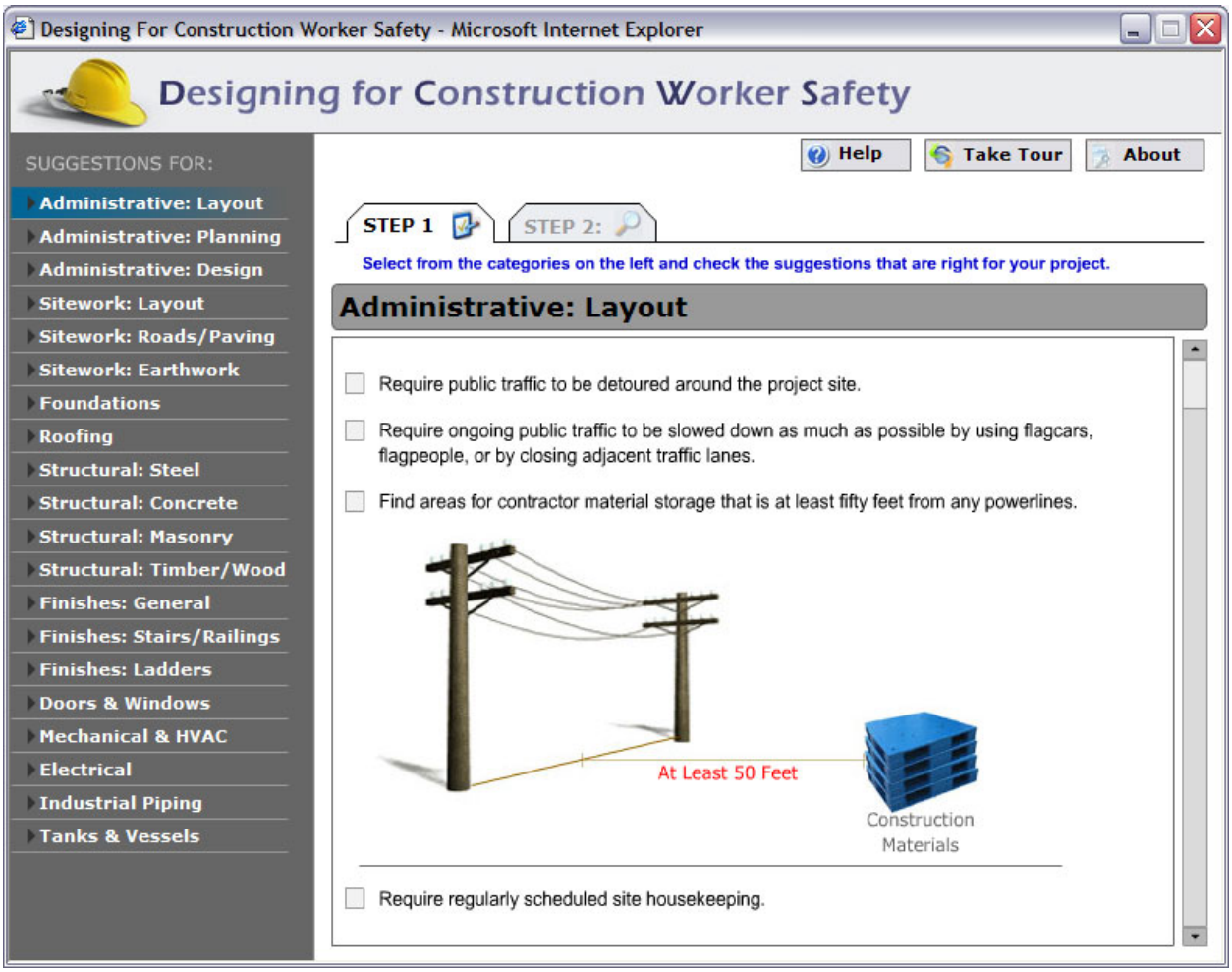


Figure 4-2. Screenshot of Step 1 screen.

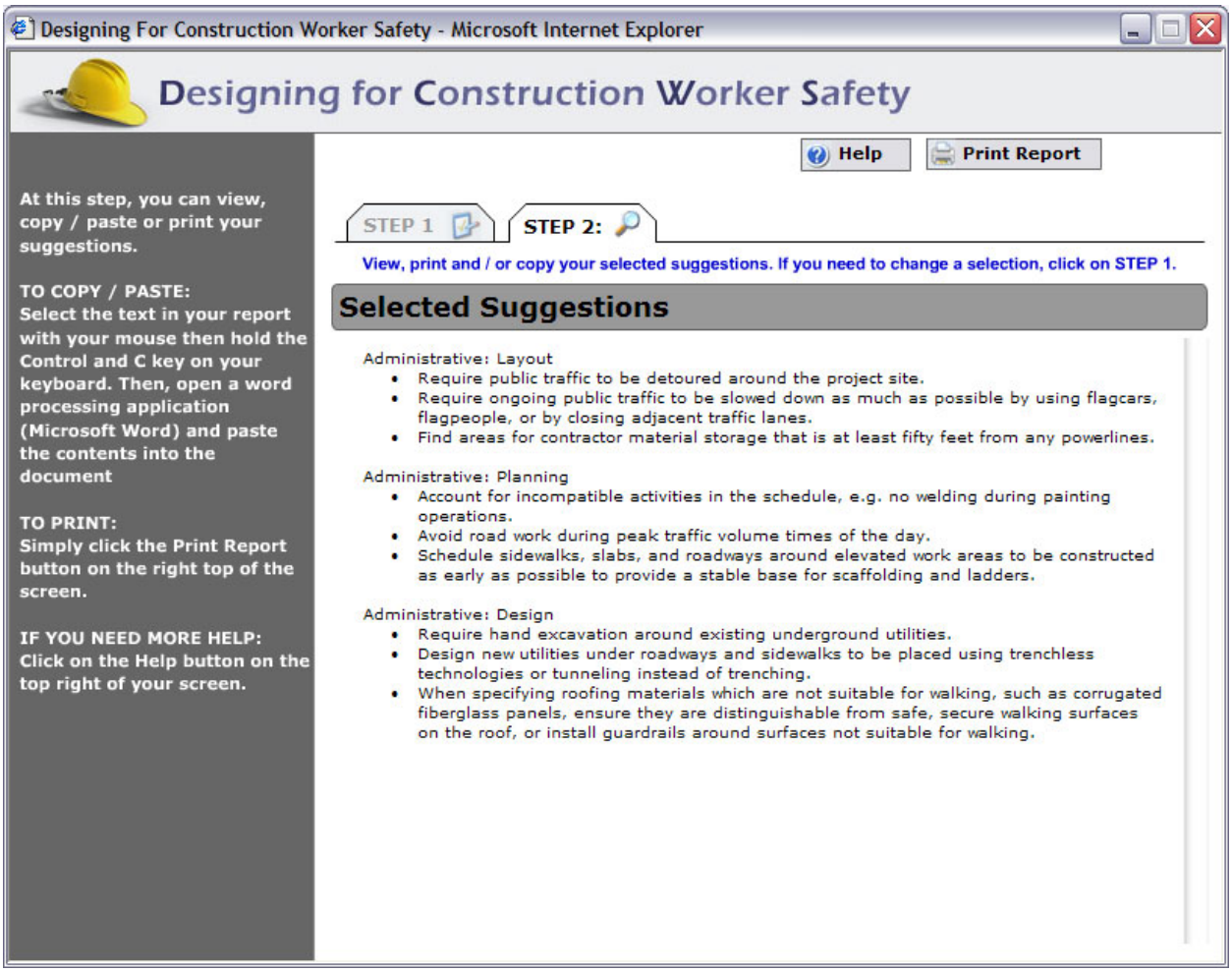


Figure 4-3. Screenshot of Step 2 screen.

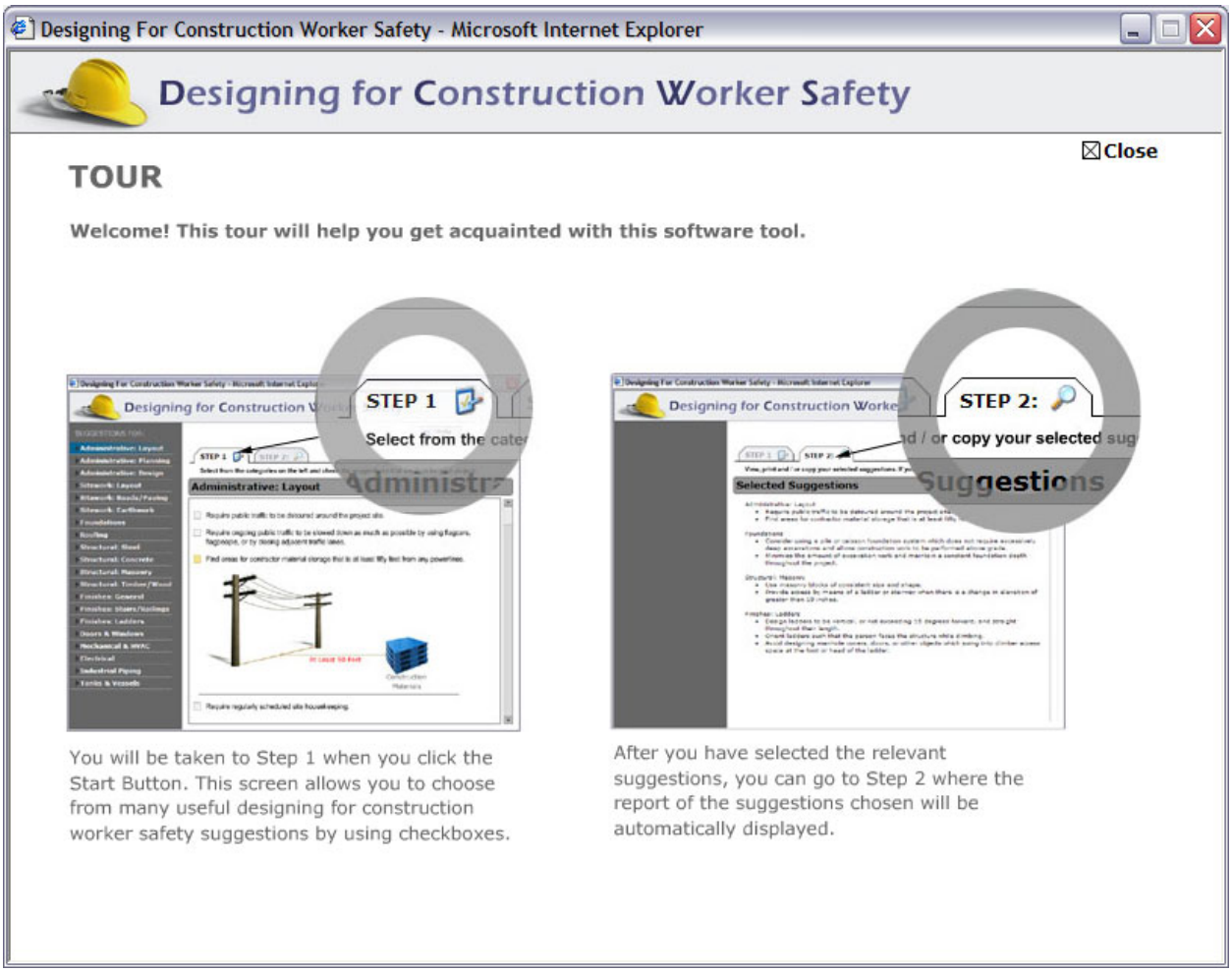


Figure 4-4. Screenshot Take Tour screen.

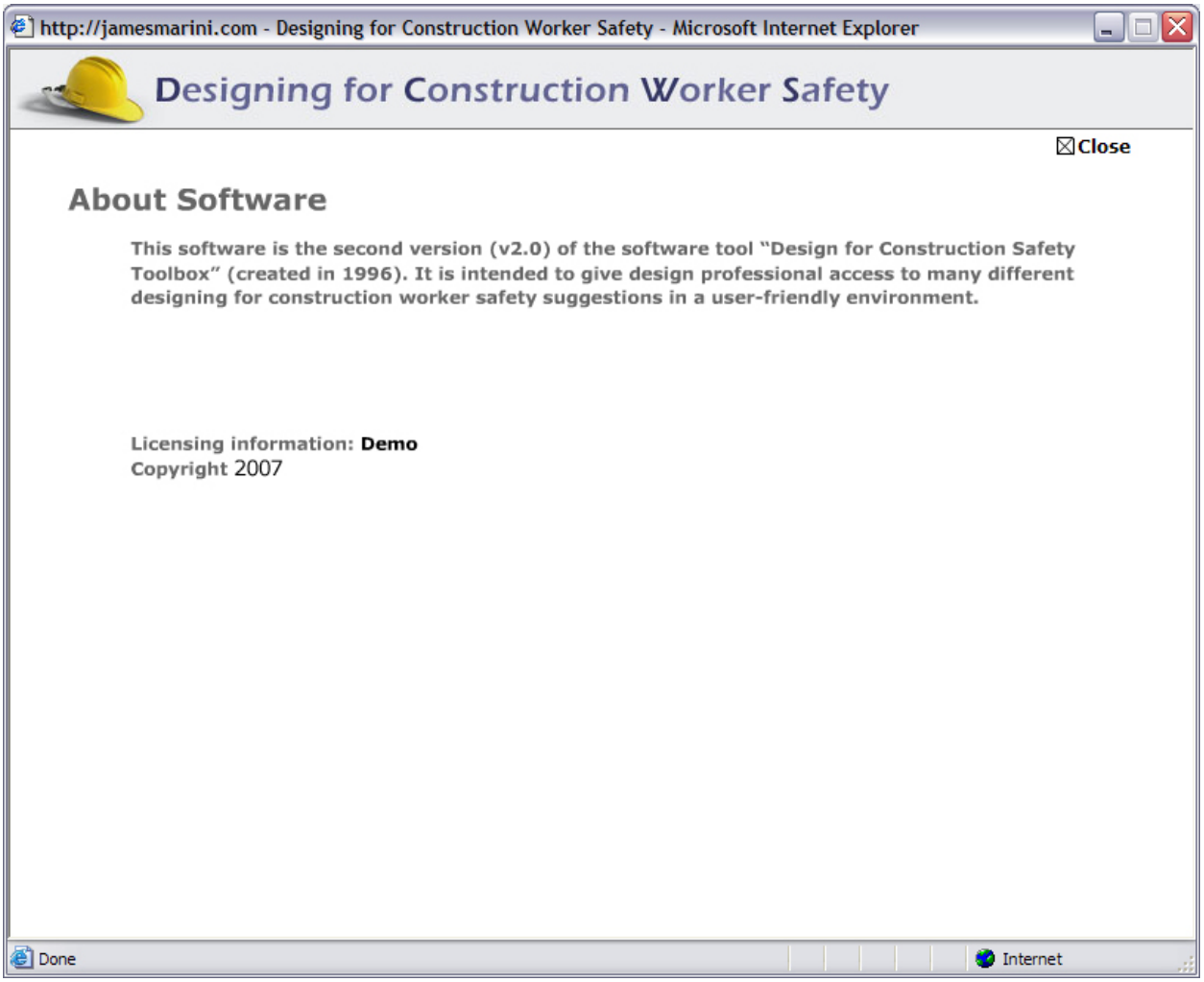


Figure 4-5. Screenshot of About screen.

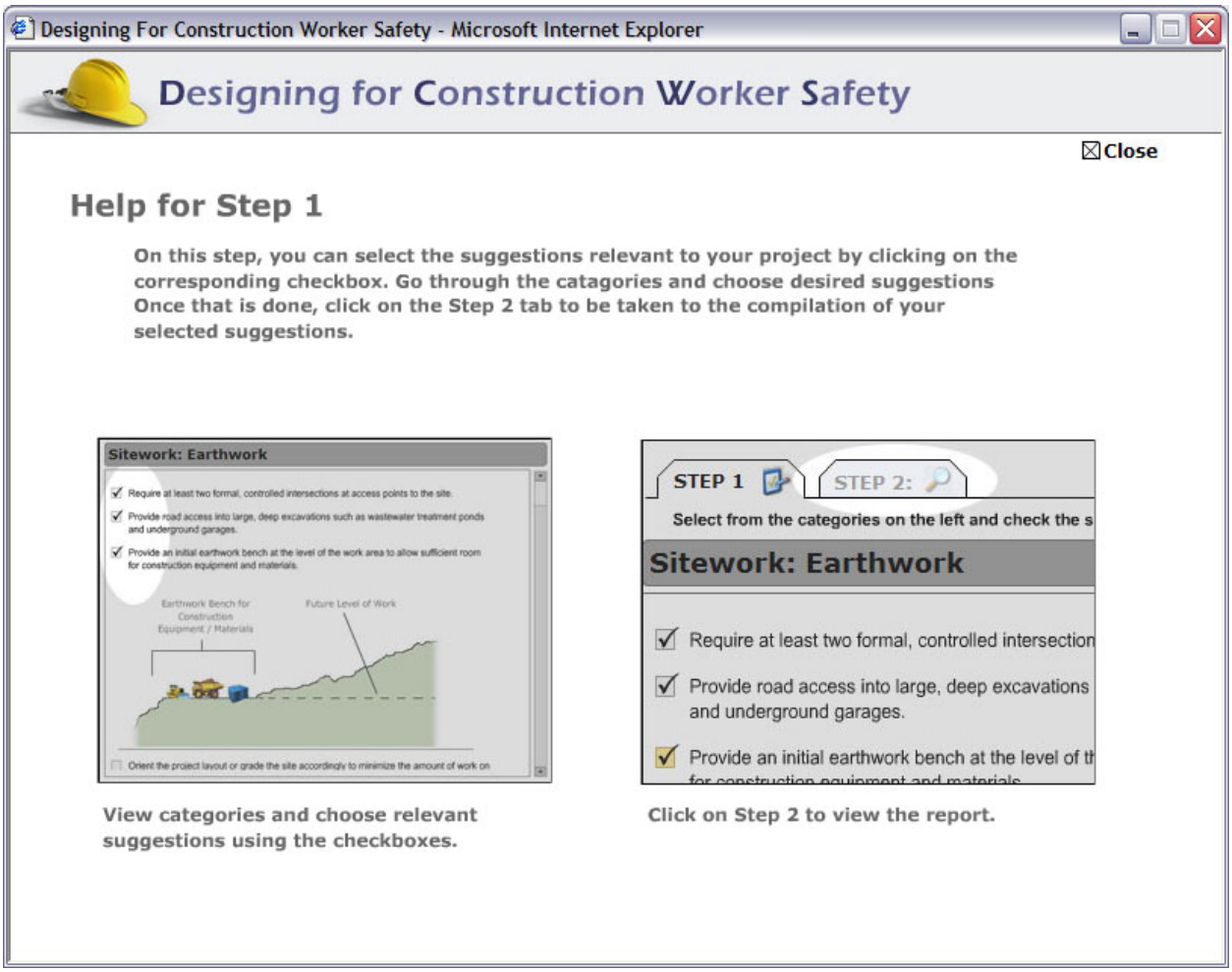


Figure 4-6. Screenshot of step-specific Help screen for Step 1.

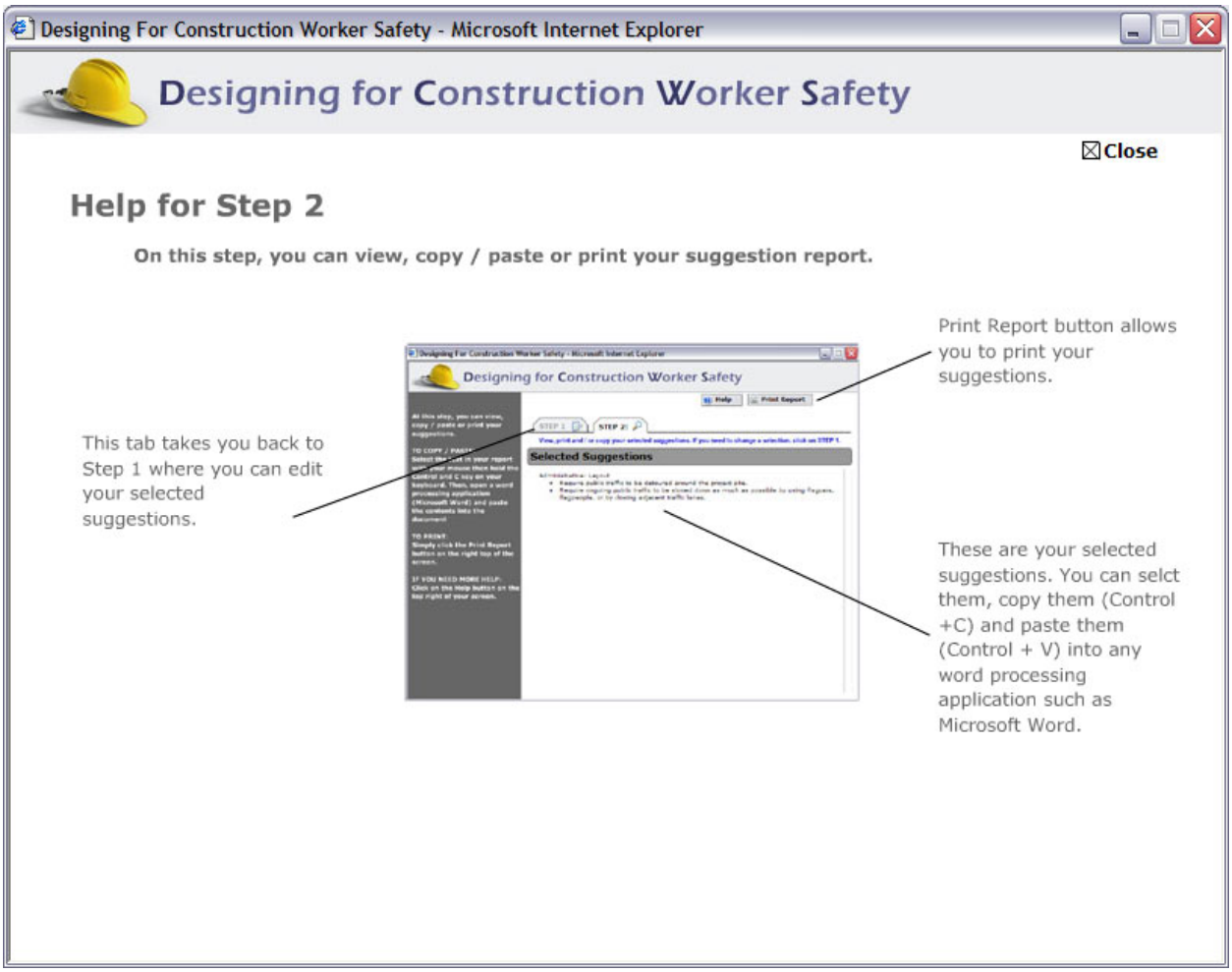
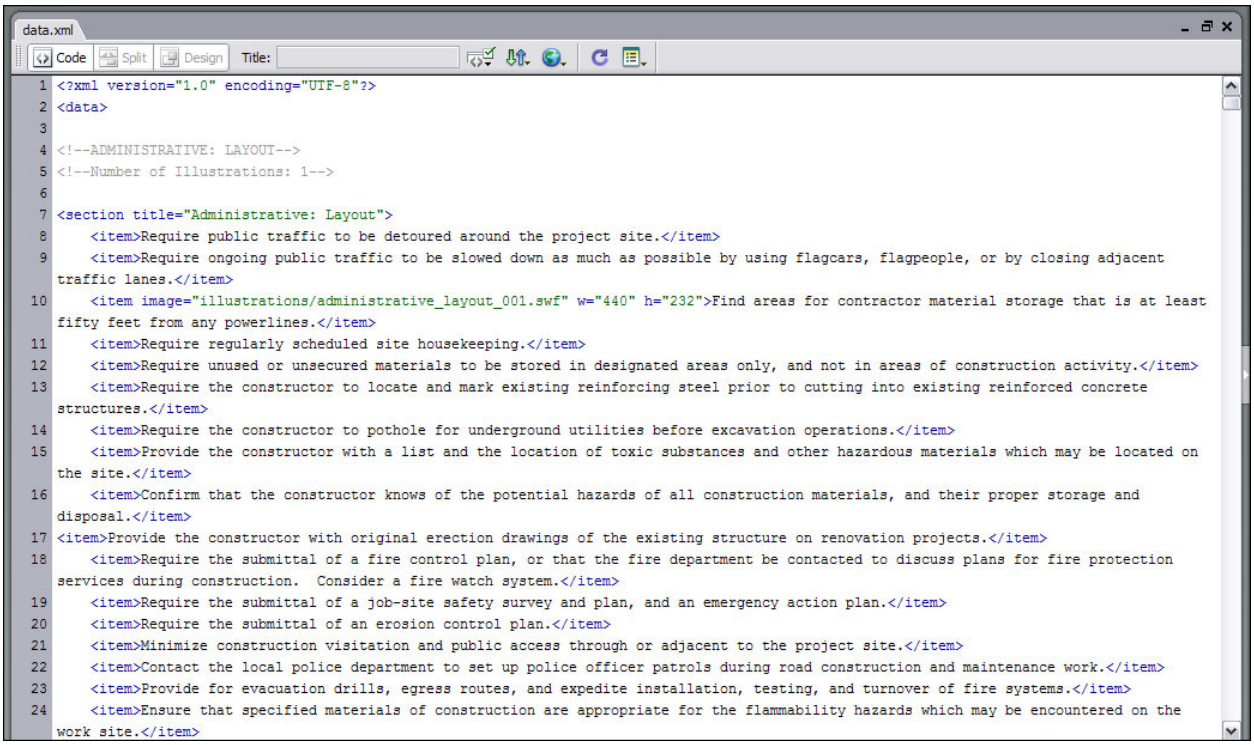


Figure 4-7. Screenshot of step-specific Help screen for Step 2.



```xml
<?xml version="1.0" encoding="UTF-8"?>
<data>

<!--ADMINISTRATIVE: LAYOUT-->
<!--Number of Illustrations: 1-->

<section title="Administrative: Layout">
    <item>Require public traffic to be detoured around the project site.</item>
    <item>Require ongoing public traffic to be slowed down as much as possible by using flagcars, flagpeople, or by closing adjacent traffic lanes.</item>
    <item image="illustrations/administrative_layout_001.swf" w="440" h="232">Find areas for contractor material storage that is at least fifty feet from any powerlines.</item>
    <item>Require regularly scheduled site housekeeping.</item>
    <item>Require unused or unsecured materials to be stored in designated areas only, and not in areas of construction activity.</item>
    <item>Require the constructor to locate and mark existing reinforcing steel prior to cutting into existing reinforced concrete structures.</item>
    <item>Require the constructor to pothole for underground utilities before excavation operations.</item>
    <item>Provide the constructor with a list and the location of toxic substances and other hazardous materials which may be located on the site.</item>
    <item>Confirm that the constructor knows of the potential hazards of all construction materials, and their proper storage and disposal.</item>
<item>Provide the constructor with original erection drawings of the existing structure on renovation projects.</item>
    <item>Require the submittal of a fire control plan, or that the fire department be contacted to discuss plans for fire protection services during construction.  Consider a fire watch system.</item>
    <item>Require the submittal of a job-site safety survey and plan, and an emergency action plan.</item>
    <item>Require the submittal of an erosion control plan.</item>
    <item>Minimize construction visitation and public access through or adjacent to the project site.</item>
    <item>Contact the local police department to set up police officer patrols during road construction and maintenance work.</item>
    <item>Provide for evacuation drills, egress routes, and expedite installation, testing, and turnover of fire systems.</item>
    <item>Ensure that specified materials of construction are appropriate for the flammability hazards which may be encountered on the work site.</item>
```

Figure 4-8. Screenshot of database formatting.

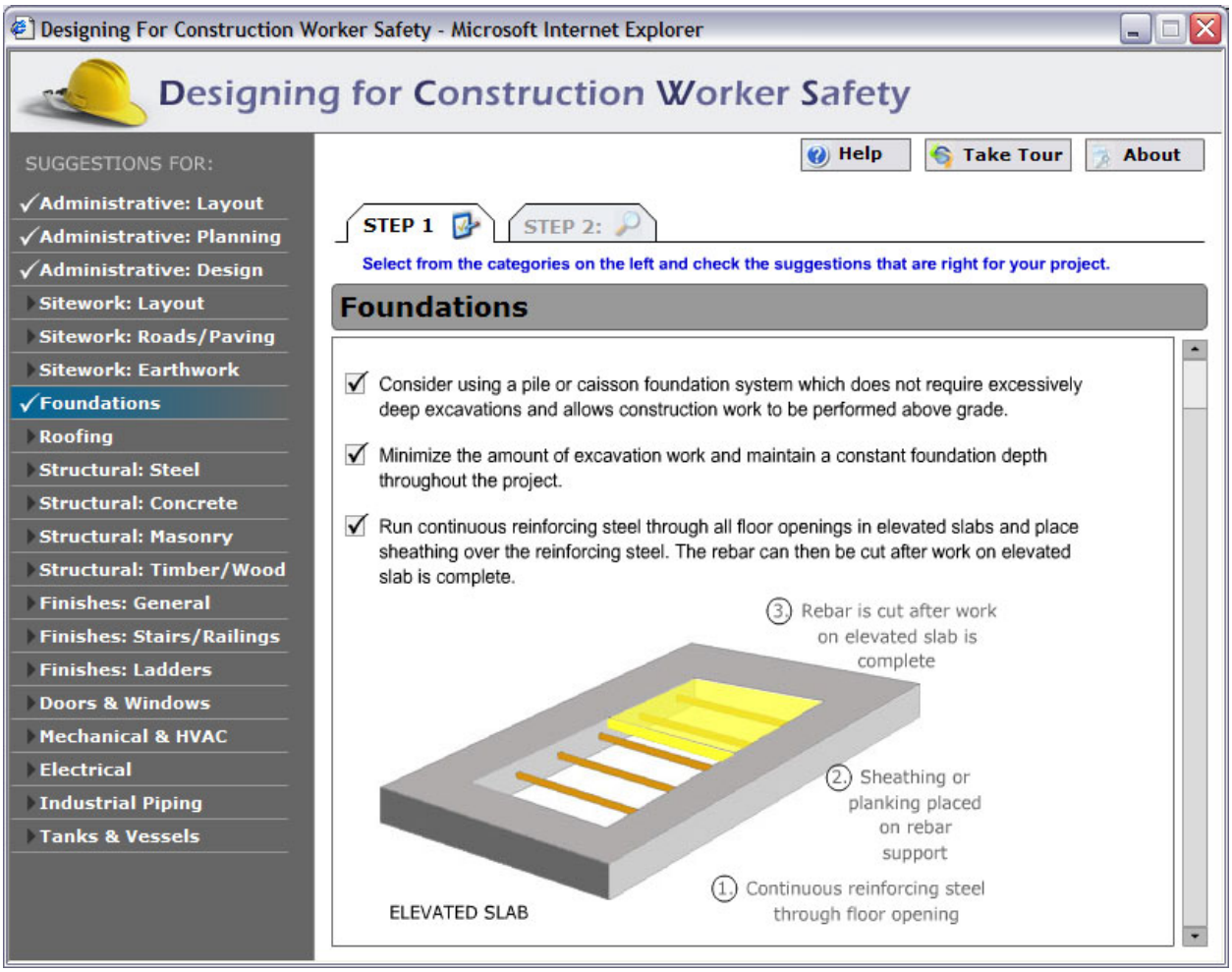


Figure 4-9. Screenshot of Step 1 with random selections made.

CHAPTER 5
CONCLUSIONS

A Useful Tool

In 1996, the CII recognized that designing for construction worker safety software could prove invaluable in promoting jobsite safety. The goal of the CII software created in 1996 was "to provide a simple means by which a designer could be introduced to a variety of design suggestions that would make the facility safer for construction workers" (Page 32, Gambatese, 1996). The software tool developed through this research achieves the same goal and is even more powerful due to its simplicity. It gives design professionals access to over 800 designing for construction worker safety suggestions in an easy-to-use application that requires little training or computer knowledge. It does not confuse the user with extraneous screens and features because it works in a sequential manner by using two simple steps. Help, Tour and other features are incorporated into the software to further ensure usability. An easily expandable database, along with the original, editable Flash (FLA) files, gives this software the potential to be used for years to come. In short, it performs the primary tasks associated with the 1996 software in a much more manageable virtual environment, making it a very useful tool.

Delivering the Software to Users

Another useful property of the new software is the ease with which it can be delivered to many users with minimal effort. That is, the software can be accessed by users via the Web, a compact disc, a hard drive or even a small storage device such as a flash memory card. With its relatively small file size (the application itself is only about 250 kilobytes), the application is deliverable by almost any means available today. This means that downloading the software via the Web, even with a dial-up connection, will be fast. It also means that widespread distribution of the software will be simplistic should this be the desire of the CII. Deliverability of the

software is crucial in order to increase awareness of the tool which will increase exposure to designing for construction worker safety. This can help ensure that the concept will be put into wider practice.

User Comments

After more than 50 individuals had the opportunity to utilize and examine the software, the most consistently positive comments were about its ease-of-use. These positive comments prove that the software is user friendly. Most negative comments related to the software's inability to save a session, but this can be solved by simply saving the design suggestions chosen in one session to a Microsoft Word (or other word-processing application) and begin another session of the software at the same point where a user left off. In essence, there has been a trade-off of certain functionality (e.g., the ability to save) for simplicity and deliverability. However, after examination of both the positive and negative feedback of the new software, those that have used the software in the testing phase tend to agree that it has numerous advantages when compared to the original CII software developed in 1996.

CHAPTER 6
RECOMMENDATIONS

Introduction

As mentioned in Chapter 2, there is a "compelling need to better understand how to put the safety-in-design concept into practice" (Weinstein et al. 2005). Since construction is a dangerous industry in which to work and since several million workers are employed in the industry, every step necessary should be taken to ensure that workers on construction projects return home safely at the end of each day. Focusing on safety in the design phase of construction is one such step. After this research was performed and the software was developed, it became clear that recommendations could best be expressed by being broken down into both general recommendations for the industry and software-specific recommendations.

General Recommendations

If the general attitude towards the designer's role in construction worker safety can be changed by tools such as the software application developed in this research or by increasing awareness of designing for construction worker safety in other ways, then the practice could become more widely accepted in the industry. Along with institutions such as the CII, owners, construction managers, general contractors, subcontractors and even vendors can all play a role in expressing to architects and engineers that design elements in projects often make a difference and may ensure a safer working environment for construction workers. Therefore, general recommendations for increasing the practice of designing for construction worker safety are to increase its importance in the minds of everyone involved in the construction industry by placing more emphasis on the practice in universities, making tools such as the one developed for this research easily accessible, and continuing research to solve the problems associated with liability exposure and designers' lack of knowledge of designing for construction worker safety.

Architectural classes and classes for design engineers are encouraged to incorporate the concept of designing for construction worker safety. In fact, the accreditation boards for architecture and engineering are encouraged to stipulate that designing for construction worker safety principles be included in the curriculum of these professionals.

Software-Specific Recommendations

Although the software tool created for this research for the CII is an improvement over the original tool developed in 1996, it is by no means perfect. Certain functionality excluded from the new software such as the ability to save, the ability to search and the ability to edit suggestions in the interface itself could increase the usability and convenience of the software tool. One recommendation is that the software be run from a web server utilizing database technologies such as SQL enabling the creation of accounts which would allow the above mentioned functions to be incorporated. While this would require hosting services, additional action scripting and database coding, it would be helpful if designers concluded that the inability to save a file reduced their willingness to use the software. Such a server could also allow for a suggestion submission form allowing users to enter their own design suggestions for analysis and possible inclusion in the database. Creating this sort of online presence for designing for construction worker safety would initially be costly but the system would be usable for many years or even indefinitely.

Another recommendation specific to the software has to do with distribution. Making this software (and other tools like it) readily available to design schools, construction management schools, and any other schools where graduates plan to enter careers related to the construction industry could help facilitate awareness in future generations of construction professionals and bring about a wider realization of the effectiveness of incorporating worker safety in the design phase. Making this software free and available on the Web to anyone wishing to access it could

also promote the practice of worker safety-in-design. Exposure to designing for construction worker safety is the key element needed to encourage the construction industry to embrace the concept of designing for construction worker safety. Making tools such as this new software easily accessible will increase the exposure to the concept, thus increasing the practice and reducing injuries and fatalities in the construction industry.

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BIOGRAPHICAL SKETCH

James Marini, Jr. was born April 17, 1978 in Miami, Florida. He is the only son of James Marini, Sr. and Dorothy Beaupied. Although born in Miami, he spent most of his life in the small town of Hawthorne, Florida where he earned his high school diploma at Hawthorne Junior / Senior High School in 1997. He earned his Associate of Science in Engineering from Santa Fe Community College in Gainesville, Florida in 2003. He went on to the University of Florida also in Gainesville, Florida where he earned his Bachelor of Arts degree in English in 2005. Upon receiving his Bachelor of Arts degree, he continued his education at the University of Florida in pursuit of his Master of Science in Building Construction.