

# **Design of a Construction Safety Training System Using Contextual Design Methodology**

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## **ABSTRACT**

In the U.S., the majority of construction companies are small companies with 10 or fewer employees (BLS, 2004). The fatality rate in the construction industry is high, indicating a need for implementing safety training to a greater extent. This research addresses two main goals: to make recommendations and design a safety training system for small construction companies, and to use Contextual Design to design the training system. Contextual Design was developed by Holtzblatt (Beyer and Holtzblatt, 1998) in an effort to address the challenge of designing new systems. Ethnographic in nature, the Contextual Design methodology requires field data collection, requirements analysis, model building, visioning and story boarding, and prototyping. A sample of 12 participants consisting of 7 tradespersons, 3 forepersons, and 2 owners/ managers, was selected for data collection. The data was analyzed based on the Contextual Design approach and a training system prototype was designed. The results of this study are recommendations for safety in small construction companies, a low fidelity paper prototype of the training system, and recommendations on future use of Contextual Design for developing training systems.

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## 1. INTRODUCTION

Small construction companies (10 or fewer workers), which comprise the majority of the construction industry in the U.S. (BLS, 2004), can be considered as sociotechnical systems with an internal environment, external environment, and technology<sup>1</sup> (hardware/ software), that affect the flow of its daily activities. This research project is related to the project “*Training needs analysis of informal construction work systems*” that is exploring the training needs of small construction companies. The training needs analysis project is targeted towards developing a safety intervention by conducting an individual and group level needs analysis. It is essential to examine various aspects of technology and its application to ensure that the training programs are effective for the workers in small construction companies. There is a need, not only to explore the use of technology in these small construction companies, but also to understand and evaluate the work system. The Contextual Design (CD) approach helped examine the role of the construction workers specific to the environment of small construction companies, which was crucial for understanding the workplace and designing a safety training system.

According to Macroergonomics’ approach of analyzing a sociotechnical system, it is important to design systems to enable people to interact with technology efficiently (Hendrick and Kleiner, 2001). To examine the various aspects of technology in relation to small construction companies, and to apply that information for the design of a safety training system, the CD approach was suggested. Hence, taking a general approach and using CD will examine:

- 1) The effectiveness of CD in evaluating informal work systems, such as small construction companies, implemented in harsh conditions such as outdoor environments. (Note that exploration of CD in informal work systems is different from the traditional use of CD – in office work environments with formalized work

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<sup>1</sup> Technology means the process, method or knowledge applied to do a task. It also comprises of the tools used to perform a task.

systems.)

2) Insight on how small construction companies function as sociotechnical work systems and how safety interventions such as training systems can be designed to fit into their environment.

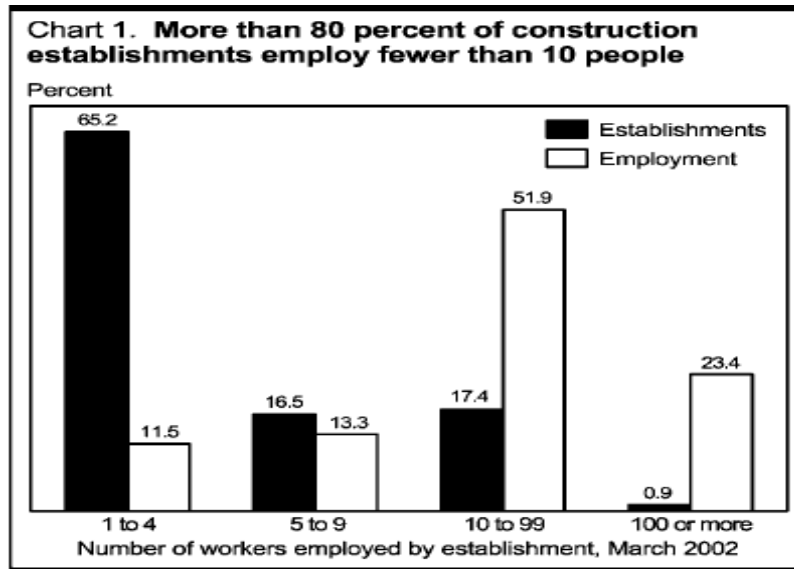
While discussing the above-mentioned issues, different aspects and sub-disciplines related to Human Factors and Ergonomics were explored for this research. Some of the important focus areas of this research are: Macroergonomics (participatory ergonomics, work system design/ redesign), Computer-Supported Cooperative Work (CSCW) (social interaction, culture, application of technology), Human Computer Interaction (design methods such as CD, User-centered design), and Usability Engineering (Evaluation techniques). Combinations of the above-mentioned topics were studied while conducting the research work so that they were applicable to this research project of designing a safety training system for small construction companies.



## 2. PURPOSE OF THE STUDY

### 2.1. Why Small Construction Companies?

According to Hendrick and Kleiner (2001), a *work system* is one that has an internal environment, external environment, hardware and/or software, and an organizational design. These work systems can be categorized as formal or informal work systems. The small construction work systems in the U.S. are typically not formalized through incorporation (BLS, 2001). This means that most of the small construction companies do not have formalized lines of authority. A report published by the Bureau of Labor Statistics (BLS) showed that over 80 percent of construction companies employed 10 or fewer workers, and 1.6 million jobs in the construction industry were in the categories of self-employed and unpaid family nongovernmental jobs (see Figure 1 as adapted from BLS, 2004). The BLS defines self-employed persons as people who work for their own business for profit or fees (BLS, 2005). According to Minchin et al. (2006), the construction job is one of the most dangerous of all occupations. Fatality rates in small construction companies have been increasing in the last few years. Some of the major identified causes of fatalities in the construction industry are falling from heights, lacerations, alcohol and drug abuse, and gas intoxications (Minchin et al., 2006).



**Figure 1:** Construction establishments' graph (adapted from BLS, 2004)

Over the years, the government has made attempts to reduce the number of injuries in the construction industry. Several training programs have been designed and implemented by the Occupational Safety and Health Association (OSHA) and the National Institute of Occupational Safety and Health (NIOSH) to assist small construction companies in preventing fatalities by improving safety standards. Program information is available via the internet and in person in the form of visitations. However, the question is whether these safety programs are being implemented. If they are, then why does the fatality rate remain so high? One claim, which was the basis of this research, was that there is a gap between the available resources for safety practices and the small construction companies. This gap is the inability of the small construction companies to practice safety and to access the safety programs, services, and assistance offered by the government organizations such as OSHA and NIOSH to reduce fatalities in the construction industry.

To bridge the gap, a deeper understanding of the work environment of small construction companies is required. To develop this understanding, the CD approach is proposed to conduct field research and observe workers while they conduct work tasks, analyze their work practices, and identify the issues that prevent them from practicing

safe behaviors. Also, since technology is an important dimension of a sociotechnical system, it is critical to understand how technology as a whole fits into the environment of small construction companies. CD is particularly helpful in such circumstances as it provides a systematic approach for field research and data analysis. The application of CD to construction safety research was new. That supported another purpose to use CD as a tool to evaluate small construction work systems.

## 2.2. Research questions and Hypotheses

1. What would be an effective medium for designing safety interventions, such as training systems, for small construction companies?

**Hypothesis:** It is hypothesized that personal communication mixed with computer technology will be suggested as a medium for safety training. Computer-based and online training has been found to be beneficial in the field of health care and safety training. (Kasten et al., 1998; Liebeskind, 2005). With the significant advances in computer-based technology, it is hypothesized to be an effective medium for safety training in small construction companies.

2. What are some of the problems that currently exist in small construction companies that may contribute to the rising fatality rate? (The problems identified here are in the context of work)

**Hypothesis:** Some of the problems that currently exist in small construction companies that are responsible for high fatality rates are hypothesized as follows: Lack of communication and awareness of safety and health issues, lack of resources due to the small size of the companies, and low prioritization of safety by the management (Champoux and Brun, 2003; Lingard and Holmes, 2001).

3. How feasible is the CD methodology for designing training systems for small construction companies?

**Hypothesis:** It is hypothesized that the CD methodology would be feasible to design a safety training system for small construction companies. Successes in the healthcare industry in understanding design aspects (Blechner, et al., 2003; Revere, et al., 2001) by using CD led to the hypothesis that it would be a successful methodology for designing safety interventions for small construction companies. The healthcare and construction industry share similarities as both domains are viewed as sociotechnical work systems in terms of requirements analysis. The importance of safe working procedures and reducing human error by training are predominant in both domains. The healthcare and construction industry are high-risk work environments where human errors can cause accidents (Leape et al., 1998; Wuebker, 1986). With appropriate training, safety at the workplace can be improved to a great extent (Wolford et al., 1997). The CD methodology is used to design work systems based on the requirements of the users in context of the natural work environment, which is crucial in terms of requirements analysis from a sociotechnical systems perspective (Reddy et al., 2003).

4. How can CD be implemented in the field of construction safety? What alterations would be required so that it can be efficiently used in terms of time, resources, and demands of the construction industry?

**Hypothesis:** The state-of-art approach of understanding how users interact with the environment, while considering the social factors, made CD a powerful research tool to conduct studies that involve field studies. The methodology is flexible and can be implemented according to the requirements and limitations of the research. Therefore, it was hypothesized that the CD methodology, with minor alterations, would be useful for this research project of designing a safety training system for small construction companies.

### 3. LITERATURE REVIEW

#### 3.1. Safety issues in the construction industry

The construction industry in the U. S. employs approximately 6.7 million people, and has one of the highest numbers of fatalities when compared to other industries (Minchin et al., 2006). According to Wright (1986), working under time pressure to meet deadlines causes workers not to follow safety procedures, which results in unsafe work practices, often leading to fatalities and accidents (as cited by Hofmann and Stetzer, 1996). In reviewing some common themes of industrial accidents, Wright (1986) mentioned time pressure and defective communication systems between supervisors and workers. In regard to supervisor-worker communication, Zohar (1980) noted that the attitude of workers towards safety becomes very casual if they see that their supervisors are not serious about safety. While discussing all the above-mentioned issues, Hofmann and Stetzer (1996) have kept their focus on organizational factors that can affect unsafe behavior. Among other findings, they also found that unsafe behavior was significantly affected by inadequate time, training, and resources.

Employee attitude towards safety has been a major field of research as it is a contributing factor to fatal and nonfatal injuries at high-risk workplaces in general (Lingard and Holmes, 2001; Orlandi, 1986; Williamson et al., 1997; Wuebker, 1986). The construction industry is one that is ever-changing in terms of workforce, with a high rate of employee turnover (Hunting et al., 1999). This is another challenge that general contractors and subcontractors must deal with in regard to safety training. However, this does not undermine the fact that safety training is necessary and that more research is required in occupational safety and health in general. Effective safety interventions can help bring a change in the attitudes and perceptions of people towards safety at the workplace (Williamson et al., 1997). In order to design safety interventions effectively, it is important that the context of the work environment and the dynamics of the

workgroup are examined carefully.

One of the goals of this research is to explore small construction companies as sociotechnical work systems and understand the context of work so that an effective training system could be designed. Champoux and Brun (2003) conducted occupational health and safety research in small-size enterprises and reported the lack of resources as a critical reason for the low level of safety practiced in these workplaces. Small-sized construction companies, in contrast to medium or large construction companies, have fewer resources available in terms of finances and technology. Furthermore, non-declaration of accidents is commonplace in these small-scale industries (Champoux and Brun, 2003). With such circumstances in small construction companies, the attitudes of people in general become less concerned with safety. According to Wuebker (1986), most workplace accidents occur because of human error, not unsafe mechanical or other conditions. Ore and Stout (1997) conducted studies that examined laborers in the construction industry. According to them, natural and environmental factors turned out to be one of the 10 leading causes for deaths among laborers in construction. The other main causes were falling from heights and lacerations. Williamson et al. (1997) conducted a study to develop a measure of the safety climate and reported that personal motivation of workers is one of the strongest factors towards practicing safety at workplaces. Hence, it is important that when training systems are designed towards enhancing safety in small construction companies, the workers' attitude in relation to their environment is considered. The sociological factors of the workplace are important and can significantly affect employee attitudes regarding health and safety at workplaces (Holmes et al., 1999).

The sociological factors of the small construction industry are unique in terms of worker demographics and working conditions. According to Spilman (1988), the construction industry is male-dominated, where most of the jobs are blue-collared, and workers are highly resistant to health and safety programs in the workplace (as cited by Lingard and Holmes, 2001). The education level of most of these workers is low and the level of participation is also low in regards to safety and health issues. Orlandi (1986),

and Hollander and Lengermann (1988) have conducted research indicating that small construction companies have fewer economic resources, which may restrict their ability to implement technology to improve safety at the work place compared to the larger construction companies that typically have more accessibility to technology (as cited by Lingard and Holmes, 2001). There are several government websites such as NIOSH (<http://www.niosh.com.my/index.asp>) and OSHA (<http://www.osha.gov/>) that have information on construction safety and health, and occupational safety and health in general. However, as mentioned above, many of the small construction companies lack resources in terms of finance and technology, which makes government efforts to intervene in construction safety and health issues less productive and inefficient.

Another important feature of small construction companies is that a large number are family-owned. Ram (2001) studied the dynamics involved in small family-owned businesses and showed that there is a significant influence of family life on work life when closely related people work together. Eakin (1992) and Gardner et al. (1999) mentioned that there can be adverse effects from close familial relationship ties at work. When supervisors or managers have close social relations with their employees, it can be difficult to exert authority as the effects can go beyond work in personal life (as cited by Champoux and Brun, 2003).

Alcohol and drug abuse have been a major cause of concern at high-risk workplaces, specifically in the construction industry (Minchin et al., 2006; Gleason et al., 1991). According to Gleason et al. (1991), blue-collar job workers exhibited a higher rate of drug abuse compared to white-collar job workers. Gleason et al. (1991) reported data from 1984 National Longitudinal Survey of Youth showing that white men between the ages of 19 to 23 reported the highest use of drugs in the work place. However, Hanse and Jarvis (2000) found that when children work in family-owned businesses, they receive more parental support. Alcohol and drug abuse is reported to be lesser when children work in a family-owned business compared to a private enterprise (Hanse and Jarvis, 2000). Hence, it can be inferred from the above mentioned excerpts that working with family and friends can have a significant effect on work habits, and

health and safety at work place.

### **3.2. User-Centered Design of Interventions**

#### *3.2.1. User-Centered Design*

For a system to be usable and reliable, it is important that it is designed in the context of its use. DeJoy (1996) reviewed past attempts of research in the area of construction safety and found that the context of work was not considered. The construction industry is one that is ever-changing in terms of workforce and in the case of small construction companies, there is a lack of financial and technological resources (Champoux and Brun, 2003; Lingard and Holmes, 2001). Hence, making interventions that are not easy to use in terms of cost or accessibility is unreasonable. Interventions have to be designed by doing research that involves stakeholders such as NIOSH, OSHA, Insurance agencies, Personal Protective Equipment (PPE) manufacturers and dealers, and the end-users (workers of small construction companies). All the aforementioned stakeholders can influence the working conditions acting as external environmental factors for the small construction work system. The sociological factors such as the ones mentioned above, play an important role in the functioning of the workplace (Holmes et al., 1999).

King and Hudson (1985) concluded that investing in safety is always beneficial compared to the amount of work hours lost due to accidents (as cited by Lingard and Holmes, 2001). Designing an effective training program that is usable and accessible can act as an incentive for the supervisors and employees of small construction companies. Employee attitude towards safety has been a major field of research as it has a huge impact on fatalities at high-risk workplaces (Lingard and Holmes, 2001; Orlandi, 1986; Wuebker, 1986). While designing safety interventions, it is important that worker attitudes are understood and incorporated in the design of the training program.



This can be done by understanding the characteristics of construction workers in the context of their work environment. For example, their work practices, the environment that they work in, the social factors affecting the work place, and the organizational structure (DeJoy, 1996). This type of research, where the designers try to understand how the users perform their everyday activities in the actual environment, falls under the domain of ethnographic research.

Ethnography as a term has been subjected to controversy due to its differing definitions (Atkinson and Hammersley, 1994). As defined in the American Psychological Association (APA), Dictionary of Psychology (2007), an ethnographic approach is “A strategy frequently used by anthropologists for studying a community as a way of life. The method requires extensive residence in the community, fluency in local languages, and active participation in community life in order to develop insight into its total culture” (p. 345). According to Blomberg et al. (2003), ethnographic research was introduced around the 1980s as a method of design. It was a time of realization that designers and developers could no longer rely on their own opinions and ideas about design of systems. They had to conduct field research and gain an understanding of the users in the natural work environment. Recently, ethnographic research has been significantly used across educational institutions, research laboratories, private businesses, and corporations (Blomberg, Burrell, and Guest, 2003). One of the advantages of using ethnographic research is its emphasis on gaining an understanding of the people by observing their daily work activities, which is also emphasized in User-Centered Design (UCD). The main focus of UCD is on providing value by analyzing and recognizing the needs and requirements of the users. A system designed by keeping the end-user in consideration throughout the process of design and development provides optimum value, which is the main goal of the User-Centered Design approach (Kramer, Noronha, and Vergo, 2000).

According to Wuebker (1986), workplace safety related research in the past has examined mechanical problems or the environment, while overlooking the human factors involved in the process. To enhance workplace safety, it is important that all

aspects of the workplace are incorporated in designing safety training programs, not just the user or the environment by itself. The interventions can be more effective if the workers believe that its implementation is within their control. Otherwise, interventions go unheeded and the safety behavior remains unchanged (Lingard and Holmes, 2001). By bringing the users of the training system into the design phase, there is a higher probability that it would fit their needs and requirements, and meet their expectations. This way, their attitude towards safety can be elevated to a certain extent

### *3.2.2. CD as it relates to UCD*

As discussed, there is a need for designing safety interventions while understanding the user, the environment, and the interaction of the user in the context of the workplace. In recent years, one method that has received attention in terms of UCD is CD. Mainly used for design and development of software, CD began as a method to perform a Contextual Inquiry (CI). CI is the first step of CD and was developed by Holtzblatt to overcome the challenge of designing new systems (Holtzblatt and Beyer, 1998). The co-founders of the CD methodology, Holtzblatt and Beyer (n.d.), helped Systems, Applications, and Products (SAP), an international leader in software development, to apply CD to design a new travel planning and expense reporting software. The results were positive with users rating highly the usability of the software. CD provides the tools from field data collection to the final design stage. It provides a holistic understanding of the work system and is considered to be a state-of-the-art approach to understanding how users interact with the environment, while considering the social factors (Beyer and Holtzblatt, 1998). The principles of CD are similar to ethnographic research methods. Both methods emphasize understanding the user and conducting research in the natural setting, viewing the activities and understanding them within the larger context of the work system, and innovating design for the future by gaining knowledge and understanding of the current work practices (Blomberg et al., 2003; Holtzblatt and Beyer, 1996).

Gunther, Janis, and Butler (2001) found in their survey of 100 usability practitioners about the User-Centered Design approach, that customer interviews, paper prototyping, and usability tests are the most important and common activities for the development lifecycle. The three above-mentioned phases of the development lifecycle are also a part of the CD methodology. One of the crucial aspects of CD is the fact that the design team has to conduct field studies and acquire data from the end-user and then identify requirements for the system. This helps the design team to understand how the users work in the specific domain. The users' activities should be understood as they exist in the natural environment. Only then would the designers acquire data that is reliable and that encompasses a holistic view of the work system (Blomberg, Burrell, and Guest, 2002).

For this particular research project, the users are small construction company workers. Because of the size of their companies, a majority are financially fragile and incapable of incorporating technology-based interventions. The construction industry is male-dominated and the jobs are blue-collar with a majority of workers having a high school education or less (Lingard and Holmes, 2001). According to Eakin (1992) and Gardner et al. (1999), small-sized enterprises have close friends, acquaintances, and family employed within the company, which affects the work group dynamics and organizational structure to a great extent (as cited by Champoux and Brun, 2003; Ram, 2001). Furthermore, a growing number of workers in the construction industry are Hispanic workers, which poses language and cultural barriers to safety training (Anderson, Hunting, and Welch, 2000). The designers have to make sure that all the above-mentioned characteristics specific to small construction companies are studied and carefully observed at the design phase of safety interventions for training at workplaces. By using a UCD approach, such as CD, interventions can be designed while ensuring that the user and the context of use are both kept under consideration (Kramer, Noronha, and Vergo, 2000).

### 3.2.3. *Application of Contextual Design in other fields*

CD as a methodology for research has recently been applied in the healthcare industry. Blechner et al. (2003) used CD in the field of healthcare to test its feasibility and found that it was beneficial. Some of the benefits reported were that the team conducting research did not need to have much expertise in using CD, which implies ease of use. This is an advantage as training and development of research teams can sometimes be time consuming. Overall, the methodology was found to be applicable for understanding design requirements in the healthcare industry. The healthcare and construction industry share some similarities as both domains are viewed as sociotechnical work systems in terms of requirements analysis. The healthcare and construction industry are high risk-work environments where human errors can cause accidents (Leape et al., 1998; Wuebker, 1986). With appropriate training, safety can be improved significantly leading to safe workplaces (Wolford et al., 1997). Another study involved the review of mobile applications in a museum, where the aim was to examine whether the existing applications supported all the dimensions of context to sustain the interaction between the user and the exhibits (Raptis et al., 2005). The purpose of the museum study was to develop a theoretical framework of context so that it could be extended to other context-aware mobile application design. The application of CD to inform design and its positive results in other fields offered encouragement to implement CD as a new methodology for informing design of a safety training system for small construction companies.

Another important feature of the CD methodology is the observation (shadowing) of the participants during the CI phase. While conducting the CI, the interviewer observes the user performing work tasks in the natural work environment. Observation of the construction workers is a crucial factor in this research as the field of construction is hands-on and involves activities that are labor intensive. If questions regarding their work activities were kept purely to verbal interview, then the data gathered would not be accurate. According to D'Andrade (1995), interview questions cannot make people easily access information that is tacit (as cited by Blomberg, Burrell and Guest, 2002).

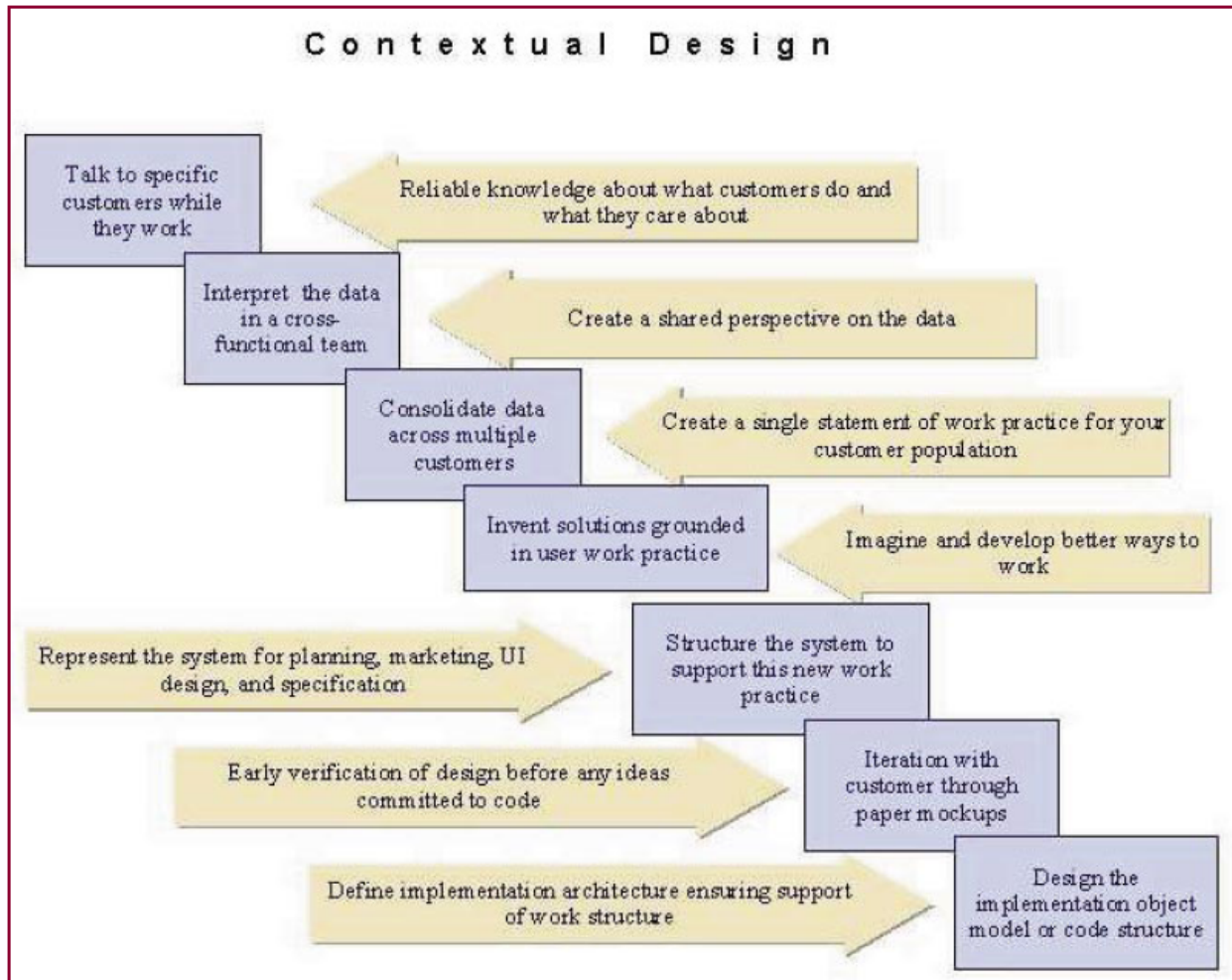
With the emerging paradigms in technology, the significance of context in design has increased tremendously. We are now in the age of ubiquitous computing, where context-aware applications are being developed for interventions. The concept of ubiquitous computing was introduced in the 90's by Mark Weiser, when computing transformed from the desktop to the outside environment, adapting dynamically to the user's activities and the work environment (Dey et al., 2004). Although CD is mainly used for developing software systems, there is no specific methodology to its usage. Based on the requirements of the system, the design methodology can be tailored (Holtzblatt and Beyer, 1996). The methods have to be altered to fit the purpose of the research, as traditional and conventional approaches sometimes do not exactly fit the needs and requirements of the research (Mirel, 2005). Mirel (2005) suggests this in her research with Economic Research Service in the United States Department of Agriculture (USDA), where she conducted CIs with 40 policy analysts from 10 different organizations. While conducting CIs, she also introduced semi-structured interviews to understand the complexity of policy analysis in more detail. Her emphasis in the USDA research was that sometimes, supplemental design strategies have to be used in order to get the design right.

### **3.3. Contextual Design**

As discussed, one of the main purposes of this research was the application of CD methodology for designing a training system. CD is typically used to design or redesign software applications. In this study, CD was used to conduct research for construction safety in the natural environment. Changes were made in the CI stage due to time constraints and other limited resources such as personnel for design team, and budget. Furthermore, the first paper prototype of the training system design was iterated only once. For reference, Contextual Design: Defining Customer-Centered Systems by Beyer and Holtzblatt (1998), and Chapter 49- Contextual Design by Holtzblatt (2003),

from the Human Computer Interaction Handbook edited by Jacko and Sears (2003) were used.

The CD methodology is a step-by-step process. Figure 2 below is a depiction of the process adapted from Beyer and Holtzblatt (1999):



The Contextual Design process, showing the parts and where they fit.

**Figure 2:** Contextual Design steps (adapted from Beyer and Holtzblatt, 1999)

### 3.3.1. Contextual Inquiry (CI) - Interview

The CI is the first and one of the most important stages of CD. Field studies such as CI are rated highly by usability practitioners. In a survey of 100 usability practitioners

conducted by Vredenburg et al. (2002), field studies and requirement analysis were rated as most important practices for UCD. Smith-Jackson et al. (2003) have discussed the importance of requirements analysis in their Needs Analysis and Requirements Acquisition (NARA) framework for designing interfaces and training systems. It is important that the users are identified, and their work practices are understood in as much detail as possible. Sometimes the users may experience difficulty conveying or understanding the requirements in relevance to the research domain (Holtzblatt, 2003). Hence, it is important to observe the user in the natural work environment, ask questions, and make notes. This enables a thorough understanding of the user's activities in the context of their work environment (Holtzblatt, 2003). Typically, a cross-functional interdisciplinary design team conducts these interviews one-on-one with the users at their workplace while they perform their work activities. The following are some of the principles of CI:

1. *Context*: Collect data in the environment in which they work and understand what they are doing and how.
2. *Partnership*: It is very important that the user (interviewee) and the interviewer collaborate so that the work is understood from the user's perspective. According to Holtzblatt (2003), the interviewer should not go with a structured interview. The interview should be led by the customer, not the interviewer.
3. *Interpretation*: Understand what the user is saying by sharing what the interviewer is interpreting. This is a very useful technique as the person being interviewed can correct the interpretation immediately if he or she feels that the interpretation is inaccurate. This leads to more reliable data collection.
4. *Focus*: The interview should be focused on the goals of the research. The interview can lead in different directions based on the person being interviewed. Hence, it is crucial the interview is steered towards the required direction if it loses its path.

As mentioned in the previous section, changes were made to the CI stage to gain information about the participants that was not available through the observation session. These changes were made since construction jobs are some of the most dangerous jobs in the U.S. (Minchin et al. (2006). The observation sessions were limited in providing the required information. In addition to the observation session, two questionnaires (Demographic and Safety) and a semi-structured interview were added to the CI. Details about the information gained from the questionnaires and semi-structured interview are discussed in the Methods and Results section of this research project. In this study, each participant was observed for the duration of one hour. However, information about safety at the workplace, hazard recognition, and background information about the participants was not gained from the observation. To gain this information, the questionnaires were added to the CI stage.

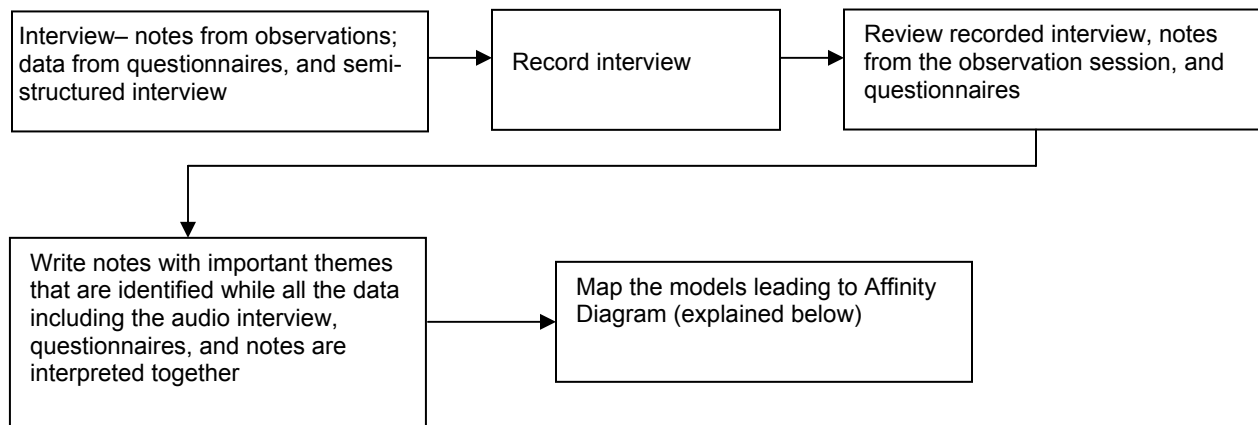
Furthermore, the semi-structured interviews were also added to the CI stage to gain information about existing work practices, design requirements for the training system, and other work related information. Smith-Jackson et al. (2003) created a framework that helps designers gather required information for designing interfaces. The framework is called Needs Analysis and Requirements Acquisition (NARA). The overall framework of NARA is different from CD, but the elicitation method used to gather data was semi-structured interviews and focus groups, which was reported to be highly useful to identify the user requirements. Mirel (2005) also used semi-structured interviews while conducting CI for her study. Interviewing after observation can add depth to the data (Fontana and Frey, 1994). Fontana and Frey (1994) have also suggested that participant observation and interviewing go hand-in-hand, and can provide more insight. In this study, the semi-structured interviews were conducted after the observation session to gain perspective about their work practices and gather requirements for the design of the safety training system prototype.

### *3.3.2. Interpretation and Work Modeling*



After data are collected in the CI stage, the next step is interpreting the data and building models that represent different dimensions about the work system and the customer. Typically, between four and six people are considered optimal in doing the interpretation and building the work models. After one person conducts the interview, he/she conducts a discussion session with the rest of the team, where the interviewer tries to recall and recollect the interview. As the interviewer recollects the information from the interview, the other members of the team ask questions and add their own perspective to the information (Holtzblatt, 2003).

Typically the interviewer, along with the team, takes on different roles: those of recorder, note taker, model builder, or moderator. During this session, the design team tries to conduct a discussion so that the data can be interpreted at a detailed level. For this study, a step-by-step procedure was followed for interpretation and work modeling stage as shown in Figure 3.



**Figure 3:** Interpretation session and work modeling process map

As mentioned above, the data needs to be interpreted and translated into models so that an affinity model can be prepared. The models are prepared from the notes that are derived by compiling all the data together. The following is the description of the five

models as explained by Holtzblatt (2003).

1. *Flow model*: This model shows the responsibilities of the people in the work system, their communication, and coordination on the job.
2. *Cultural model*: This model reflects how the organization's internal environment and the external environment influence the person in the work system. This can include things like company regulations, policies, and laws.
3. *Sequence model*: This model provides the sequence of the steps while each task is performed. For example, for a roofer, the basic steps would involve strapping for fall protection, setting up a ladder with foot rests, and so on.
4. *Physical model*: The physical model is a description of the general physical layout of the work environment. It shows the constraints of the work environment, the way people structure their work in that environment, and how they design the environment to fit their needs.
5. *Artifact model*: This is a diagram of how the artifacts are situated in the work environment. Here, suggestions can be made as to how the structuring of the artifacts can be extended to make the environment safer, specifically for construction sites.

By the end of this stage, the design team members start to immerse themselves in the data. An understanding of the basic work practices, roles, responsibilities, limitations, needs and requirements start emerging at this stage. This is an important stage in terms of gathering user requirements for the training system. A thorough understanding of the user needs and requirements is an essential aspect of designing a training system (Goldstein, 1993).

### 3.3.3. *Affinity and Work Model Consolidation*

The main aim of this stage is, as the name suggests, consolidation of the data. The models created from individual interviews are consolidated so that the design is

representative of the target population. Taking a systems design approach, the whole system is viewed holistically. This stage can be viewed as an extension of the previous stage, where the work models and affinity diagram are mapped based on interviews. The goal is to understand the work structure, similarities, and the variations that exist in the work system.

The information from consolidation models is gained by discussions and walk through of the data, so that rich and complex information is captured about the target population and the work system. Getting the most information out of each model efficiently is important as this data is synthesized in a view that informs the designers what the new product or system design needs to support. As Holtzblatt (2003) states, “*Systematic interaction with consolidated models becomes the basis for design thinking and informal prioritization of customer needs*” (p. 948). The following is a description of the consolidated models:

1. *The Affinity Diagram*: The notes from the interpretation stage are first used to categorize common themes across the population, and posted on the walls. This brings out the common work practices, and variations in that population, while not losing any individual data. While examining affinity diagram, extensions and new ideas that enhance the underlying themes can be added by making notes on paper.
2. *Consolidated Flow Model*: This model reflects the major roles of the people in the work system and the roles that the system design would support. It assists the design team to visualize how responsibilities are shared based on roles, how artifacts are used, and other relevant information that affects the system’s everyday flow of activities.
3. *Consolidated Cultural Model*: This model is a reflection of the influences, policies, laws, and other cultural factors that affect the day-to-day activities of the people in the work system. This is very important, as the design team can suggest new changes that affect the existing culture of the work system in a significant way.

These changes must be consistent with the existing culture. Furthermore, if a new culture is to be introduced, then an understanding of the current culture is also necessary, so that resistance from the employees can be avoided.

4. *Consolidated Physical Model*: This model shows the big picture of the physical layout for the entire population. It shows how people interact with the environment and how they organize work activities that affect their daily actions. The consolidated physical model also gives the designers an opportunity to examine the physical layout and explore how the design of the system can be made compatible to the physical model of the workplace.
5. *Consolidated Sequence Model*: This model is a diagram of the work structure of the system, and provides the designers a chance to understand the work structure in general for the tasks conducted. Generic patterns and variations can be recognized and used for redesign of the work process.
6. *Consolidated Artifact Model*: This model in its consolidated form, like other consolidated models, helps the designers envision the big picture and make recommendation for improvement in the system design. The consolidated model can reflect the artifacts that are more useful, compared to those that are less useful. A consolidated artifact model can depict other information about the basic artifacts used in the work system, which can help the designers provide a system design accordingly.

This phase of interpreting data is an important step in terms of needs assessment. According to Goldstein (1993), needs assessment is like taking a photograph of the job. It should encompass all the dimensions of the organization. In order to design a training system, the needs assessment strategy should provide all the information about the work in context. Only then can the designers provide relevant training system instructions.

### 3.3.4. *Visioning and Storyboarding*

Visioning relates to designing for the future (Beyer and Holtzblatt, 1998). Sometimes, the vision can involve a mere change in the ongoing technology that is being used, and sometimes it can be a complete renovation or innovation depending on the needs identified for the population. At this stage, the designers start thinking about how the new technology or measures can be implemented with the current work practices, roles, responsibilities, and context of the work. According to Holtzblatt (2003), the details should not be the focus of design at this stage. The focus should be on the sociotechnical system as a whole, rather than on low-level details. The primary goal is to enhance the entire work system, not one particular interface.

For any change to be effective in a work system, the system should be viewed as a sociotechnical system, which has two or more employees interacting with the machine (hardware and/ or software), internal environment, external environment, and an organizational design. There is more to a sociotechnical system as the consolidated models demonstrate-- the workflow, the environment, context of work, artifacts, technology, laws, roles, responsibilities, and culture. All these dimensions make a work system a sociotechnical system, where even a small change can affect the overall work system directly or indirectly. Hendrick and Kleiner (2001) have also discussed similar issues in their book *Macroergonomics: An Introduction to Work System Design*.

It is important that before the design team reaches the visioning stage, they are made to walk through the data. The whole process is based on the data gained from the user. People who have not participated in the data interpretation stage cannot be a part of the visioning and storyboarding team (Holtzblatt, 2003). Without the knowledge of the data, one cannot understand the needs and requirements of the user. A design idea from a person who has not participated in the data walk-through stages is meaningless from the CD aspect (Holtzblatt, 2003).

As the designers initiate the visioning stage, a starting point is picked and stories are written with the work practices, roles, responsibilities, artifacts, and physical layout. Visions are transformed into stories and are further discussed by the team while keeping the vision in mind. By doing so, the negative and positive aspects about the vision can be identified. Using positives from the stories and keeping the negatives aside as alternative solutions, a final synthesized vision is created in the form of a story.

According to Holtzblatt (2003), one synthesized vision helps the designers to further envision and design interventions applicable to the current work system. A synthesized vision can help the designers view the big picture, but in a summative vision. Without a synthesized model, the design team can lose focus on the sociotechnical system (Holtzblatt, 2003). Storyboarding of situations reflects details of the vision as a whole, which is helpful as the work practices, roles, and other details of the work system can be seen in the form of a story. It can act as a catalyst agent that allows the designers to move from data interpretation to visioning and storyboarding of the data. Storyboarding is different from scenario building, however (Holtzblatt, 2003). One problem with building scenarios is that they are instance-level descriptions (Uchitel et al., 2004). Story boarding is different from scenario building as it is data-driven and guided by the synthesized vision developed from the preceding steps of CD.

Storyboarding the vision after preparing the consolidated models can be a checking point for the design team, where they can examine specific details about design of the system (Holtzblatt, 2003). In the end, the focus remains on the needs of the user in context, and not on the designers. Visioning and story boarding does that by immersing the designers completely into the data on a higher level. The designers are made to think of situations reflected by the data, making sure that the design is data driven and not based on personal opinions (Holtzblatt, 2003).

### *3.3.5. User Environment Design*

In the CD methodology, the focus is on the sociotechnical system as a whole, rather than on parts of the work system. The User Environment Design is analogous to a floor plan of the work system that maps the structure, function, and flow, and the various parts that relate to each other. According to Holtzblatt (2003), any product has three layers: user interface, implementation, and work layer. The work layer is the core layer of the product.

The User Environment Design helps the designers examine the product and evaluate how it fits in the work system as a whole. For example, in the case of designing a website, the User Environment Design would closely resemble the site map, a structural representation commonly available in a lot of websites. It reflects the different system components and how the work activities are structured between the components of the system. As mentioned before, CD is typically used for designing software systems. In the case of developing a product of that nature, User Environment Design helps the designers understand the structure of user activities in the system and how the interface is linked with other systems that already exist.

In the case of designing a training system, User Environment Design would reflect the structure, the flow of the components of the system and the functions that support the system. Focus Areas are recognized from the User Environment Design for each activity as the structure of the system is designed. Focus Areas are places that define the functions and objects that can be accessed from that particular place. Similar to the consolidated models, the User Environment Design guides the designers to adopt a systems view (Holtzblatt, 2003).

### *3.3.6. User Interface Design and Mock-Up*

Until this stage, the design ideas, structure, and aspects of the system are in models and diagrams prepared from the data collected through the CIs. If the data is interpreted as suggested and the models are prepared appropriately with thorough

consolidation, further reflected into the visioning and story boarding, and finally transitioned into User Environment Design, then the system should better support the user activities. One way to test this is by making a paper prototype of the product that is being designed. Based on the scope of the project, the prototype should be built. However, it is suggested that the first prototype should be a paper prototype (Holtzblatt, 2003).

The paper prototype can be a simple mock-up of the artifact or the product in such a way that it reflects all the design elements. Similar to CI, interviews with users of the system should be conducted in the real work environment to gain feedback on the paper prototype. At this stage, the users can provide suggestions and make notes to recommend changes in the design. The main foundation of the product is the users' data. Hence, if all the steps of CD are followed as suggested, then the product should fit the needs and the requirements of the work system efficiently supporting the user activities.

The process of field testing and evaluating the prototype is iterative in nature. This is similar to usability testing, where usability engineers try to evaluate if the product built fits the user needs and requirements. There are two kinds of testing: Analytical and Empirical. Analytical evaluation is conducted with experts, whereas, empirical with users in lab settings (Rosson and Carroll, 2002). Changes should be made based on the suggestions from the evaluators and then the prototype must be field tested and repeatedly evaluated. A minimum of three times is suggested, but more may be required based on the scope of the project. Similar to other stages of CD, time and budget constraints play an important role here. Hence, it is very important that the scope of the project is kept under consideration from the beginning of the project, so that the process is not rushed and the results are not delayed significantly from what was originally projected. For this construction project, a mix of analytical and empirical evaluation was conducted. The first paper prototype was evaluated only once for this study by two expert evaluators and two users. The feedback from the evaluators was used to complete the first iteration of the paper prototype of the design of the safety



training system.

### 3.4. Rationale for Contextual Design

In this section, other UCD methods for designing systems will be reviewed and justification for using CD for this study will be provided. Cognitive Work Analysis, Work Domain Analysis, and Instructional Systems Development were selected as these methods have been used in the past for designing training systems (Lintern and Naikar, 2000; Vicente, 1999). Scenario-Based Design was selected as it is also used to inform the design of systems (Rosson and Carroll, 2002). Table 1 gives a brief description of the above-mentioned methods used for designing systems. The table is not necessarily a comparison as each methodology has its own advantages over the other. Based on the needs, requirements, and limitations, the most appropriate methodology should be used.

**Table 1: UCD methods**

Description	Limitations	Justification for using CD
<b>Method : Work Domain Analysis (WDA)</b>		
<ul style="list-style-type: none"> <li>- Framework to identify the functional properties of a work system. Main emphasis is on functional structure (Lintern and Naikar, 2000)</li> <li>- Starts with the analysts reviewing documents relevant to the system and verifying with subject matter experts (Lintern and Naikar, 2000)</li> <li>- Abstraction hierarchy (means-ends matrix diagram) model is built to show the relationship between functions at different levels of abstraction. This model helps the designers in understanding the major work domain constraints and allows them to focus on the aspects of the work system that are relevant to the context of work (Vicente, 1999)</li> </ul>	<ul style="list-style-type: none"> <li>- Demanding in terms of effort (Vicente, 1999)</li> <li>- Limited to the information covered in the documents and insight of the subject matter experts (Lintern and Naikar, 2000)</li> <li>- WDA does not provide complete specifications for training systems design. Needs to be combined with CWA or other methods. Does not specify the type or form for implementation of training device. Fidelity of the training device is also not specified in WDA (Lintern and Naikar, 2000)</li> </ul>	<ul style="list-style-type: none"> <li>- CD method acquires data straight from the user in the CI stage. The user is observed as the task is performed in the natural work environment. No reliance on documents or subject matter experts (Holtzblatt, 2003)</li> <li>- CD is a step-by-step approach with specific techniques that helps designers to build a system to the needs and requirements of the user, as it fits in the context of work. The steps of Visioning and Storyboarding, User Environment Design and Prototyping can help designers in specifying and refining design aspects of the</li> </ul>

		system (Holtzblatt, 2003)
<b>Method: Instructional System Development (ISD)</b>		
<ul style="list-style-type: none"> <li>- An analytic procedure towards gathering requirements and specifications for training systems. The data is gathered by interviewing instructors and subject matter experts (Lintern and Naikar, 1998)</li> <li>- Data gathered is used to identify the relationships between the sources of the data so that information can be gained for design, development, and implementation of instructional programs (Lintern and Naikar, 1998)</li> </ul>	<ul style="list-style-type: none"> <li>- Labor intensive method; possibility of gathering huge and unmanageable data (Lintern and Naikar, 1998)</li> <li>- Cognitive tasks not emphasized enough for identifying training needs (Lintern and Naikar, 1998)</li> </ul>	<ul style="list-style-type: none"> <li>- According to Holtzblatt (2003), a team of 3 – 4 cross-functional interdisciplinary people is optimal to implement the CD methodology</li> <li>- The CI is conducted in the natural work environment and then the tasks are analyzed. The work structure is understood in detail during the interpretation session models (Holtzblatt, 2003)</li> </ul>
<b>Method: Cognitive Work Analysis (CWA)</b>		
<ul style="list-style-type: none"> <li>- A framework to inform design of support systems that matches workers' performance criteria (Vicente, 1999)</li> <li>- Geared towards designing computer-based systems in complex sociotechnical systems (Vicente, 1999)</li> <li>- Five Phases: Work Domain Analysis, Control Task Analysis, Strategies Analysis, Social Organization and Cooperation Analysis, and Worker Competencies Analysis (Vicente, 1999)</li> </ul>	<ul style="list-style-type: none"> <li>- The analysis of the work is given emphasis, which informs design. However, the methodology is not comprehensive as it brings in the disadvantages of WDA. Crucial to design life cycle, for evaluation of the system designed, a supplemental evaluation methodology has to be used (Vicente, 1999)</li> <li>- The method is a tool oriented to design computer-supported systems for complex sociotechnical system. It is high on resources and efforts (Vicente, 1999)</li> <li>- Other practical bottlenecks exist like adaptation of this framework in lieu of existing corporation constraints, and recommendations to reduce efforts with the application of CWA to industry-scale problems. According to Vicente (1999), these bottlenecks are not addressed as the CWA method is not well understood by people in general</li> </ul>	<ul style="list-style-type: none"> <li>- One of the strongest points of CD is its step-by-step approach that guides designers with techniques for each step towards designing systems. Its flexibility allows addition or modifications of tools and techniques to the framework. But overall the methodology is comprehensive and can be incorporated as a standard methodology (Holtzblatt, 2003)</li> <li>- As discussed, it is not resource or labor intensive. Blechner et al., (2003) used CD in healthcare industry and reported that the designers were able to implement CD successfully step-by-step with little training and expertise. This saved time in training the team</li> <li>- Most of the bottlenecks such as getting corporate management to adapt to this method, and application based on the scale of problems are addressed by Beyer and Holtzblatt (1998)</li> </ul>
<b>Method: Scenario-Based Design (SBD)</b>		
<ul style="list-style-type: none"> <li>- The framework of SBD starts with analyzing requirements, then designing, where activity scenarios and information scenarios are used to inform design. Followed by designing, usability testing is</li> </ul>	<ul style="list-style-type: none"> <li>- The scenarios are instance-level trace descriptions. The interaction of the components of the system is based on the specific instances. Also, scenarios are often described</li> </ul>	<ul style="list-style-type: none"> <li>- The state-of-the-art approach of CD provides a holistic understanding of the system. The visioning and storyboarding allows the users to understand the entire</li> </ul>

<p>performed to develop the system (Rosson and Carroll, 2002)  - In each stage, problem scenarios are used to illustrate the tasks performed in context and claims analysis are used to make key implications of use and to test hypothesis (Rosson and Carroll, 2002)</p>	<p>in simple and understandable words. They might not convey the complexities of the actual system which needs to be designed (Uchitel et al., 2004)</p>	<p>work system as a sociotechnical system in a synthesized vision, which is data driven. Storyboarding is different from scenario building as it is guided by the synthesized vision developed from the preceding steps of CD. The designers not only get to see the complexities of the work system, but also, they can examine how their new design of the system fits into the work environment and identify its complexities (Holtzblatt, 2003)</p>
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The methods mentioned in the table are not detailed. The purpose of outlining these methods is not to undermine the strengths of other methods. Every method has tradeoffs based on its framework and the requirements of the research that is being conducted. CD as a methodology is well structured and suited for this study of construction research when compared to some of the other methods, especially considering the goal of the research: to design a training system for small construction companies. If the designers were researching the domain of training systems for complex military systems, then CWA as a framework would be advisable. Lintern and Naikar (1998) have used CWA for training at the Australian Defense Force and found it to be useful.

The steps of CD can guide designers to design a training system in the context of construction work. It allows the designers to thoroughly understand users by observing them as they perform work tasks. Without thoroughly understanding the user, training system specifications or the type of training can be difficult to identify. To overcome this issue WDA is combined with CWA, which brings in other issues such as time and resource intensiveness, and training and expertise. As shown in Table 1, SBD is a useful framework for designing software systems. However, the framework is incorporated and guided by building scenarios and claims analysis, which makes it instance-specific in terms of design. Comparatively, CD is driven by the insight gained from the users and does not use scenario building for design specifications. In the stage

of story building in CD, the design ideas are envisioned after envisioning the synthesized vision of the work system, which is different from building scenarios. The visioning and story boarding in CD is data driven and based on the findings from the preceding steps of CD (Holtzblatt, 2003).

According to Holtzblatt (2003), the CD methodology is a systematic approach to inform design. According to Holtzblatt (2003), *“The strength of Contextual Design is that it tells people what to do at each point so that they can move smoothly through the design process from customer data to specific interaction design and code.”* (p. 942)

### **3.5. Relationship between CD and MEAD**

According to Holtzblatt (2003), the CD methodology provides a systematic framework for designing systems. Typically, the CD methodology is used to design software systems. However, if the research goals are larger than informing the design of the systems, then the CD methodology can be used with other larger frameworks such as Macroergonomics Analysis and Design (MEAD), which performs a more detailed analysis of the work system. As mentioned in the Introduction section, this project is related to the research project- Training Needs Analysis of Informal Construction Work Systems (in progress). The latter project involves the application of MEAD framework developed by Hendrick and Kleiner (2001). In case of MEAD, CD can be used as a Macroergonomics method towards understanding the user requirements and informing the design of the system. There are several phases of MEAD that can use the techniques of CD.

The first three steps of CD (Contextual Inquiry, Interpretation and Work Modeling, and Affinity and Work Model Consolidation) can be used to facilitate MEAD Phases 1 (Initial Scanning), 4 (Variance Data), 5 (Construct Variance Matrix), and 6 (Variance Table and Role Network). The last three steps of CD (Visioning and Storyboarding, User Environment Design, and Paper Prototype) can be used to facilitate MEAD

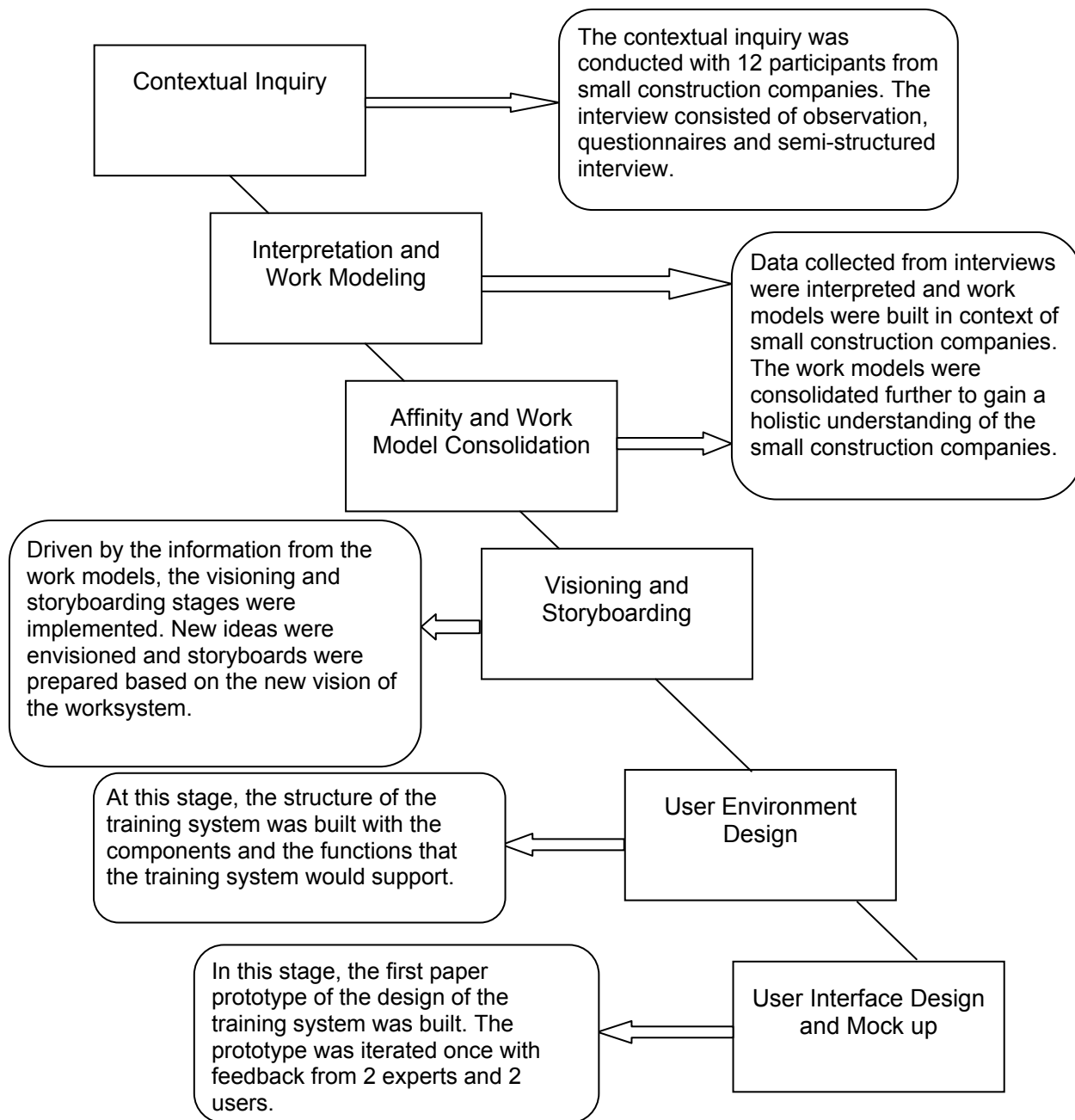
Phases 8 (Roles and Responsibilities), 9 (Design/ Redesign), and 10 (Implement, Iterate, and Improve).

A detailed description of the relationship of CD steps to MEAD phases is provided in the results section.

## **4. METHODS**

### **4.1. Research Methodology**

The research methodology used for this study was the Contextual Design (CD) methodology. Figure 4 illustrates step-by-step how CD was used for this research project. Since the implementation of CD was new for designing a safety training system, necessary changes were made to some of the phases.



**Figure 4:** Contextual Design methodology as applied in this study

The first step of CD is CI, in which 12 construction workers were interviewed on the construction site. The CI provided information about their work practices, the artifacts used to conduct work activities, the workflow, existing training methods, and all the other important aspects necessary for designing the training system. As mentioned earlier, two questionnaires and a semi-structured interview were added to the

observation session to gain the above-mentioned information.

The second and third steps involved interpreting data and building individual work models from each interview, followed by consolidated work models. The different work models helped the designers understand the similarities, variations, roles, responsibilities, restrictions, workflows, and structures of small construction companies. The first three steps of the CD methodology addressed needs assessment. The needs and requirements for designing a training system were identified during these stages. The first two research questions were answered based on the information gained from analysis of the data (explained in the data analysis section). The first two research questions are restated below in Table 2.

**Table 2:** Research questions 1 and 2

Num.	Questions
1.	What would be an effective medium for designing safety interventions, such as training systems, for small construction companies?
2.	What are some of the problems that currently exist in small construction companies that may contribute to the rising fatality rate?

A design room (Figure 5) was dedicated for this research project to perform the CD steps, as the data interpretation and the other steps required diagrammatic models of the data (Figure 6). The next step was visioning and storyboarding. During this step, the designers envisioned how the new system would look and storyboarded the vision in frames of work sequence. At this phase of the CD process, the design room contained work models, consolidated work models, a vision diagram, story boards, short notes of emerging themes of work practices, and other design-relevant issues of the training system.





**Figure 5:** Design room



**Figure 6:** Design room with models

Following the method of CD, the next step was User Environment Design, which helped the designers structure the design of the training system. Based on all the findings from each of the steps of CD, the first paper prototype was built. The prototype was evaluated by experts from the field of construction and training systems, and by small construction company workers. The evaluation of the prototype helped to determine the effectiveness of the entire design process in terms of findings and design of the training system prototype. At this point, the following two research questions would be answered (explained in the discussion section).

**Table 3:** Research questions 3 and 4

Num.	Questions
3.	How feasible is CD methodology for designing training systems for small construction companies?
4.	How can CD be used in general in the field of construction safety? What alterations would be required so that it can be efficiently used in terms of time, resources, and demands of the construction safety research?

The paper prototype was demonstrated to four evaluators—one expert from the domain of construction, one expert from training systems, and two workers from small construction companies—to receive feedback about the design aspects. The prototype of the design of the training system was redesigned based on the feedback from the evaluators. The evaluation and redesign process was done only once for this study due to time restrictions.

#### *4.1.1. Alterations to the methodology*

As mentioned earlier, the CD methodology was altered to fit the needs of this study. Figure 4 illustrates the CD process as it was applied in this study. Changes were made to two stages: the CI stage and the User Interface Design and Mockup stage.

In the CI stage, in addition to the observation session, two questionnaires and a semi-structured interview were added. One reason for adding the questionnaires and semi-structured interview was the nature of the job, and the other reason was time. Due to the nature of the job, the observation session was limited in terms of providing the required information. For example, when a roofer worked on heights, it was difficult for the interviewer to go onto the roof to observe the activities. Alterations were made to the CI to gain a deeper perspective about their work practices. Furthermore, the participants were observed for one hour each. During this one hour, all the required information

regarding the participants was not available. The questionnaires and semi-structured interviews were helpful in gaining information such as work experience, demographic information, motivation for the job, safety at the work place, and suggestions about the design of the training system.

The other stage altered for this study was the User Interface Design and Mockup. In this stage, the first paper prototype was designed in order to receive feedback on the design aspects. According to Beyer and Holtzblatt (1998), the prototype should be iterated at least three times before the design is finalized. In this study, the first paper prototype was iterated only once. This was done mainly due to time and budget constraints. Multiple iterations would have required more time and budget. In order to get feedback and to finish the first iteration of the design of the training system, the first paper prototype was evaluated by two experts and two users.

Besides the above-mentioned changes, the CD methodology was applied as suggested by Beyer and Holtzblatt (2003). Detailed information about the analysis conducted during the CD process is provided in the following sections.

## **4.2. Participants**

Twelve participants were recruited for this research project from the states of Virginia and North Carolina. To conduct the study, contacts were established with general contractors and owners of small construction companies. As the research project's focus was on small construction companies, the participants were recruited from construction companies with sizes ranging between 3 and 20 employees. According to the BLS, over 80 percent of construction companies employ less than 10 workers (BLS, 2004). The mean size of the construction companies recruited for this study was 12 people ( $SD = 5.13$ ). The participants for this study were required to be at least 18 years of age. The mean age of the participants was 34 years old ( $SD = 12.41$ ). The participants were selected across six different construction companies since

cultural factors, work habits, and other environmental factors vary among organizations. Participants recruited from all six companies reported that there were at least two accidents in the past year in their respective companies.

The sample in this study included two African American participants, nine Caucasian American participants, and one participant of Hispanic ethnicity. The participants included three forepersons, one owner/ supervisor, one project manager/ supervisor, and seven tradespersons. The seven tradespersons included three framers (carpenters), two vehicle (backhoe, excavator) operators, one plumber, and one drywall laborer. It was important to recruit a minimum of three participants who had supervisory responsibilities as the literature suggested that owners and supervisors have a significant effect on their employees (Zohar, 1980). All of the participants had attended some high school, including four participants who had attended college. Two participants were college graduates. Overall, the owners, supervisors, and forepersons reported being at least high school graduates. The level of education as a factor has to be considered when the training system is being designed.

Eleven of the twelve participants recognized their jobs to be hazardous. The mean number of accidents in the past for the participants was 1.66 ( $SD = 1.30$ ) with a range from zero to as many as five accidents. Eleven of the twelve participants reported having incurred at least one accident in the past while performing construction jobs. In terms of digital devices, eleven out of the twelve participants reported using cell phones, three reported using computers, and one participant reported using a PDA.

### **4.3. Equipment and Apparatus**

#### *4.3.1. Observation set-up and Equipment*

The study was conducted at the construction sites in Virginia and North Carolina. Contacts were established in advance with general contractors and owners of small

construction companies. The participants were observed as they performed work activities at their construction sites. The researcher was assisted by an undergraduate student with an adequate background in construction work to conduct the observation sessions.

During observation, notes were handwritten on regular paper using pens and pencils. Digital voice recorders were used to record the semi-structured interviews that followed after the observation session with each participant. The participants were interrupted only when actions were not completely comprehensible by the researcher.

#### *4.3.2. Questionnaires*

The participants were required to complete a demographic questionnaire (Appendix A) with information such as name, age, gender, profession, ethnicity, and work-related information. Following the demographic questionnaire, a safety questionnaire (Appendix B) was also administered with questions about worksite safety, workers' attitudes towards safety, supervisor attitudes, risk perception, hazard recognition and prevention, and work practices. The questionnaires were administered on site after the observation session. The participants were instructed to report to the interviewer, after their task under observation was complete, for the administration of questionnaires and the semi-structured interview (Appendix C). The semi-structured interview questions consisted of questions about their major influences at the job, knowledge about safety, current methods of training, and their needs for training programs to enhance safety at workplaces.

Additionally, the demographic questionnaire consisted of two questions about the participant's likelihood of injury and satisfaction with the job. The two questions were Likert-type with scales ranging from 1 – 10. The safety questionnaire consisted of three multiple-choice questions; five questions with a Likert-type scale ranging from 1 – 5 (Strongly disagree – Strongly agree); five risk-perception questions (Leonard et al.,

1989) with a scale ranging from 1 – 8 (Not at all risky – Extremely risky); and two questions where they ranked the options from 1 – 4 (lowest – highest).

#### **4.4. Procedure**

In this section, the procedure used for conducting the CI is described. Since the interview included an observation session, it was important that the CI was conducted on the construction site as the participants conducted their daily work activities in the natural work environment. After the observation session, the participants were requested to complete two questionnaires followed by a semi-structured interview script (Appendix C). The CIs were conducted at the construction site with the permission of the construction company owner.

The interview began when the participants received a short briefing about the research and the interview procedure. After the introduction, the participants were requested to sign the informed consent (Appendix D), which was an agreement to participate in the study. After the informed consent was signed, the participants were observed for a time period of 60 minutes as they performed their daily work activities. To avoid any bias towards safety, the questionnaires were administered only after the observation session was completed. Following the observation session, the participants were asked to complete a demographic questionnaire (Appendix A) and a safety questionnaire (Appendix B). During this observation session, the interviewer noted information that was required for the research project, and interrupted the worker if anything crucial from the research aspect occurred. Interrupting the participants during work was kept to a minimum as construction work is considered to be a high-risk occupation in general. The estimated time of the entire interview including the observation session, two questionnaires, and the semi-structured interview was 120 minutes. At the end of the CI, the participants were compensated at the rate of \$10.00 an hour. Table 4 shows the procedure sequentially as it was implemented for each CI.

**Table 4:** Interview Procedure

	<b><i>Event</i></b>	<b><i>Time</i></b>
1.	Basic introduction of participant and interviewer	10 minutes
2.	Informed consent	
3.	Observation of the participant during work	1 hour (60 minutes)
4.	Buffer time ( <i>Miscellaneous</i> )	5 minutes
5.	Demographic questionnaire	20 minutes
6.	Safety questionnaire	
7.	Post-observation semi-structured interview	20 minutes
8.	Miscellaneous comments/ notes by interviewer or interviewee	5 minutes
	<b><i>Total time</i></b>	<b><i>2 hours or 120 mins.</i></b>

#### 4.5. Data Analysis

The following section explains in detail the entire CD analysis process from data collection to the first training system prototype.

##### 4.5.1. Contextual Inquiry (CI)

The CI is the first and one of the most important steps of the CD methodology. The CIs were conducted on the construction sites as the participants performed their daily work activities. The data was collected in the form of notes from the observation session, two questionnaires, and a semi-structured interview that was recorded on a digital voice recorder.

The notes taken during the observation session were about the work activities

that the participants conducted at their workplace. The number of people working with each participant, partnerships, artifacts, workflow, and sequence of work were noted during the observation session.

Furthermore, two questionnaires were used to gain additional information about the construction company for which the participants worked and the participants' basic background information. The demographic questionnaire provided information such as age, gender, job type, number of accidents in the past, and other basic information. The safety questionnaire provided information about their work practices such as factors associated with injuries at their workplace, enforcement of safety at workplace, hazard recognition and prevention, and risk perception. After administering the questionnaires, a semi-structured interview was conducted with open-ended questions about work habits, safety at the workplace, safety training, relationship influences, and recommendations for design of the training system.

The remaining steps of CD describe how the data collected in CI was used towards the final prototype.

#### *4.5.2. Interpretation and Work Modeling*

As discussed in the literature review section, data are interpreted into five work models for each participant. Below is a description of the process involved in building each one of the models for the data collected during the CIs conducted with twelve participants.

##### *Flow Model*

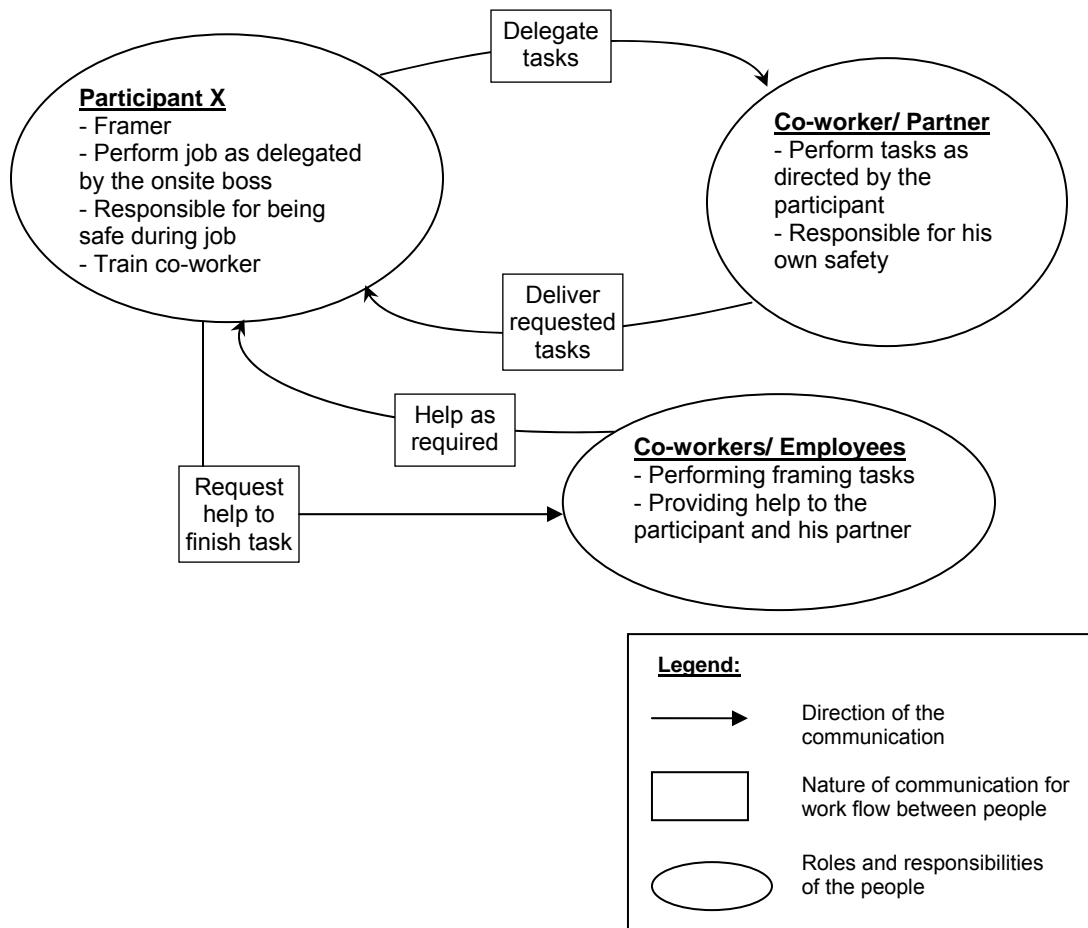
The flow model is a depiction of the roles, responsibilities, and communication strategies that the people of the work system engage in to perform work activities. The information for this model was collected mainly through the observation session and the semi-structured interview. To step through the process of preparing the individual flow



models for the 12 participants, one example is described below.

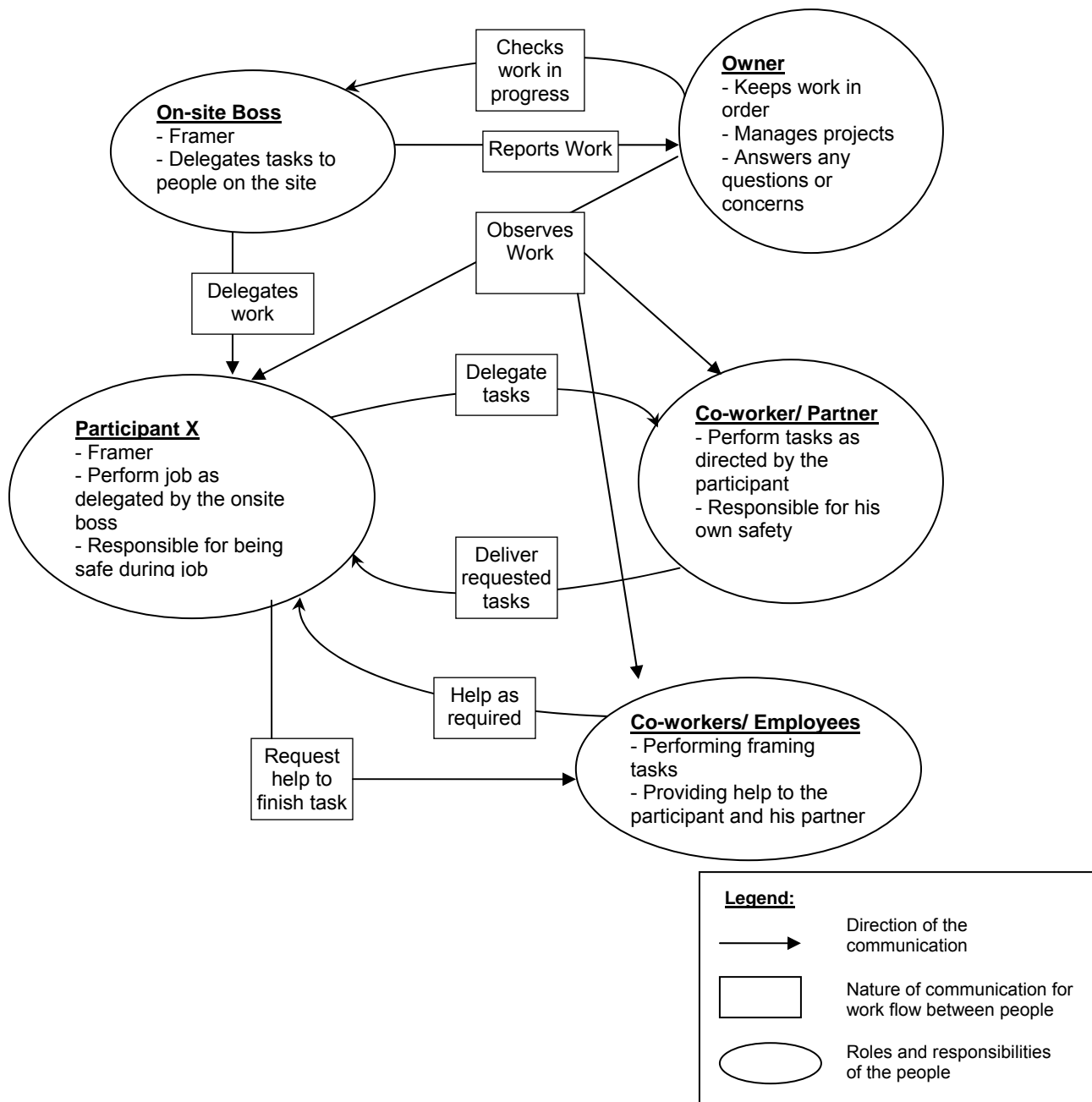
In this example, the participant was a framer in a small construction company and worked with a co-worker to perform the task. During the observation session, it was noticed that the participant was working with his co-worker in partnership. Later, during the interview, the participant mentioned that he was directing and training his co-worker to perform the job. Furthermore, it was observed that the participant sought help from other co-workers also when help was needed in order to finish the framing job.

Based on this information the following workflow (Figure 5) was drawn for the participant and the co-workers



**Figure 7:** Flow model of a participant from a small construction company

It was also noted that the participant had an on-site boss to whom he reported. During the observation session, the owner of the company also visited the site to observe the work and receive an update from the onsite boss. As the focus was on the participant, the information received about the on-site boss and owner of the company was partly based on the observation and from the interview with the participant. Figure 8 is an illustration of the workflow model after the owner and onsite boss are added.

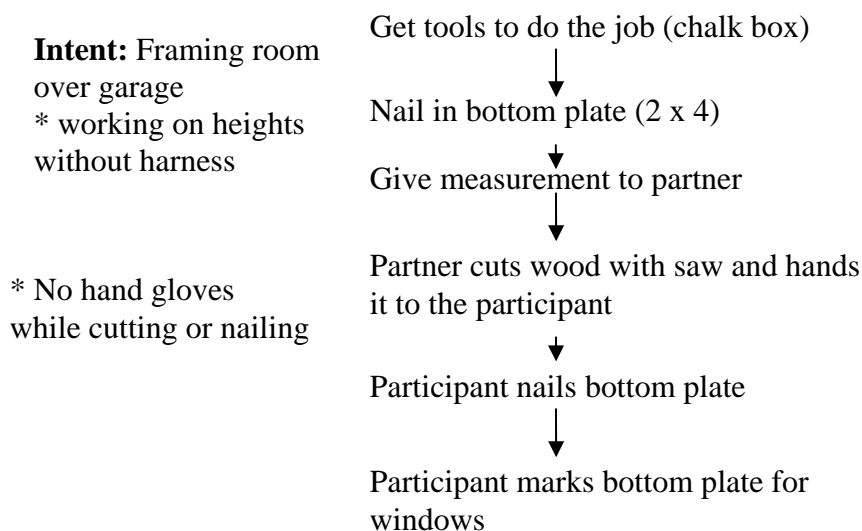


**Figure 8:** Flow model of a participant from a small construction company

The boxes in the diagram represent the communication that takes place and the arrows represent the flow and direction of the communication between different people in the work system. The various people's roles and responsibilities, and how they contribute to the flow of work, are described in the ovals representing their job duties. The flow models were prepared in the above-mentioned manner for all the 12 participants.

### Sequence Model

The sequence model is a depiction of the steps involved in performing the work. Each task is done in a certain order to continue the flow of the work. The sequence model emphasizes the sequence of actions that are taken to perform the work activity. For this study the sequence model was written step-by-step as observed during the observation session. In this model, safety implications were also noted as and when the participants performed a task in an unsafe manner. The following is an example of the framer as he was framing the house in coordination with his co-workers.



**Figure 9:** Sequence model of a participant from a small construction company

The example above shows the sequence for framing a room above a garage as observed by the interviewer. As seen above, it is a simple step-by-step depiction of the flow of the work, the artifacts used to do the work, and the safety implications involved in the work. The Sequence models were prepared in the above-mentioned manner for all the 12 participants. In most of the cases of the construction job for this study, the sequence showed that certain tasks are done repetitively to finish a job.

### Artifact Model

The artifact model shows the different artifacts that are used for the work activities. Depending on the intent of the study, the structure, the intent of use, and the information it provides can be understood. For this study, the artifact model represented all the artifacts that were used to perform a job by the participant. During the observation sessions, notes were made regarding the tools and equipment used to perform the job. The personal protective equipment (PPE) used to conduct the job safely was specifically emphasized during the observation session. The artifact model was categorized as illustrated below in Figure 10.

Work Tools:		PPE:
- Tool Bag	- Power Saw	- Eye Protection (glasses)
- Hammer	- Nail Gun	- Nail Gun
- Tape Measure	- Ladders (step and extension)	- *No Harness (Lack of fall protection)
- Speed Square	- Broom	- *No Hard Hat
- Box cutter	- Chalk box	- *No shirt
- Framing Pencil		- *No steel toe boots

**Figure 10:** Artifact model of a participant from a small construction company

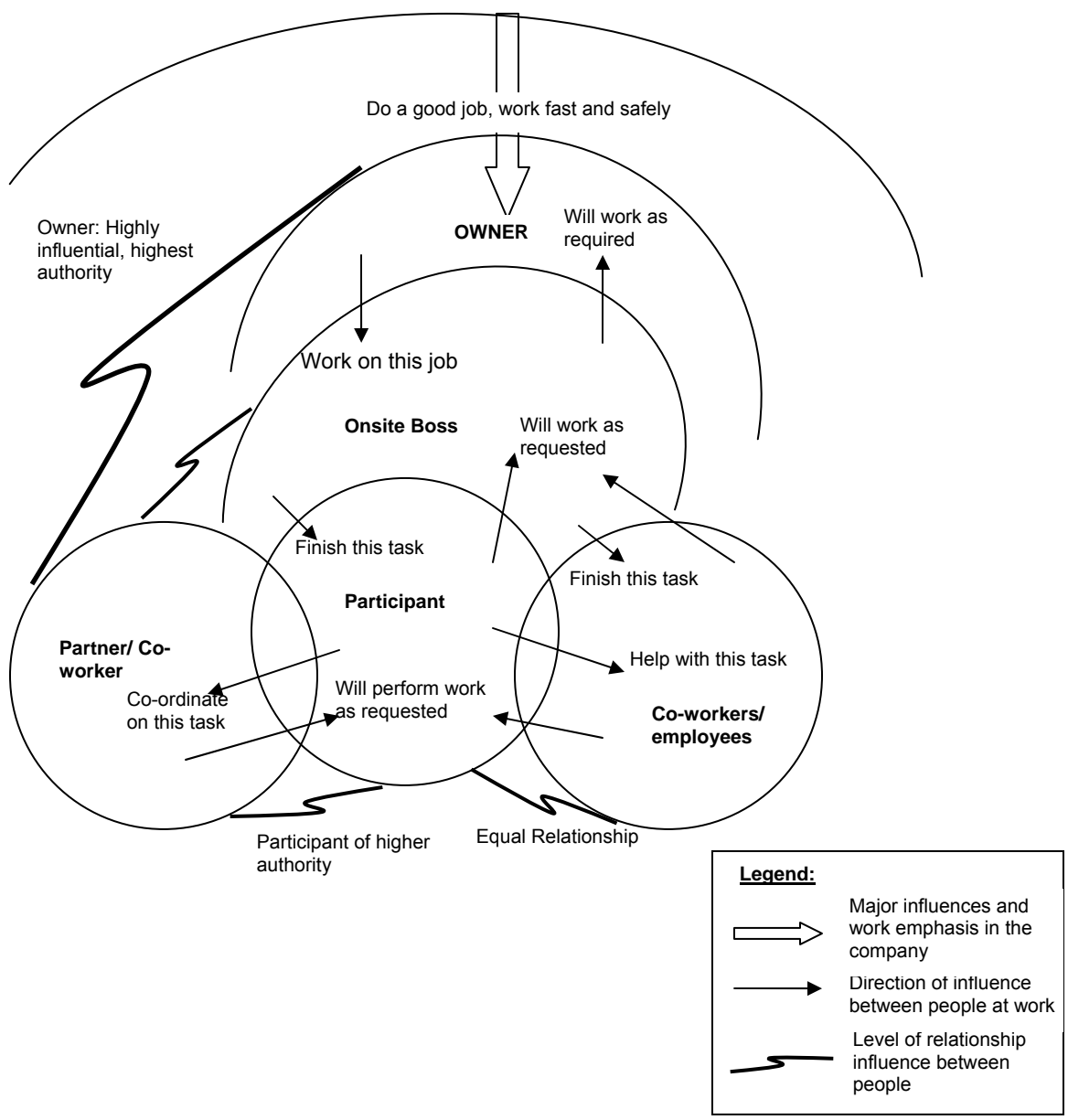
In the above artifact model, the list was prepared based on the tools, equipment, and PPE that was observed during the observation session. During the interview following the observation session, the participants were further asked if they particularly felt that the design of any tools or equipment needed any improvements. Also, training-

related questions about using tools and equipment were asked during the interviews. The artifacts models were also prepared for all the 12 participants.

### Culture Model

The cultural model as explained by Beyer and Holtzblatt (1998) is a depiction of the various influences that affect the workflow of the users, the constraints, and the policies of the work system. Even though Holtzblatt does recognize the fact that the information gathered during this observation, and post-observation (questionnaires and interview), is based on the perspective of one person, it does not truly represent the culture. The safety culture of an organization is concerned with the shared values of the members of that organization (Zhang et al., 2002). In this study, one hour of observation does not provide that information. The information gained during the CI is the '*climate*' rather than '*culture*'. The safety climate is the state of safety observed for that particular time period and is subject to change (Zhang et al., 2002).

For this study, information for the cultural model was gained from observation, questionnaires, and the interview. During the observation session, the emphasis was on communication styles, which was also used for the flow model. In the questionnaires, particular questions were asked about participants' priorities in terms of safety, job satisfaction, and the hazards of the job. The interview further inquired about their major influencers in the job, motivation, and their attitude towards safety. The following is an example of the cultural model based on the information received from a participant who was a framer in a small construction company.



**Figure 11:** Cultural model of a participant from a small construction company

In the example above, the participant had indicated during the interview that speed of work, money, and safety were highly emphasized in their company. Furthermore, this was also indicated in the questionnaire. The participant also mentioned that their on-site boss and the owner were the main people who influenced them in the company, thus showing the influences of those people. The influences on their work are shown in the circles and the direction of the work influence is shown by the arrow. For example, the participant and other workers were in a relationship of

equals. But co-workers influenced the participant's work in terms of helping with work and coordinating. In this particular case, there was no mention of any government organizations by the participant. Hence, there are no government organizations shown in the cultural model above (Figure 11).

The cultural models were built for the 12 participants using the same methodology described above.

### *Physical Model*

The physical model describes the physical environment in which the work takes place. For this study, a rough sketch of the physical environment was drawn in which the participant was working. The emphasis, as usual, was on safety aspects so that they could be addressed during the design of the training system. In general, the construction work environment is dynamic. The jobs keep changing on a regular basis, and so does the physical environment. For this research, this model was helpful in generating a generic view of the physical environment, people involved, and the hazards of the job. The framer from the example above was working in an environment with wires coming from generators; nail guns lying around; wooden logs placed to be framed; and with co-workers around him. A diagram was drawn to show all these aspects of the physical work environment.

#### *4.5.3. Affinity Model and Work Model Consolidation*

The affinity and work model consolidation stage is the summation of the first two stages. At the end of the work models stage the 12 participants each had 1 flow model, 1 sequence model, 1 artifact model, 1 cultural model, and 1 physical model. The sixty models combined reflected different dimensions of the work system. The models were lined up against a wall so that they could be seen together.

The process of creating the affinity model and work model consolidation is inductive. All the information from the CIs is examined together in this stage to create one generalized view that captures all the instances of the data. Following is the process used to build the affinity model.

The affinity model building is a bottom-up process. Individual affinity notes were prepared during the interpretation session that preceded this stage. Affinity notes are individual notes that relate to the research issue being investigated. The notes are grouped together and then labeled based on the themes that emerge from them, rather than creating categories and putting the notes into those categories. The emphasis is on letting the data define categories rather than predefining categories of interest upfront. The following is a step-by-step approach used to build the affinity model.

- i. First, individual affinity notes that emerged during the interpretation session were placed on a table, creating different columns (groups). Design ideas and questions were not used to create the columns at this point.
- ii. The next step was to go through all the individual notes and place them with affinity notes that belonged to the same theme. Each column with the affinity notes was considered as a group that represented an aspect of the data (Figure 12). For example, notes about lack of training as a factor for injury at workplace were placed together. The following are examples of notes about the lack of safety training.

Int. 9: We have no safety training due to the size of the company.

Int. 8: No safety training – because our company is new and small.

- iii. If a particular note in any instance did not fit into any of the categories, then it was placed in a new column. All the notes that were not relevant to any of the categories were placed together in a miscellaneous column.



- iv. After all the notes were placed in columns, design ideas were discussed. The goal was to identify the distinctions as much as possible so that the design ideas could address the emerging issues from the data.
- v. The next step was to add blue labels to the existing columns of notes. The blue labels on the top of each column described what theme that column represented. The following is an example of a group with a blue label:

**Blue label:** I do not require safety training because I am experienced.

*Int. 5:* I am fully experienced and safe while working. I do not need any training.

*Int. 5:* I do not feel the need for safety and health information.

*Int. 3:* I know it all. There is no need for training.

- vi. Similar to the process of building the columns with affinity notes, the next step was to move the blue labels, which represented a common theme of the work system, and place them into columns. At this point certain blue labels might require re-writing, but that is done only to organize the columns. The idea that the label represents is still the same.
- vii. After the blue labels were placed different columns, pink labels were used to describe the columns of blue labels. The following is an example of a column of blue labels with the pink label on top.

**Pink label:** I am not concerned about safety.

*Blue label:* I am very experienced, hence safe.

*Blue label:* I do not need safety training.

*Blue label:* My job is not risky at all.

- viii. It was made sure that each pink label did not have more than three or four blue labels in the column. This was done to ensure that all the variations in the data were captured under different columns.
- ix. The next step to finish the process of building the affinity model was to add green labels to columns of pink labels that represented themes about the work system.

The following is an example of a column of pink labels with a green label on the top.

**Green label:** There is a high level of safety practiced at the workplace

*Pink label:* Safety is emphasized at the workplace.

*Pink label:* There exists a good safety climate at the workplace.

The hierarchical structure of the affinity model helped in identifying all the key elements of the workplace that were relevant to the research being conducted. The problems, issues, training suggestions, and design elements were identified in an organized manner during the preparation of the affinity model. The following are some pictures of the affinity model built for this research project. The discussion of the model and the information it revealed are discussed in the results section.



**Figure 12:** Affinity notes



**Figure 13:** Affinity diagram

After the affinity model was prepared, the consolidated models were designed. As the name suggests, this stage is a consolidation of the work models built during the second stage of the CD process. The five consolidated models built for this project were flow, sequence, artifact, culture, and physical. The following steps were used to consolidate the models:

- i. First, all the work models were organized together on a wall so that common themes could be recognized. Common themes refer to similar aspects of the models recognized between the individual work models. For example, all the flow models suggested that there was an owner that delegated duties to the foreperson and the employees, and the foreperson further managed work and delegated work to the employees. This pattern was seen in ten out of twelve flow models.
- ii. After recognizing the common themes, the consolidated models were prepared by placing information such as roles, responsibilities, artifacts, work structure, influencers, and other aspects of the work system in their respective models. The emphasis of this process is on recognizing similarities in the population and building on them, rather than looking for variations. After the similarities are incorporated the individual variations can be added so that the system is customizable based on the individual needs and requirements.
- iii. Following the last step of placing recognized similarities of work practices in their respective models, the consolidated models were compared against the individual models and any missing information from the individual models to the consolidated models was added, making the consolidated models completely representative of the data collected from the particular population.

Specific information about each consolidated model is discussed in the results section. Also, the purpose and the contribution of each consolidated model in the CD process were explained in the literature review section. It is evident that the consolidated models serve as the basis for designers to develop a design overview that

serves the whole population, rather than a particular user. Holtzblatt (2003) does consider the fact that the number of participants can be questioned here when compared to studies that have hundreds of participants or 10 or more focus groups. To address this issue, an example by Holtzblatt (2003) is provided where data on system management is collected for a period of 13 years across various companies. It was found that most of the work practices were similar and the basic flow of activities was the same. If the research focus is on variations, then a different system has to be designed for each individual, as on some level every individual is unique. However, if the similarities are studied, then a product can be built with options and preferences that can be set to fit individual needs.

The aim of CD is to understand the work practice of the people in the work system, and at the same time keep under consideration that variations do exist at some level. As Holtzblatt (2003) said, "*Contextual design gets its power from designing from an understanding of work practice structure without losing variation.*"(p. 950)

#### *4.5.4. Visioning and Storyboarding*

The first three stages of the CD process provided a deep understanding of the various dimensions of the small construction work system. The affinity model and the consolidated models revealed important information about roles, responsibilities, influences, constraints, similarities, variations, and key design elements of the training system for the small construction companies. Using all the information, design ideas were brainstormed for the safety training system for small construction companies. This process is called visioning. The following are the steps for the visioning process:

- i. Several visions were created initially as broadly as possible, but within the project focus. The ideas were driven by the data interpreted during the first three stages of CD.

- ii. The positives and negatives of each individual idea for the vision were compared based on the information from the preceding stages of CD. The main aim was to envision how the new workplace would function with the training system, not the details about the interface or the implementation of the training system.
- iii. Finally after brainstorming several visions, one final vision was created that incorporated all the design ideas of the training system. For example, the consolidated culture model revealed that owners and supervisors have a significant influence on their employees. This was considered in the design aspect of the training system in the visioning process. The affinity model revealed that the participants preferred safety meetings and demonstration of safe work practices. Hence one idea that was provided in the visioning process was to use videotapes for demonstration of safe work practices as a form of safety training.

Following the visioning process was storyboarding. To be able to design efficiently it was important to storyboard the vision in the context of the work system. Storyboarding was the means for examining the system design in the context of the work activities. In this stage, the ideas generated in the synthesized vision of the new work system were sketched in relation to the sequence of the work activities. This was done in the storyboards with pictures and words that described in detail the new work practices envisioned during the visioning session. For example, in this study, a new work practice was envisioned where the training system would encourage toolbox talks (short hazard analysis and precautionary measures discussions) before starting a new job. The following figure is an example of how the idea mentioned in the vision is storyboarded.



**Figure 14:** Toolbox talks on the site

Figure 14 shown above is a frame from a storyboard that was drawn for this study. The storyboards helped examine whether the design ideas of the training system would work in the sequence of daily work activities for the small construction company environment. Detailed discussion and depiction of the entire storyboard is provided in the results section.

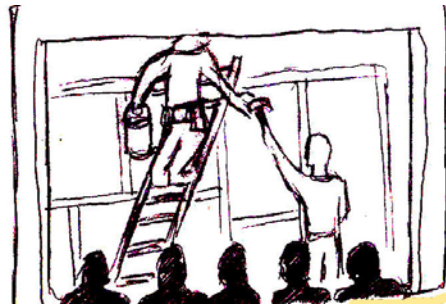
#### 4.5.5. *User Environment Design*

The next step after visioning and storyboarding is the user environment design (UED). This stage of the CD process is similar to drawing a floor plan for a house. It is a depiction of the entire system structurally, the functions and flow, and the various parts of the system that relate to each other. The UED for a website would be the site map of the website that shows the various components of the website and the functions and flow of the components so that a user can step through them as required. For this study the following steps were used for the process of building the UED.

- i. The first step of the UED is to step through the storyboard frame by frame. The following are examples of some frames that were utilized to step through the process of building the UED for this project.



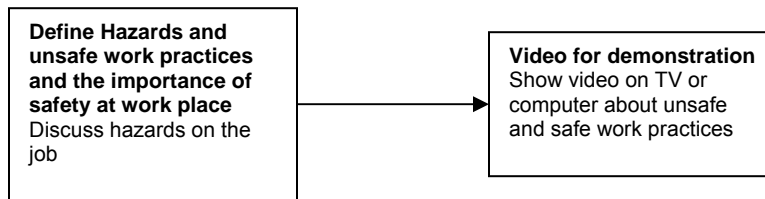
**Figure 15:** Safety training meeting



**Figure 16:** Safety training video

- ii. From each storyboard frame, structural implications related to design were obtained. The designers recognized focus areas for the system by stepping through the storyboard frames. According to Beyer Holtzblatt (1998), “*Focus Areas* show the coherent places in the system that support doing an activity in the work”. To explain further, *focus areas* are places in the system where an activity takes place from a systems design aspect. They support a work activity in terms of structure. Each *focus area* has a purpose statement that defines the work it supports. The following examples show how the structural implications were drawn out of the frames shown above. Remember that each cell or frame of the storyboard is traced step-by-step to design the UED and extract structural

implications for the system.



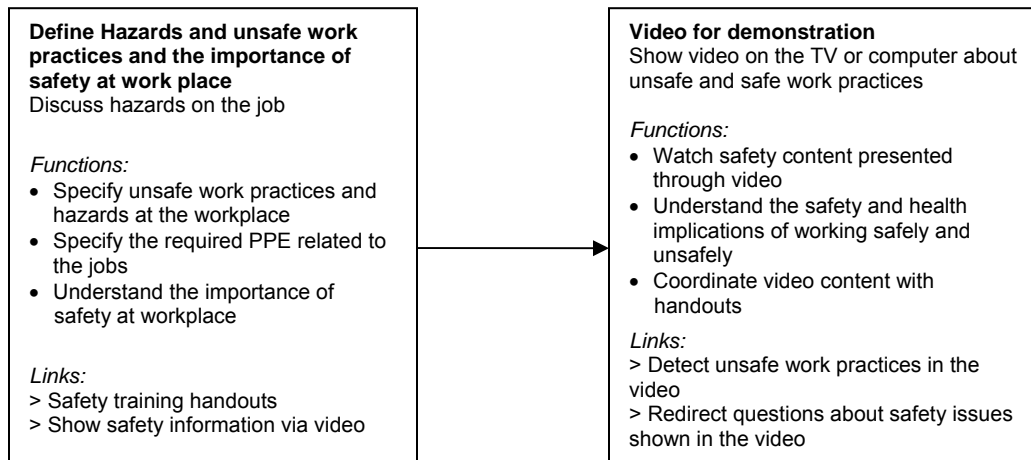
**Figure 17:** UED focus area

- iii. The next step was to add *functions* to the focus areas and links that connect the focus areas to other parts of the system.

*Functions* can be automated or invoked by the user. They are a description of what the user is enabled to do from that place in the system. In the above example, the “Video for demonstration” focus area enables the user with the following functions: Watch demonstrations of safe and unsafe work practices in the video, co-ordinate the video content with the handout provided, and understand the importance of safety at workplace.

There are two kinds of *links*. A single arrow (>) represents a *link* that connects two focus areas and the functions they support. A straight arrow is used to represent a single link between two focus areas. A double arrow (>>) represents a *double link* and is represented by two straight lines between the two focus group functions that are being supported by that work activity. If the user needs to perform work in a different focus area in the context of another focus area, then a double link is used between them, and the focus areas are mentioned with a double arrow (>>) under the links. In the figure below, a single link is drawn between the “Define hazards and unsafe work practices and importance of safety at workplace” focus area and the “Video for demonstration” focus area. This link suggests that the user is linked to the “Video for demonstration” focus area from the “Define hazards and unsafe work practices and importance of safety at workplace” focus area to support the functions that each one of those focus area have offered in that place.





**Figure 18:** UED with functions and links

- iv. The next step was to add the *objects* and *constraints* involved in that particular focus area. According to Holtzblatt (1998) *objects* are “The things that user sees and manipulates in the focus area”. In other words, *objects* are things that the users interact with in terms of design in that focus area. In this case, for the “Video for demonstration” focus area; the objects are the safety training video, handouts and the company personnel that are involved in the training. These are all the objects that are a part of the focus area, that support the functions offered by it. *Constraints* are simply the constraints involved in implementing that focus area.

As described above, the results from the visioning and storyboarding stage were implemented in this stage to prepare the UED. Structural implications were drawn from the storyboards as the UED was prepared, so that the information gained could be used for the design of the training system. The emphasis was on structure as well as sequence. By considering both the structure and the sequence, a UED was prepared that was structurally representative of the training system and transferable in terms of design implications for the prototype.

#### 4.5.6. *User Interface Design and Mock-up*

Finally, after thorough interpretation of user data in the second and third step of the CD process, brainstorming design ideas in the vision and storyboarding stage, and deriving structural implications of the design of the training system in the UED stage, the next step was to prepare the first paper prototype. Beyer and Holtzblatt (1998) suggest that the first prototype of the newly designed system should be a paper prototype that represents key design elements of the system. Paper prototypes are easy to prepare, they take less time and effort, and are easily editable. At this stage, the design implications are very preliminary, and changes in features and interface design might be required based on the needs and requirements of the user. Typically, the prototype is iterated several times to obtain full specifications for the further development and implementation of the system. However, as mentioned earlier, in this study the prototype is iterated only once with the feedback from the expert evaluators and the users.

For this study, the first paper prototype was built using stock paper as suggested by Beyer and Holtzblatt (1998). The key design elements transferred from the UED were represented in the prototype. Microsoft PowerPoint software was used to design the prototype. The prototype of the training system design was organized on cards structurally so that the evaluators could step through the cards in an orderly fashion. Due to time and resource restrictions, the prototype was demonstrated only to two expert evaluators: Dr. Thomas Mills and Dr. Glenda Scales, and two users: construction tradespersons.

For this study, experts were defined as individuals who had knowledge and experience in training systems. The project goal was to design a training system for small construction companies using Contextual Design methodology. Hence it was important that the experts for this project possessed knowledge about training systems.


Dr. Mills is an Associate Professor in the Building and Construction Department




at Virginia Tech and possesses knowledge and experience in designing training systems. He has taught classes that emphasized implementing information technology in the field of construction.

Dr. Scales is an Associate Dean for Distance Learning and Computing at Virginia Tech. Dr. Scales was the instructor of the Training Systems Design class during the fall 2005 semester and possesses expertise in training systems and instructional technology. The process of Contextual Design emphasized the context of use. The design incorporated the features of small construction companies to a deep level. With her expertise in training systems design, and after a short briefing about small construction companies, she was able to provide valuable feedback about the design of the training system as it related to small construction companies.

The two other evaluators were construction workers. The paper prototype was demonstrated to the evaluators and they were asked to comment on the structure, organization, and functionality aspects that the training system supported. Structure refers to the sequence/flow of the training system with reference to the links between different components of the training system. For example, first owners and supervisors receive training from an external organization; then they provide training to their employees. Organization refers to how the various components were arranged within the training system. For example, videos and handouts for demonstration of work practices were grouped together for the safety meetings, while toolbox talks were suggested for the on-site training. Functionality refers to the utility that the various components of the training system would provide in terms of safety training. For example, posters and warning signs would help the workers to recognize hazardous areas. Since several small cards were used to show the different parts of the prototype, the evaluators were able to go back and forth and make comments in writing on the cards. Furthermore, the interviewer also made notes about the comments and suggestions for design improvements for the prototype. The figure below shows a sample card of the prototype with comments written on it by the evaluators. The full prototype is shown and discussed in the results section.

The image shows a prototype poster for 'Toolbox Talks' on an orange background. The poster features a central list of four items, each with a checkbox and an icon. Handwritten notes in brown ink are present on the poster, and three callout boxes with lines pointing to specific parts of the poster are overlaid on the image.

**Toolbox Talks** 

- Brief orientation at the beginning of a new job with emphasis on safety *written hazard analysis* 
- Understand the hazards
- Use of PPE 
- Actions to be taken in case of accidents during work activities 

*Empirical UI movie*

*Toolbox tools*

*all workers carry their tool*

**Job Hazard Analysis**

**Toolbox tools**

**All workers carry tools**

**Figure 19:** Toolbox component of the prototype

## 5. RESULTS

As stated in the beginning of this project, the primary goals of this research are to design a safety training system for small construction companies and to understand and explore the needs of workers in small construction companies by using the CD methodology. To achieve the above-mentioned goals, the research questions restated below were framed:

1. What would be an effective medium for designing safety interventions such as training systems for small construction companies?
2. What are some of the problems that currently exist in small construction companies that may contribute to the rising fatality rate? (The problems identified here are in the context of work)
3. How feasible was the CD methodology for designing training systems for small construction companies?
4. How can CD be implemented in the field of construction safety? What alterations would be required so that it can be efficiently used in terms of time, resources, and demands of the construction industry?

### 5.1. Contextual Inquiry (CI) interview data

#### 5.1.1. Demographic questionnaire data

To answer the questions stated above, the CD framework was implemented as discussed in the Literature Review and Method sections. The data gathered for each participant consisted of observation notes, two questionnaires (demographic and safety), and a semi-structured interview. Table 5 summarizes different aspects (relationship status, accidents, job status, etc) of the data collected from the 12 participants through the demographic questionnaire.

**Table 5: Demographic questionnaire data**

Participant	Job	Relationship with Owner	Relationship with Co-workers	Company Size	Age	Education	Accidents in Past	Accidents in company last year
1	Framer	Relative	Relative	18	20	High School Graduate	2	3
2	Owner/ Sup	N/A	Siblings	4	46	Attended College	5	0
3	Dry wall	Friend	Friend	8	55	High School Graduate	2	0
4	Backhoe operator	Friend	Friend	14	54	Attended College	2	0
5	Plumber	Friend	Friend	14	43	Attended High School	1	2
6	Foreperson	Friend	Friend	18	21	High School Graduate	1	2
7	Framer	Friend	Friend	18	29	College Graduate	1	2
8	Foreperson	Relative	Relative	10	29	Attended College	1	0
9	Laborer/ operator	Friend	Friend	10	25	High School Graduate	1	3
10	Project Manager	Parent	Siblings	18	29	College Graduate	3	2
11	Carpenter/ Framer/ General	Friend	Relative	7	24	Attended College	0	2
12	Lead carpenter/ Foreperson	Friend	Friend	7	31	Attended High School	1	2

The results of the demographic questionnaire concluded that all the participants worked with either friends or family members at their respective construction companies. The participants were recruited from six different small construction companies and the number of accidents in the past year in those companies ranged from 0 – 3, with a mean of 1.50 ( $SD = 1.16$ ). The mean number of accidents in the past for the participants was 1.66 ( $SD = 1.30$ ), with a range of 0 – 5 accidents.

Additionally, the participants were asked to rate two Likert-type questions about the likelihood of injury and job satisfaction. The scale ranged from 1 – 10 (Lowest - Highest). The mean rating of the likelihood of injury at the job was 4.33 ( $SD = 2.05$ ), and job satisfaction was 8.66 ( $SD = 1.30$ ).

#### *5.1.2. Safety questionnaire data*

The safety questionnaire consisted of questions about safety in the workplace, contributing factors to accidents, communication, and risk perception. Table 6 shows the responses of the participants for the factors contributing to injury, enforcement of safety, and hazard recognition. The responses shown are with a frequency of 2 or higher.

**Table 6:** Worksite safety questions

<b>Safety questions</b>	<b>Frequencies (N = 12)</b>
<b>Factors associated with injuries at the workplace</b>	
Lack of Training	6
Speed of work	6
Slippery Surface	5
Weather	5
Co-worker	4
Fatigue	3
Time Pressure	3
Task too heavy	3
Lack of help	2
Wrong tool for task	2
<b>On-site safety controls enforced by the company</b>	
Wearing PPE	10
Tool box talks	9
Fall protection plan	7
Safety manual	4
Hazard Communication plan	3
Designated Safety Personnel	2
<b>How do you recognize the hazards in your work site?</b>	
I recognize hazards based on what I see	12
I recognize hazards based on what my supervisors or employees tell me	2

As shown in Table 6, lack of training (50%, N = 12), speed of work (50%), slippery surfaces (42%), and weather conditions (42%) were the most-selected responses for factors contributing to injuries at workplace. Regarding on-site safety controls, wearing PPE (83%) and toolbox talks (75%) were selected most frequently by the participants. The response about the enforcement of wearing PPE by the company was not consistent with the observation sessions. During the observation sessions, only



three participants used hard hats and steel toe boots, and six participants used eyeglasses. The safety questionnaire revealed that all participants recognized hazards based on what they saw. In terms of safety, training can be provided specifically about hazard analysis and recognition so that the construction workers can better recognize hazards efficiently and take precautionary measures to prevent accidents from occurring.

The safety questionnaire also consisted of five Likert-type scale questions with the scale ranging from 1 – 5 (Strongly disagree – Strongly agree). Table 7 shows the descriptive statistics for the five supervisors and Table 8 shows the descriptive statistics for the seven tradespersons. The questions and the mean responses are grouped by supervisors and tradespersons to examine whether differences existed in terms of on-site safety between the two groups.

**Table 7:** Supervisors' responses for on-site safety

<b>Supervisors (n = 5)</b>	<b>Mean</b>	<b>SD</b>
In your company, employees/ workers have problems in communicating with the managers/ supervisors	1.60	0.89
You know how to improve safety at your construction site	4.40	0.89
You are responsible for your employees' health and work safety	4.20	0.83
You tell your employees to follow the safe working procedures when they are working	4.60	0.54
You know the hazards with respect to each task	4.40	0.54

**Table 8:** Tradespersons' responses for on-site safety

<b>Tradespersons (n = 7)</b>	<b>Mean</b>	<b>SD</b>
In your company, employees/ workers have problems in communicating with the managers/ supervisors	2.28	0.75
You know how to improve safety at your construction site	3.85	0.89
Your supervisor cares about your health and work safety	4.42	0.53
You are told to follow the safe working procedures when you are working	4.28	0.48
You know the hazards with respect to each task	4.42	0.53

The differences in the mean ratings of most of the questions between supervisors and tradespersons were insignificant (Tables 7 and 8). To further confirm whether any significant differences existed between the responses of the owners and supervisors, the Wilcoxon-Mann-Whitney U tests were conducted. The Wilcoxon-Mann-Whitney U test is a non-parametric test conducted to examine whether significant differences exist between two groups with small sample sizes (Mundry and Fischer, 1998). The Wilcoxon-Mann-Whitney U tests indicated that no significant differences were found in the responses between supervisors and tradespersons (see Table 9). The high *P* values (greater than .05, which is the level of significance) indicate that there is no significant difference in the mean ratings between the owners and supervisors for the questions shown in Table 9.

**Table 9:** Wilcoxon-Mann-Whitney U Test results

Questions	Z	P
In your company, employees/ workers have problems in communicating with the managers/ supervisors	-1.28	0.19
You know how to improve safety at your construction site	0.95	0.34
The supervisor is responsible employees' health and work safety	-1.28	0.19
The supervisors ask the employees to follow the safe working procedures when they are working	0.94	0.34
You know the hazards with respect to each task.	0	1

Furthermore, the safety questionnaire also consisted of risk perception questions (Leonard et al., 1989). The risk perception questions were Likert-type with the scale ranging from "1– Not at all risky" to "8 – Extremely risky". Table 10 below shows the means for the responses of the participants for the risk perception questions.

**Table 10: Risk-perception questions**

Risk perception questions	Mean	SD
Not wearing ear plugs in a high-level noise environment	4.81	2.82
Not wearing steel toe safety shoes on the job	3.27	2.45
Not wearing a hard hat in construction areas where posted signs state that they are required	5.54	2.11
Walking on slippery surfaces while at work	4.90	1.92
Not wearing fall protection when working at elevated heights	6.54	1.86

Based on the range of the scale (1 – 8), if the rating 4 is considered “risky”, then the mean ratings for not wearing steel toe boots were low ( $M = 3.27$ ,  $SD = 2.45$ ). Comparatively, the mean ratings for not wearing fall protection while working on elevated heights was 6.54 ( $SD = 1.86$ ). Additionally, the participants were asked to rank what was most appropriate to increase safety at the workplace and what was most important to them for their job. The scale ranged from 1 to 4, with 1 being lowest to 4 being highest. In terms of most appropriate measure to increase safety at the job, safety training and education had the highest rating ( $M = 3.41$ ,  $SD = .66$ ) followed by management enforcing safety ( $M = 3.16$ ,  $SD = .71$ ). In terms of what was most important to the participants for their job, the mean score of worksite safety ( $M = 3.27$ ,  $SD = 1$ ) was the highest followed by the amount of money ( $M = 2.72$ ,  $SD = 1.19$ ) made on the job.

### 5.1.3. Semi-structured interview data

As mentioned earlier, the semi-structured interviews were conducted with the 12 participants to elicit information about their work practices, training methods, and design of the safety training system. The frequencies of responses by the participants are shown in Table 11. The table only shows responses with a frequency of 4 or higher from each category in a descending order and raw data is provided in Appendix J.

**Table 11: Semi-structured interview data**

<b>Semi-structured interview</b>	<b>Frequencies</b>
<b><i>Safety Responsibility</i></b>	
I am responsible for my safety at the workplace	8
Owner/ Supervisor responsible for safety	4
<b><i>Emphasis by the construction company</i></b>	
Work fast (time)	8
Safety	6
Do a good job (quality)	5
<b><i>Motivation on the job</i></b>	
Job Satisfaction (Love the job, like the job, enjoy working)	6
Money	5
<b><i>Who influences you the most at the workplace</i></b>	
Boss/ Supervisor	8
<b><i>First thing that comes in your mind about safety</i></b>	
Fall protection (working on heights)	4
Just be careful	4
<b><i>Awareness of safety rules</i></b>	
Wear harness (fall protection)	4
Not aware of rules	4
<b><i>Current method of safety training</i></b>	
Safety meetings	7
<b><i>PPE used at work</i></b>	
Eye glasses	4
Harness	4
<b><i>Advantages of working with family and friends</i></b>	
Get along well (like a family). Comfortable due to strong relationship	6
Family and friends do not affect safety at workplace	5
<b><i>Disadvantages of working with family and friends</i></b>	
Family and friends can give problems	4
<b><i>Suggestions for design of safety training system</i></b>	
Safety meetings (in groups, classes)	9
Demonstration of work practices	6
<b><i>Formal safety training is necessary</i></b>	
Yes	9

The information elicited from semi-structured interviews was critical for generating the design suggestions of the safety training system. It was found that the employees of small construction companies were highly influenced by their bosses and supervisors. In terms of working with family and friends, they felt comfortable due to their familial relations. However, it was also found that working with family and friends could be difficult due to close relationships and the fact that safety was not as emphasized at the workplace.

Table 11 shows that the participants felt responsible for their safety at the workplace. However, in terms of emphasis on work by the company, it was found that time was given the greatest emphasis. Following time, safety was given the next-greatest emphasis. In terms of motivation for the job, job satisfaction and money were the responses with the highest frequencies. In terms of awareness of safety rules, four participants responded about using harnesses for fall protection. At the same time, four other participants also responded that they were not aware of any rules and regulations about safety at the workplace.

To understand the current methods of training, the participants were asked to describe the existing training method in their respective companies. The most common method of training was found to be safety meetings. Other methods mentioned were manuals and handouts in meetings, on-site monitoring of safety by the boss, demonstration of work practices by insurance companies, and toolbox talks. Three participants responded that their construction companies did not provide any kind of safety training.

Another important aspect of safety training that was explored in the semi-structured interviews was their suggestions about the design of a training system to improve safety in small construction companies. Mostly, the participants suggested safety meetings and the demonstration of safe work practices for safety training. Other suggestions included computer-based training, toolbox talks, videos, and teaching

workers to pay attention. The above-mentioned information was used to make suggestions about the design of the training system.

## 5.2. Data interpretation sessions

The interpretation sessions involved analyzing the data collected from the CIs. Several interpretation sessions were conducted and the end result was a total of 60 work models (12 each for flow, sequence, artifact, culture, and physical models), 5 consolidated models (1 each for flow, sequence, artifact, culture, and physical model), and 1 affinity diagram. All these models assisted in identifying the breakdowns of the work system in small construction companies.

It is not feasible to discuss all 60 work models, as they were further represented as consolidated work models. Hence, in this section the results of consolidated work models and the affinity diagram will be presented, which encompass all the data gathered from the participants.

The **consolidated flow model** (Appendix D) revealed that the small construction companies' hierarchies consisted of an owner, a foreperson or supervisor, and tradespersons (ranging from general laborers to specialized jobs). The focus was to understand the roles, responsibilities, workflows, and interactions in the small construction company work systems and understand design implications for a safety training system that would fit the flow of work. The consolidated flow models showed that general contractors hired sub-contractors to work on specific parts of the house. The sub-contractor hired would have a hierarchical structure similar to the one mentioned above for small construction companies.

It was found that in terms of roles and responsibilities, the owner's responsibilities were to find projects, manage and supervise jobs, work on the jobs,

complete the work quickly, perform quality work, keep employees safe, and financial profits. It was found that the owner was highly influential on the employees of the company. The role of the foreperson was also found to be an important one. The forepersons not only had supervisory responsibilities, but also job responsibilities similar to the tradespersons. Forepersons were highly influential on the tradespersons as they worked together on most jobs. The tradespersons specialized in a certain construction job in most cases, but due to the size of the companies, they frequently performed different types of jobs. It was found that the tradespersons usually worked in teams of two or more people. The tradespersons reported to the foreperson and the foreperson reported to the owner. Unlike in big corporations, there was direct interaction between the owner, foreperson(s), and tradespersons. In terms of responsibility for safety at the workplace, it was found that each individual was expected to be responsible for his or her own safety. The owners and supervisors used the phrase “watch out” for their employees’ safety. But in terms of accountability, the employees were responsible for their own safety. There was clearly a lack of a formalized safety training system in the small construction companies.

The **consolidated sequence model** (Appendix E) revealed the general work procedures of the workflow. It is not a detailed set of step-by-step work procedures, but rather, a holistic view of the sequence of work. It was found that the work sequence involved the following high-level steps: plan task, perform task, co-ordinate task, provide and receive help with task, and continue task until finished. The sequence model showed that in most cases the construction workers worked in teams of two or more. They often requested help from the surrounding crews for lifting heavy materials. In terms of safety, this posed a threat as it was observed in certain cases that helping another employee interrupted the workflow and led to unsafe work practices. It was also found that there was a lack of defined safety procedures in the overall sequence of work. For example, a safety orientation during the planning of the task can help ingrain safety at work. The process of understanding the sequence provided an overview of the workflow. This information was crucial in generating design implications that matched the requirements of the small construction company environment.

The **consolidated artifact model** (Appendix F) was another useful informational model. It provided information on all the tools and equipment that were used to perform construction jobs. No special need for redesign was found for any tools or equipment (nail gun, saw, hammer, etc). Another category of artifacts explored in terms of safety was personal protective equipment (PPE). It was found that there was a lack of use of PPE in general. It was found that seven out of the twelve participants did not wear a hard hat for their jobs. Other artifacts that were observed to be lacking on the jobs from a safety standpoint were: proper clothing, steel toe boots, facemasks, and hand gloves. This tied back to the sequence model, which indicated a lack of safety planning for the construction jobs. The usage of digital devices such as computers, cell phones, or PDAs for safety training was also considered for the design of the training system. Through questionnaires and observation it was found that the only digital devices participants typically used were cell phones. Only three participants, all three of whom were supervisors, reported using computers. Cell phones were used by all except one participant and only one participant reported using a PDA. This information was crucial in deciding whether computer-based training should be implemented in the training system.

The **consolidated cultural model** (Appendix G) was one of the most important in terms of information for designing a safety training system. However, what Beyer and Holtzblatt (1998) referred to as *culture*, is more suitably the *climate* of the organization. The safety climate is the state of safety observed for that particular time period and is subject to change (Zhang et al., 2002). Culture is concerned with the shared values of the people at every level of the organization and is resistant to change over time (Zhang et al., 2002). However, for this study, it is referred to as culture, as suggested by Beyer and Holtzblatt (1998), but interpreted as the climate of the small construction companies. An in-depth analysis would have to be conducted to gain an understanding of the overall culture of the organization. In this study, through an hour-long observation, two questionnaires, and a semi-structured interview, it was difficult to gain an understanding of the culture of small construction companies as a whole.



The cultural model revealed the internal and external influences of small construction companies, the important motivators of work, as well as other information that was crucial for informing the design of this safety training system. Consistent with the flow model, it was found that the owners and supervisors were highly influential on their employees. The cultural model was also used to explore the level of emphasis placed on safety in everyday work life in small construction companies. It was found that speed of work and money were emphasized over safety at the workplace in most cases. In terms of external influences, PPE manufacturers and insurance agencies were mentioned as organizations that influenced safe work practices. It was found that most participants were not aware of OSHA requirements for safe work practices. However, the participants were aware of authorities from city and state government departments that came to check on building standards and codes. However, these standards were oriented towards building codes rather than safety of the construction workers.

The **consolidated physical model** (Appendix H) revealed important physical environment-related information that was crucial to the design of the training system. The small construction company workers move from one job to another and work on different stages of a house. Hence, it is difficult to generalize one consolidated physical model and suggest improvements. It was found that different crews may work on a house simultaneously, making the physical work environment hazardous. Unwanted material was another safety hazard that was observed on construction sites. It was also found that wires from power generators for power-operated equipment could cause trip hazards and electrical hazards for job sites. Additionally, it was observed that none of the worksites posted any warning signs or posters for restricted areas or required PPE. All this information was used directly for design ideas for the training system.

The **affinity diagram** is one of the most important models for informing the design of the training system for small construction companies. In this process, the observation notes and design ideas were organized into categories that shared a natural relationship (affinity) between them. All the ideas were organized in themes

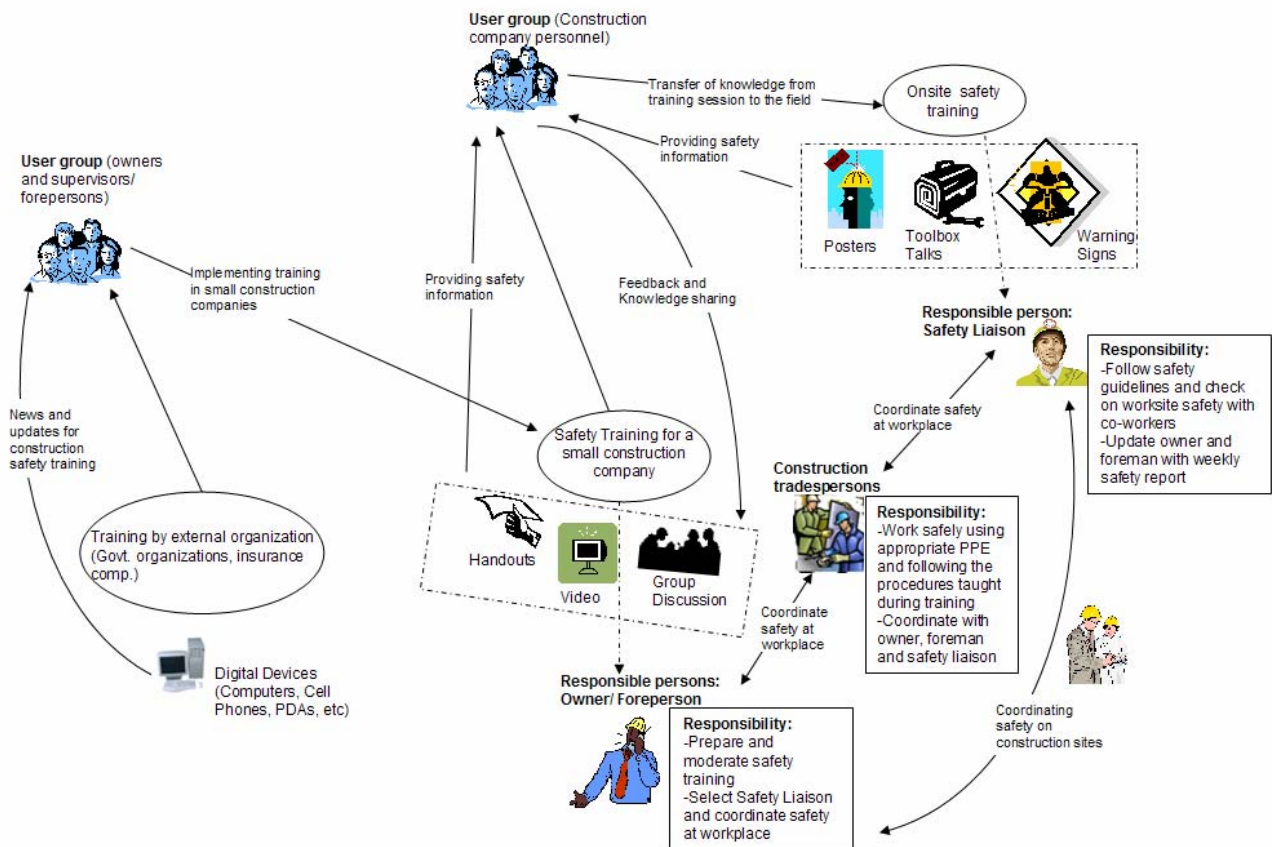
enabling a smooth transition from interpreting data to developing design ideas. The affinity diagram revealed that there was clearly a lack of safety training in small construction companies. There existed an awareness of safety, but a conscious effort was not made to integrate it into the workplace. Due to the small size and the familial relationships that existed in the small construction companies, it was found that people were concerned for safety, communicative, and influenced by each other. On the other hand, it was also found that working with friends and family could be difficult, there was a lack of safety training, and negative safety attitudes prevailed in the small construction companies. In terms of improving safety, a majority favored safety meetings for training and demonstration of safe work practices to help them see and understand safe work procedures. The affinity diagram was one of the most helpful of all the models for making design implications and understanding the needs and requirements of the small construction companies.

### **5.3. Design of the training system**

The interpretation sessions provided an in-depth understanding of the small construction companies' work environment and suggestions for the design of the safety training system. As discussed earlier in the Literature Review and the Data Analysis sections, the steps following the interpretation sessions to translate the findings into design ideas were Visioning and Storyboarding, User Environment Design, and User Interface Design and Mock-up.

In the visioning stage, new design ideas for the training system were discussed based on the information from the interpretation stage. The user groups, the technology involved, the components, and the effect of a training system on the workflow were examined while envisioning the new work system. For example, as mentioned in the sequence model, there was a lack of safety orientation and emphasis on safe work practices during the planning stage of the work. Hence, one design implication made to

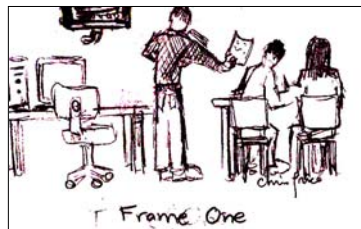
solve this issue was *toolbox talks*. *Toolbox talks* are short meetings that discuss issues specific to the job. In this case, the issue involved would be safety at the workplace. The questionnaires and the affinity diagram also revealed that toolbox talks were being used and favored by construction persons for safety in the workplace. Other similar design implications such as safety meetings, demonstration of safe work practices, and management enforcing safety on the work site were envisioned as design ideas for the new training system. After brainstorming various ideas as mentioned above and incorporating all the information retrieved from the consolidated models, one final synthesized vision was formed for the training system. Figure 20 illustrates the vision created for the new work system with the safety training system in place.



**Figure 20:** Vision for a small construction company with the training system in effect.

In the vision presented above (Figure 20), the focus is on improving safety by incorporating a training system. The vision incorporates the ideas generated from the consolidated models into one synthesized vision of the work system. In the vision, the owners, supervisors, and forepersons are required to receive safety training from an external organization such as OSHA. The external training would help leverage some of the existing training programs that are currently offered by organizations such as OSHA and NIOSH. The external training was suggested for the owners, supervisors, and forepersons as the results of this study indicated that they highly influenced their employees at the workplace. Furthermore, since time and money are an important aspect of the work, it would not be feasible to send all the company personnel for external training. The owners and supervisors would then pass the information gleaned from that safety training to their respective companies. The training involves handouts, videos, and group discussion. These components of training were generated from the feedback provided by the participants during data collection. At the end of the group discussion, a safety liaison is chosen so that training can be further transferred to the field and regulated on a day-to-day basis. Toolbox talks, posters, and warning signs are the major components of the onsite safety training. The safety liaison is expected to report to the owner of the company about the safety procedures on the worksite.

In the next stage, the vision was storyboarded into frames that depicted the sequence of everyday work practices of the construction workers. The storyboards depicted pictorially, as well as in words, how the new training system would work hypothetically. It helped examine details of the work practices, the design implications, and how the training system would fit in the sequence of work activities of the small construction companies in general. The following are the storyboards that were drawn to represent the envisioned work system with the new training system in place.



Frame 1: Training session.  
Moderator providing handouts



Frame 2: Moderator talking  
about job hazards, PPE, etc



Frame 3: Attendees watching  
video demonstration of work  
activities



Frame 4: Attendees noting  
unsafe work practices while  
watching video

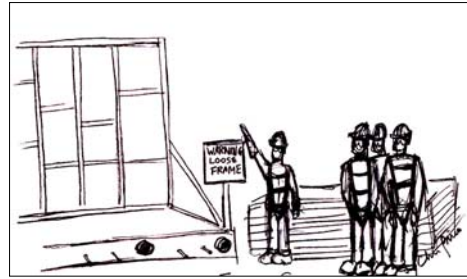


Frame 5: Group Discussion  
and demonstration of  
corrective work measures



Frame 6: Selection of Safety  
Liaison.

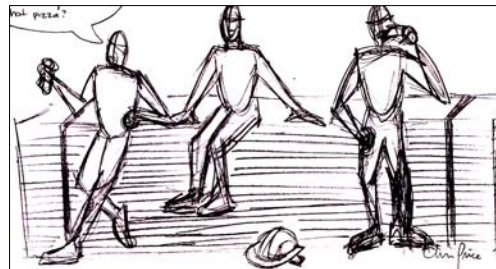
**Figure 21:** Storyboard for safety training in a small construction company



Frame 1: Onsite toolbox talk before start of job about putting up warning signs, wearing PPE and working safely



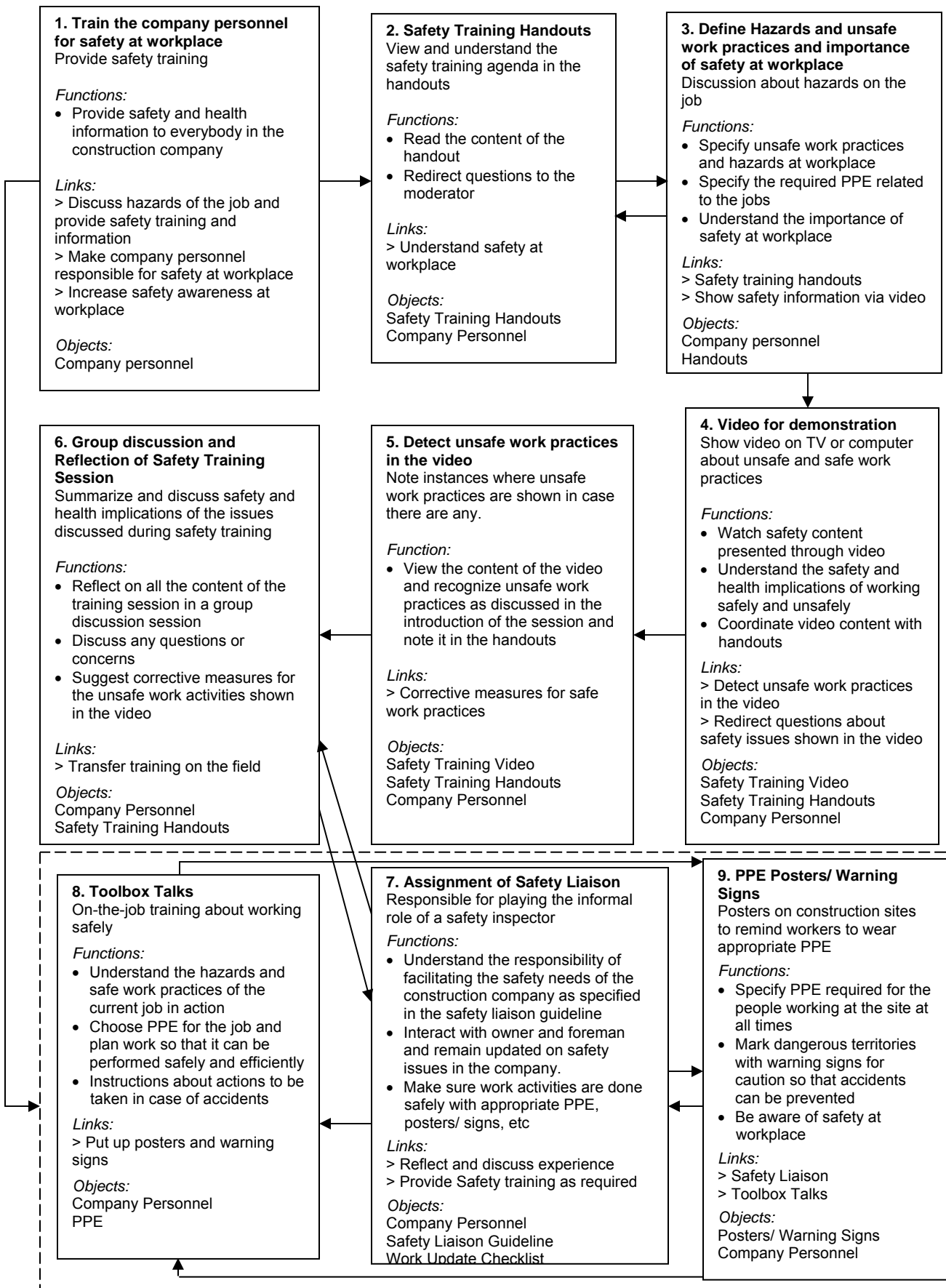
Frame 2: Tradesperson working safely on height



Frame 3: Safety Liaison checking with co-workers about worksite safety during lunch break

### Figure 22: Storyboard for onsite safety training

The next step was to refine the design to a higher level into the User Environment Design (UED). The UED was developed from the ideas generated during visioning and storyboarding. The UED is concerned with the structure and sequence of the training system as seen fit in the small construction companies. The UED helps in developing a map of the training system and an understanding of the details about the design implications made for the training system. Figure 23 illustrates the UED developed for this training system.



**Figure 23: User Environment Design of the training system**

The UED shown above (Figure 23) was generated from the vision and storyboards. An explanation of the process and the steps involved in generating the UED is provided in the data analysis section of this thesis report. The UED shows the different focus areas of the training system and within each focus area are details about the functions, links, and objects of that particular focus area. It is a structural and sequential representation of the training system that assists in understanding how the various components of the system would interact within the small construction company work system.

The final stage of design was the user interface design and mock-up. At this point, after interpretation of data and transforming that data into design ideas, the first paper prototype was prepared with the key design elements. The prototype was evaluated by experts and users (construction tradespersons). The prototype was demonstrated to the evaluators and a discussion session was conducted to receive feedback about the design of the prototype. The paper prototype allowed the evaluators to make comments and organize the various components of the training system to understand the design elements thoroughly. The cards were color-coded to represent different phases of the training. Color-coding helped the evaluators to differentiate and organize the different aspects of the training system in a systematic manner. The following is the paper prototype as shown on cards using card-stock paper.

### Training for Owners and Supervisors

- Conducted by an external organization
  - Government Organizations, Insurance Companies, Personal Protective Equipment (PPE) Manufacturers
- For Owners and Supervisors/ Forepersons
  - Importance and advantages of safety at work
  - Wearing appropriate PPE
  - Influence of owners and forepersons on co-workers

### Components

- Training Module
  - Designed and Developed by the external organization
- Training material made available to the attendees for implementing construction safety training in their respective companies





## News and Updates

- Provide news and updates about construction field such as accidents, safety training, and other things to keep the owners and supervisors aware
- Use Digital devices such as Computers and cell phones



## Safety Training for Small Construction Company

- Training for construction company employees/ tradespersons
- Implemented once a month as **time** and **money** are key work attributes in small construction company environment
- Duration: 45 minutes – 1 Hour



## Training Responsibility

- Moderator
  - Owner or Supervisor/ Foreperson
- Moderate the training session in a group setting and provide information about safety and health
- Manage safety training session
  - Choose topic to be discussed for training and provide hazard information, required PPE, etc
- Choose a Safety Liaison towards the end of the session (Make people responsible)



## Components

- Handouts
- Video module
- Group Discussion

## Handouts

- Content about specific safety training being provided in relation to the video
- Questions to be answered in coordination while watching the video
- Noting unsafe work practices as seen on the video



## Video module

- Demonstration of work using videos
- Showcase hazards of the job by showing unsafe work practices
- Testing through video
  - Attendees view the content of the video and detect hazardous situations demonstrated in the video



## Group Discussion

- Discuss and summarize the training session
- Discuss about unsafe work practices detected in the video and suggest corrective work measures
- Demonstrate appropriate working postures

## Safety on the worksite

- Integrating safety in daily work activities
- Implemented based on training received during monthly meeting
- Implemented as and when needed
- Responsible person: Safety Liaison

## Safety Liaison

- Selected during the monthly safety training meeting
- Transfer of responsibility to a different employee each month
- Coordinate safety with co-workers, and owners and Supervisor/ Foreperson
- Follow safety guideline provided to do the job and provide weekly report to owner or foreperson



## Components

- Toolbox Talks
- Posters
- Warning Signs

## Toolbox Talks

- Brief orientation at the beginning of a new job with emphasis on safety
- Understand the hazards
- Use of PPE
- Actions to be taken in case of accidents during work activities





**Figure 24:** First prototype of the training system

In the prototype presented above (Figure 24), the key design elements of the safety training system for small construction companies are demonstrated. The prototype was developed after the UED phase. Each phase of training was color-coded, which was useful for the evaluators. For example, if an evaluator wanted to step back to a different component of the training, the color-coding made it easy to differentiate and recognize the component. The prototype shows how the training would take place, the people involved in the training, and the other necessary design aspects of the training system. The addition of graphics made the prototype more interpretable as some ideas were demonstrated in words and in pictures as well. Table 12 provides a brief description of the design ideas that were suggested in the prototype of the safety training system.

**Table 12:** Design ideas for the prototype of the safety training system

<u>Index</u>	<u>Training system design idea</u>	<u>Justification</u>	<u>Source</u>
1	Safety training for owners and supervisors by an external organization	The consolidated flow model and the cultural model showed that owners and supervisors were highly influential on their employees at the job. In the semi-structured interviews also, 8 (67% approx.) of the 12 participants mentioned that their owners and supervisors influenced them highly at work. Hence, it was important that the owners and supervisors	Consolidated flow model, consolidated cultural model, and Semi-structured interviews.

		received formal safety training such that they could further implement it at their respective work places.	
2	Updates for owners and supervisors using	It was found through the demographic questionnaires and the consolidated artifact model that three supervisors used computers, one supervisor used a PDA and all except one participant used cell phones. To take advantage of this information and to follow-up on the training by the external organization, it was suggested that safety related information could be sent to the owners and supervisors via cell phones or computers. Using computers for training has been reported to be useful and beneficial for online safety training (Liebeskind, 2005). In this study, only three out of five supervisors used computers. However, the positive results of online safety training reported by Liebeskind (2005), provides further opportunity to investigate the need for online safety training in small construction companies for owners and supervisors.	Demographic questionnaire and Consolidated artifact model
3	Safety meetings	In the semi-structured interviews, the participants were asked whether there existed a safety training system in their respective companies. Seven (60% approx.) of the 12 participants' responded that their companies conducted meeting for safety. When asked for suggestions for safety training, 9 (75%) of the 12 participants suggested safety meetings to discuss safety issues. However, it was decided to conduct the safety meetings for short durations as data from the consolidated cultural model, affinity diagram, and the semi-structured interviews clearly suggested that the small construction companies highly emphasized on time and money.	Consolidated cultural model, Affinity diagram, and Semi-structured interviews.
4	Videos and handouts in meetings	In the semi-structured interviews, it was found that following by safety meetings, demonstration of work practices were suggested by 6 (50%) of the 12 participants. Videos were suggested by 2 (17% approx.) participants and 3 (25%) participants mentioned using handouts and manuals for the meetings. The individual numbers for videos and handouts are small. However, to incorporate the idea of demonstration of work practices, which was suggested by 50% of the participants, the videos and handouts were suggested as components of the safety meeting. In a study conducted by Mandel et al. (1998) to train parents to reduce safety hazards at home, video tapes were used and found to be useful. The advantages of using video tapes are that they can be replayed	Safety questionnaires and Semi-structured interviews.

		repetitively and easily integrated with other parts of the training (Mandel et al., 1998).	
5	Safety liaison	In the safety questionnaire, the participants were asked as to which safety control would improve the safety at the workplace the most. The highest mean ratings were for safety training education and management enforcing safety. For this training system, the meetings were suggested in relevance to safety training/ education, and the safety liaison was suggested in relevance to management enforcing safety. The safety liaison was suggested in order to enforce safety on the work site.	Safety questionnaire.
6	Toolbox talks	The toolbox talks are suggested for on-site safety training. Toolbox talks are conducted on the job site and are kept very short. In the safety questionnaire, 9 (75%) of the 12 participants responded that their company enforced toolbox talks as a method of on-site safety training. Since toolbox talks are short meetings, keeping the time and money factors in consideration, they are easily applicable in the small construction company environment.	Safety questionnaire.
7	Warning signs and posters	The consolidated physical model suggested that the small construction work environment was hazardous with different crews working together using heavy tools and equipment. Some tools required electric power to operate, due to which, wires were spread throughout the sites. In the case of framing, ladders and other heavy material were left unattended at times. Furthermore, the consolidated artifacts model indicated that the appropriate PPE was not being used at the job. To avoid hazards pointed by the data from the models, posters and warning signs were suggested. Warning signs were suggested as all the twelve (100%) participants mentioned in the safety questionnaire that they recognized hazards based on what they saw during work. A poster or a warning sign could help them to recognize of any potential dangers that might exist at a work site.	Consolidated physical model, Consolidated sequence model, Consolidated artifact model, and Safety questionnaire.

The design ideas in Table 12 were mostly gained from the consolidated models, questionnaires, and semi-structured interviews. From the consolidated cultural model and the semi-structured interviews, it was found that the owners and supervisors were highly influential on their employees. Hence, it was important to start the training with them so that they could further emphasize it to their employees. To train the owners and supervisors, training by an external organization was suggested. In order to take

advantage of the finding that three supervisors used computers, it was suggested that updates and e-mails about safety could be sent to the owners and supervisors via cell phones or computers.

In terms of the desired method of training, about 75% of the participants favored safety meetings followed by demonstration of work practices, which was favored by 50% of the participants. The safety questionnaire consisted of a ranking question in which the participants were asked to rank the most favored safety control to improve safety at the workplace. The participants once again ranked safety training education followed by enforcement of safety by management as most appropriate. Based on that information, the safety liaison was suggested for the enforcement of safety. The safety liaison was further responsible to implement on-site safety training using toolbox talks, warning signs, and posters.

The first prototype that was designed based on the information gained from the observation session, questionnaires, and the semi-structured interviews, is shown in Figure 24. As mentioned earlier, the prototype was evaluated by four evaluators. Following the evaluation session, the feedback was used to complete the first iteration of the design of the safety training system.

#### **5.4. Evaluation**

As discussed earlier, the prototype was evaluated by four evaluators – two experts and two users (construction workers). The prototype was demonstrated and the evaluators were engaged in an open-ended discussion session. The evaluators were also allowed to write their comments on the paper prototype. The prototype was demonstrated to the users and the experts alike, except that the experts were also briefed on the process of CD. This was done to receive their feedback on the viability of the CD methodology in relation to the findings of the research. At the end of the

evaluation sessions, the evaluators were asked to rate the system on the following criteria: structure, organization, and functionality (explained in section 4.5.6). Additionally, the expert evaluators rated the CD process as it was applied in this research project. The questionnaire (Appendix I) consisted of Likert-type questions with the scale ranging from “1 – Very poor” to “5 – Very good.”

Table 13 below shows the ratings given for the first paper prototype by the evaluators.

**Table 13:** Evaluation ratings for the first training system prototype

	Expert 1	Expert 2	User 1	User 2	Mean	SD
<b>Function</b>	4	4	3	5	4	0.81
<b>Organization</b>	5	5	5	5	5	0
<b>Structure</b>	5	4	4	5	4.5	0.57

Based on the scales, if a particular aspect of the training system is rated 4 or higher, then it would be considered as “good” or “Very good.” All the evaluators, except one user, rated the training system as 4 (Good) or higher in terms of function, organization, and structure. The one user who rated the function of the training system as 3 (Fair) did not find the idea of “safety liaison” to be feasible for small construction companies. Overall, the training system was rated with the mean ratings of 4 ( $SD = .81$ ), 5 ( $SD = 0$ ), and 4.50 ( $SD = .57$ ) for function, organization, and structure respectively.

The expert evaluators rated the training system differently and provided feedback based on their background knowledge. An encouraging result of the evaluation was that both experts, even though from different backgrounds, rated the application of the CD methodology for this thesis project as “Very good.” The experts found the approach interesting and useful for designing a training system. Table 14 below provides some of the positive and negative feedback about the design of training system along with some suggestions for improvement.

**Table 14:** Evaluation feedback

<b>No.</b>	<b>Positive feedback</b>
1	Training for owners and supervisors is essential
2	Useful system if people would be willing to use it
3	Briefing on work before beginning
4	Updating safety information is important at different phases of projects
5	Formal safety training can add value
6	Hands-on demonstration is definitely effective
7	The training might save them money
8	We have a similar safety training for 20 minutes each week
9	Weekly training keeps safety on mind
10	30 minutes of training a week can save a lot more in the long run
<b>Negative feedback</b>	
1	Issues are with hierarchical focus that may not work well with small construction companies with less than six people
2	For updates being sent through cell phone, the charges applied might be an issue
3	Safety liaison is not practical
4	It would be difficult to implement safety meetings once a month
5	Safety training might take too much time
6	Rotation of the safety liaison might not work
7	Safety meetings might be hard to implement in a small company with established workers
<b>Suggestions</b>	
1	Use buddy system and boss supervision, and continued input on safety features
2	Safety tips on their pay check might help
3	Focus on job hazard analysis. Provide a written handout
4	Training should be invisible rather than the traditional training
5	Use on-the-job training
6	There has to be some kind of incentive for the training
7	Fit the training into something that is already existing
8	If people are working in teams then they should be responsible for each other
9	The boss would be the key person as he is the responsible person at the end



According to the first expert evaluator, the design of the training system required the consideration of the informal hierarchical structure of small construction companies to a greater extent. Due to the informal structure, the idea of a safety liaison was not seen as a good fit by the evaluator. Another important note made by the first expert evaluator was that this training system would be hard to implement in small construction companies with fewer than five or six people. The main reason mentioned was the informal organizational structure of small construction companies. The second expert evaluator felt that monthly safety training might be hard to implement. The evaluator suggested that the focus of the training should not be on safety. Rather, the training should be oriented towards improving job skills, and safety should be an integral aspect of it. According to the second expert evaluator, formal safety training in small construction companies would be resisted. Furthermore, it was suggested that some incentives would have to be provided to the employees in order to get their participation in a safety training program.

Regarding feedback from the users, one of the users reported that in his construction company, they conducted safety meetings similar to what was suggested in the training system prototype. The other user indicated that the concept of safety liaison would not work in the small construction company environment. A “buddy system” was suggested instead of a safety liaison for small construction companies. The first expert evaluator also provided similar feedback about the safety liaison. For future refinement of the design of the training system, the comments about the safety liaison were considered highly, since an expert and a user, both provided similar feedback about one of the components of the training system. Other suggestions, as shown in Table 14 were also made regarding improving the training system for future implementation. Some of the suggestions, as seen applicable, were incorporated into the existing design guidelines to complete the first iteration as proposed in this project.

## 5.5. Final design of the training system prototype

The required changes were made to the design of the prototype, taking into consideration the suggestions made by the evaluators. The data was reviewed again in order to redesign the prototype of the safety training system. One of the design suggestions of the safety training system that was not favored was the safety liaison. The evaluators suggested that a safety liaison would not fit into the structure of small construction companies. The evaluators were also concerned about the safety training meeting for the small construction companies. However, this component was not changed, as data indicated that safety meetings were a desired method of training for the small construction industry. Data from the semi-structured interviews indicated that 7 (60% approx.) of the 12 participants' companies were conducting meetings for safety at the workplace. Regarding suggestions for training, 9 (75%) of the 12 participants favored meetings for safety at the workplace. However, considering the concerns of the evaluators about safety meetings, the time was reduced to 30 minutes instead of 45 minutes – 1 hour. The duration of the safety meeting was set to 30 minutes based on the suggestions of the evaluators and considering that great emphasis is placed on time and money in small construction companies.

Based on the evaluation, the safety liaison was discarded from the design of the safety training system. However, in order to implement safety at the workplace, a “buddy system” was suggested. The “buddy system” is an unstructured approach to on-the-job training and is effective in terms of time and cost (Clements, 1995). Furthermore, safety meetings and toolbox talks were identified as important design elements of the training system as both were suggested by 9 (75%) of the 12 participants for training in small construction companies. Since the demonstration of work practices were also suggested by 50% of the participants, the videos and handouts remained as components for the safety training meeting. Figure 25 shows the prototype with the suggested changes.

## Training for Owners and Supervisors

- ❑ Conducted by an external organization
  - Government Organizations
  - For Owners and Supervisors/ Forepersons
  - Importance and advantages of safety at work
  - Wearing appropriate PPE
  - Influence of owners and forepersons on co-workers

## Components

- ❑ Training Module
  - ❑ Designed and Developed by the external organization
- ❑ Training material made available to the attendees for implementing construction safety training in their respective companies



## News and Updates

- ❑ Provide news and updates about construction field such as accidents, safety training, and other things to keep the owners and supervisors aware
- ❑ Use Digital devices such as Computers and cell phones



## Safety Training for Small Construction Company

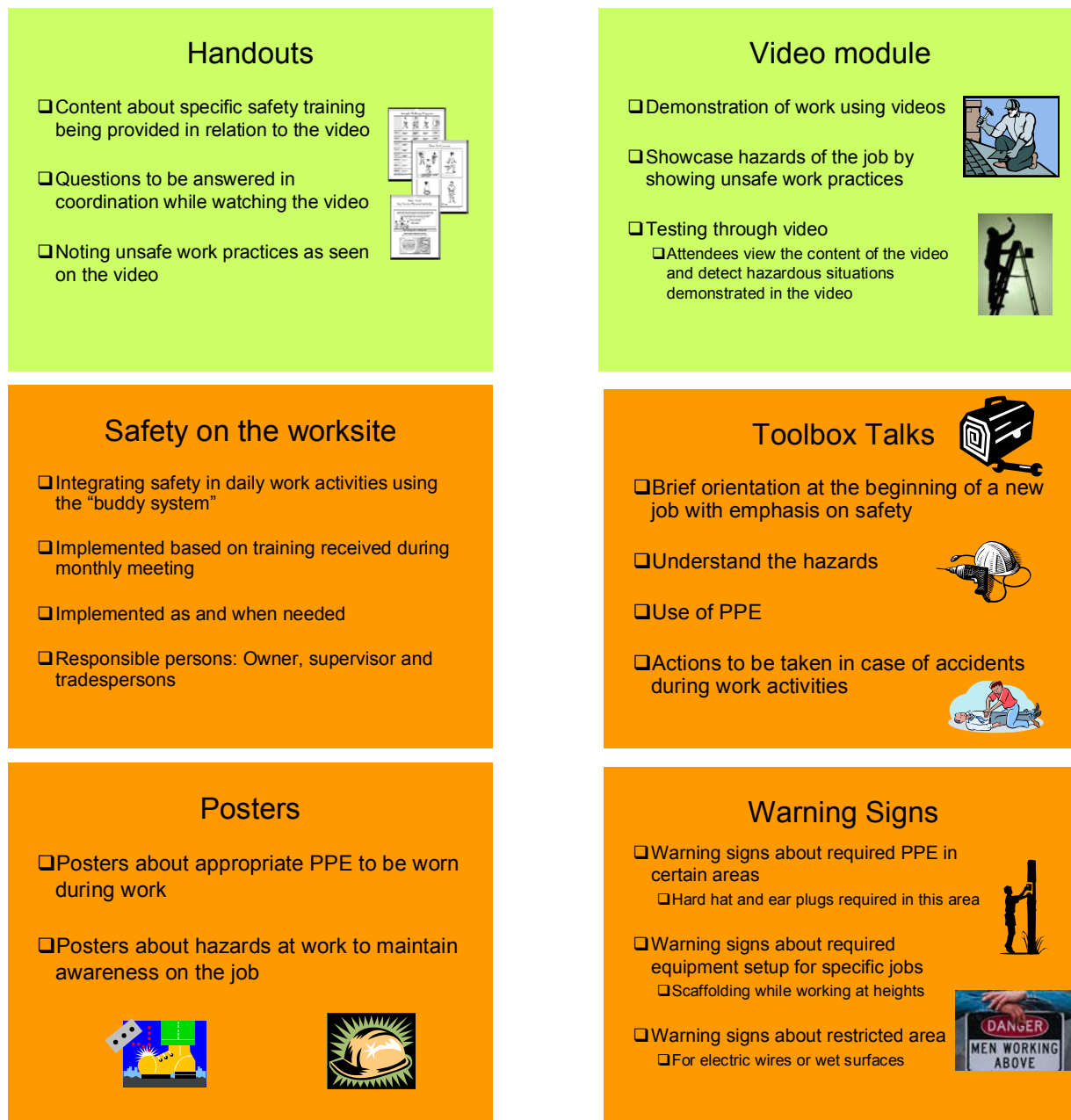
- ❑ Training for construction company employees/ tradespersons
- ❑ Implemented once a month as **time** and **money** are key work attributes in small construction company environment
- ❑ Duration: 30 minutes



## Training Responsibility

- ❑ Moderator
  - ❑ Owner or Supervisor/ Foreperson
- ❑ Moderate the training session in a group setting and provide information about safety and health
- ❑ Manage safety training session
  - ❑ Choose topic to be discussed for training and provide hazard information, required PPE, etc





**Figure 25:** Redesigned prototype of the safety training system

The training system was redesigned based on the feedback and suggestions from the evaluators. This was done in alignment with the CD process, which recommends an iterative approach to the design. The basic framework of the prototype design recommends traditional training methods. However, it should be noted that the CD methodology has helped in identifying this initial design. Further iterations must be

conducted in order to refine and finalize the design of the training system, following which the individual components can be developed and implemented. However, to support this initial design, the data was revisited in order to provide some innovative ideas that could help improve safety at a higher level. The supporting design ideas were derived based on the suggestions from evaluators, questionnaires, semi-structured interviews, and observation sessions. Some of the recommended ideas are as follows:

- **Buddy system:** Evaluators suggested a “buddy system” was suggested by the evaluators in order to maintain safety at the workplace. With a “buddy system” in place, two people would double-check with each other while working together on a task (Clements, 1995). In particular, the “buddy system” can be useful for new employees who do not have much experience or training in the field of construction. There are advantages and disadvantages to implementing the “buddy system” in small construction companies. According to Walter (2000), the “buddy system” is an unstructured approach to on-the-job training (OJT). Its structure is dependent on the partner’s (buddy’s) knowledge and experience in the related field. For small construction companies, the “buddy system” is suggested for on-site safety. One advantage of using the “buddy system” in small construction companies is that it is cost and time effective (Clements, 1995). However, compared to structured training, the level of productivity achieved is lower with the “buddy system” (Clements, 1995). In small construction companies, the “buddy system” would be easy to implement as the consolidated sequence model has shown that, in most cases, people work in teams of two or more. Furthermore, time and money are highly emphasized in small construction companies.
- **Safety tips on hard hats:** The consolidated artifact model has shown that workers do not wear the appropriate PPE (only 3 of the 12 participants wore hard hats). However, if safety related tips are printed on hard hats, then if one person wears one, the people working around that person would be able to

notice the safety tips. The consolidated physical and sequence models show that most construction jobs involve teams of two or more people working together. Hard hats with safety tips could be influential to the surrounding workers.

- **Corporate help:** Business corporations like DuPont that manufacture construction materials and protective apparel can help improve safety at the workplace significantly. One of DuPont's products known as Tyvek® ([www.tyvek.com](http://www.tyvek.com)) is widely used while constructing houses, to protect the wooden frames from air and water, and to help lower heating and cooling costs. In this example, if safety tips are printed on Tyvek® sheet covers, then the safety tips would remain in front of the workers' eyes for an extended period of time. Besides safety tips, images of workers with hard hats and other PPE can support the suggestion of posters and warning signs for the safety training system. In a study about recommendations to help quit smoking, it was recommended that brief messages and suggestions to quit smoking can be effective (Tessaro et al., 1997). Similarly, brief messages and safety tips can be printed on the construction material in order to provide safety information to the construction workers. The government may collaborate with construction material manufacturers like DuPont to print safety-related information on the materials that the construction workers use regularly in their workplace.

## 6. DISCUSSION

### 6.1. Reasons for accidents in small construction companies

As mentioned in the beginning, one of the main objectives of this study was to explore the safety issues in small construction companies. This objective was set so that a prototype of a training system could be designed that matched the requirements of the small construction companies. In relation to the objective, the second research question was framed to identify some of the problems that existed in the small construction companies that contributed to the high fatality rate. The data interpretation sessions helped to identify some of those factors.

Consistent with the literature, it was found that there was a lack of training in small construction companies (Hoffman and Stetzer, 1996). This lack of training can be attributed as one of the reasons for the high fatality rate in this industry. Another important finding was that most people that were employed in small construction companies were friends and family members. Ram (2001) studied the dynamics involved in small family-owned businesses and suggested that there is a significant influence of family life on work life when closely related people work together. Consistent with Ram's findings, in this study it was found that when friends and family members work together they are highly concerned about each other's safety, they communicate well, and influence each other to a great extent. On the other hand, it was also found through the affinity diagram and the semi-structured interviews that working with family and friends can be difficult. According to the literature, close familial ties at work can make it difficult to exert authority as the effects can go beyond work in personal life (Champoux and Brun, 2003). In terms of safety, 5 of the 12 participants mentioned that working with family and friends did not affect safety at the workplace. However, four participants mentioned that family and friends could cause problems at work and two participants mentioned that safety was not emphasized because family and friends were working together.

If people in small construction companies are closely knit with friendship and familial relationships and are highly concerned about each other's safety, then why is there a lack of safety training and why is the fatality rate on a rise? This study does answer these questions to a certain extent. The semi-structured interviews revealed that most small construction companies emphasized highly the speed of the work followed by safety and quality of the job. The speed of work is highly related to money, since working fast means earning more money. Working under time pressure can cause workers to neglect safety procedures, often leading to accidents at the workplace (Hoffman and Stetzer, 1996). However, to get more work they had to perform a high-quality job. Because of this, safety training is not given high emphasis. Rather, the notion of just being safe while working was emphasized in most small construction companies.

Safety training implies cost in terms of time and money. Buying PPE and providing training to all company personnel increases monetary costs and requires time. Most small-sized enterprises lack the financial and technological resources to provide training to their employees (Champoux and Brun, 2003; Lingard and Holmes, 2001). That is one reason that only the owners, supervisors, and forepersons are required to attend training provided by an external organization in the training system prototype of this thesis project. The time and cost would rise significantly if all the small construction company personnel were required to attend training with external organizations.

Construction jobs are one of the most hazardous of all jobs in the U. S. (Minchin et al., 2006). Literature shows that employee attitudes towards safety can act as a major contributing factor towards fatal and non-fatal injuries at the workplace (Lingard and Holmes, 2001; Williamson et al., 1997). In the semi-structured interviews, three participants indicated that they did not require safety training as they were experienced. This could result in risky behavior, leading to fatalities at the workplace. Furthermore, three participants reported personal mistakes and two participants reported not wearing PPE as reasons for accidents in the past. All the above-mentioned reasons for



accidents were considered in designing the training system so that the fatality rate can be reduced in the small construction industry.

## **6.2. Design of the training system**

The first research question of this thesis project was to find an appropriate medium for safety training for small construction companies. It was hypothesized that computer-based or other digital technology-based training would result from this research for safety training. This hypothesis was based on the fact that computer-based training was found to be beneficial in the field of healthcare and safety training (Kasten et al., 1998; Liebeskind, 2005). It was found that while most of the participants had received a minimum of high school education, not all of them used computers. Only three of twelve participants reported on the questionnaires that they used computers, versus eleven participants who reported using cell phones. Out of the three participants that reported using computers, one was an owner of a construction company and the other two were supervisors. Clearly, computer-based training cannot be implemented for everybody in the small construction company environment as it does not match with the requirements of the small construction industry. As discussed by Hendrick and Kleiner (2001) using the example of Tavistock studies, a technology-centered approach of the organizational design does not adequately consider the other elements of a sociotechnical system. According to a sociotechnical systems approach, the social aspects and the technical aspects should be interrelated in order to better support the work system design (Reddy et al., 2003). Hence, it is important that the training system design supports the requirements of the people in small construction companies. As mentioned above, only three owners and supervisors reported using computers. Using this information, in terms of design implications, computer-based training is suggested for owners and supervisors.

The consolidated models suggested that owners, supervisors, and forepersons influenced their employees to a great extent. According to Zohar (1980), the attitude of

workers towards safety is highly influenced by their supervisors. This information was used in the design of the training system. In the training system prototype, it was suggested that the owners, supervisors, and forepersons receive safety training from an external organization and further train their employees internally in their respective companies. Since the owners and supervisors influence their employees highly, it is important for them to receive the training first so that they understand the value of safety training. The consolidated sequence model showed a lack of safety procedures in the overall work sequence. This information from the consolidated sequence model, along with suggestions from participants about safety training, led to the idea of toolbox talks on the site. Furthermore, the consolidated artifact model also showed that there was a lack of usage of appropriate PPE during construction jobs. The toolbox talks suggested in the training system prototype would address the issue of appropriate PPE and on-site safety training.

In this study, the CD methodology was used to design a safety training system to understand the unique contextual factors of small construction companies and help them gain access to safety training programs. Several training programs are currently offered by the government organizations such as NIOSH (<http://www.niosh.com.my/index.asp>) and OSHA (<http://www.osha.gov/>). However, one claim, which was critical for this study was that there exists a gap between the available resources and the small construction companies. This gap exists as most of the small construction companies lack the resources to access these training programs. As the results of this study indicate, small construction companies are restricted in terms of time and money, which makes it hard for them to implement safety at the workplace. To a certain extent, the design of this training system addresses this issue. As most small-sized companies are financially fragile (Champoux and Brun, 2003), the external training is suggested only for the owners, supervisors and forepersons. The external training would help leverage some of the existing training programs that are currently offered by organizations such as OSHA and NIOSH. The owners and supervisors could further pass the information gleaned from that safety training to their respective companies. The suggested system would reduce the time and money required to train

all the employees of the company and also help them gain access to safety training programs offered by government organizations such as OSHA and NIOSH.

### **6.3. Feasibility of using the CD methodology**

The third research question of this study was to answer whether the CD methodology would be feasible in designing a training system for small construction companies. The CD methodology was found to be useful for this research project for the following reasons:

- The CD methodology was helpful to understand the contextual factors that are unique to small construction companies. The observation of the participants during the CI stage ensured that the data gathered was in context of the natural work environment.
- The methodology can be applied according to the requirements and limitations of the research. In this study, due to the nature of the job, time, and resource limitations, the observation session did not yield all the required information. Questionnaires and semi-structured interviews were added to the CI stage and were found to be useful.
- The methodology was helpful in understanding the existing work system of the small construction companies. It was also helpful in identifying the training needs of people in small construction companies.
- As discussed in section 6.7, the CD methodology can be used as a design methodology with other frameworks also.

- CD is a state-of-the-art approach to gain an understanding of how users interact with the environment. Its structured process helped in analyzing and interpreting the data step-by-step with minimal supervision and training.

The first step of the CD methodology, CI, was the most important stage. During the CI, the participants were observed as they performed their everyday work activities. This was extremely helpful as the data gathered was in the context of the work environment. Some alterations were made to the methodology (discussed in CD Literature Review and Methods), but overall the methodology was followed step-by-step as suggested by Beyer and Holtzblatt (1998).

The results of this study are applicable in the context of the small construction industry as a whole. The CIs were conducted across five different trades. Furthermore, the participants were recruited from six different small construction companies. In terms of roles and responsibilities, the sample consisted of one owner/ supervisor, one project manager/ supervisor, three forepersons, and seven tradespersons. Hence, the training system designed using the CD methodology is applicable to the small construction industry as a whole and not specifically to an individual construction company. The training system would be generic across various trades, and for people with different roles and responsibilities. The emphasis was on the context of work in general for small construction companies. Therefore, as the training system would be developed, it would be disseminated to the people in small construction companies with the intention of reducing the fatality rate for everyone in the small construction industry.

In terms of the cost and feasibility of developing the training system using the CD methodology, a hypothetical cost-justification is presented in this section. Since the small construction companies are usually financially weak, the government organizations such as NIOSH or OSHA would be targeted to design and develop the training system using the CD methodology. However, it is important that the CD methodology is a feasible methodology from the cost aspect also. The technique used to conduct the cost analysis is adapted from Mayhew and Mantei (1994). The following

assumptions were made in order to conduct a detailed cost-justification analysis:

- The training system design and development process would be conducted by three research professionals at the rate of \$50.00 an hour. According to Holtzblatt (2003), ideally a team of 3 – 4 people should work on a project that involves the CD methodology. To get an estimate for hourly rate, Salary.com was used and the job title was entered as Intermediate Level Research Associate (www.salary.com). The national high salary reported was \$92,805 per year. With that estimate, the hourly wage was calculated to be \$50 approximately (exactly \$48.33).
- The implementation of the design of the training system would take an additional four weeks at least, which was not done for this study. According to Holtzblatt (2003), even for a big project, all the CD steps can be implemented in 2 – 3 months. For this study, the approximate duration for data collection, interpretation, and design was 6 – 8 weeks while working for 20 hours each week.
- The end result of the training system is expected to reduce nonfatal injuries by at least 1% after the training system is implemented. This is a conservative estimate as it is difficult to predict the exact effectiveness of the training until it is implemented. However, there is evidence that training can improve safety at the work place (Wolford et al., 1997). Wolford et al. (1997) compared painters from Alaska, Oregon, and Washington, to examine the effectiveness of training and found that painters who had received training were 2.7 times more likely to wear respirators. The painters with training also used fans 1.65 times more than painters without training. The findings from the results stated above, imply that effective training might reduce injuries at the work place.
- According to BLS (2004), 80% of the construction companies employed 10 or fewer workers. The fatality rates obtained from BLS (2006) reported fatal and

nonfatal injuries for the construction industry. Hence, with the majority of the construction industry comprised of small construction companies, the fatality rate obtained from BLS (2006) is assumed to be a close estimate for the small construction industry.

Table 15 shows an estimated cost of the entire CD process for the design and development of the safety training system for small construction companies.

**Table 15:** Cost estimation for the CD process

PHASE	TASKS	COST	Hours/ Numbers	TOTAL
<b>Data Collection</b>	<b>Contextual Inquiry</b>			
	Participant observations and interviews	\$20	12 Participants	\$240
	Transportation and other expense			\$500
	3 Researchers @ \$50/ Hour	\$150	30 Hours	\$4,500
<b>Requirements Analysis</b>	<b>Interpretation and Work Modeling</b>			
	3 Researchers @ \$50/ Hour	\$150	30 Hours	\$4,500
	Material Cost	\$300		\$300
	<b>Affinity and Work Model consolidation</b>			
	3 Researchers @ \$50/ Hour	\$150	20 Hours	\$3,000
	Material Cost	\$300		\$300
<b>Design</b>	<b>Visioning and Storyboarding</b>			
	3 Researchers @ \$50/ Hour	\$150	20 Hours	\$3,000
	Material Cost	\$300		\$300
	<b>User Environment Design</b>			
	3 Researchers @ \$50/ Hour	\$150	10 Hours	\$1,500
<b>Testing and Evaluation</b>	<b>User Interface Design and Mockup</b>			
	3 Researchers @ \$50/ Hour	\$150	20 Hours	\$3,000
	Material Cost	\$300		\$300
<b>Implementation</b>	<b>Design and Development of the training system</b>			
	3 Researchers @ \$50/ Hour	\$150	80 Hours	\$12,000
	Material Cost	\$5,000		\$5,000
<b>Total cost for the training system</b>				<b>\$38,440</b>

After estimating costs in Table 15, the next step was to estimate benefits. To estimate an approximate benefit, the number of work days lost due to nonfatal injuries

was obtained from the BLS (2006). According to the BLS (2006), the median days away from work due to injuries in the construction industry was 10. The BLS (2006) reported that the average hourly earning by a production worker in construction was \$19.46. Hence with that information, an estimate in terms of monetary loss due to a nonfatal injury for a construction worker is calculated to be:

$$(10 \text{ work days lost}) \times (\text{average pay @ } \$19.46/\text{ Hour}) \times (8 \text{ hours/ day}) = \$1,557$$

The amount of loss calculated above is not only a monetary loss by a construction worker, but also a loss incurred by that particular construction company in terms of productivity. According to BLS (2006), in 2004, workers in the construction industry incurred a total of 401,000 nonfatal injuries and illnesses. With the amount calculated above, the following would be the loss in terms of cost due to injuries:

$$(401,000 \text{ injuries}) \times (\$1,557 \text{ loss due to injury}) = \$624,357,000$$

With the application of the CD methodology, the end result (safety training system) would be applicable to the small construction industry as a whole. As mentioned earlier, if the training system is expected to reduce the number of injuries by at least 1%, then the estimated amount of money saved would be:

$$(.01) \times (401,000 \text{ injuries}) \times (\$1,557 \text{ loss due to injury}) = \$6,243,570$$

The total benefit derived by the small construction industry, if the training system is implemented and the goals are met would be:

Amount saved with 1% decline in injuries =	\$6,243,570
Less: Training system cost =	\$38,440
Total Benefit =	\$6,205,130

The total benefit of \$6,205,130 is a significant amount of savings for the small

construction industry. However, it should be noted that the calculation done above is a hypothetical estimation. In reality, factors such as design and development of the training system, the number of small construction companies that would participate, and the percentage decline in injuries, would determine the cost feasibility of the CD methodology.

Another important factor that should be considered is the time value of money. The monetary loss projected above is based on the hourly earnings of the workers as of 2005 (BLS, 2006). Hence, the hypothetical estimate of total benefit derived is projected for 2006, if this training was fully implemented and the 1% decrease was achieved. However, the value of money in terms of total benefits mentioned above would increase if the training system was implemented and the desired results were achieved in future years. The time value of money is calculated based on factors such as the current value of money, rate of return (interest rate), and time of return (Karat, 1994). The following formula can be used to calculate the time value of money based on the time of implementation of the training system.

$$F = P * (1 + i)^n$$

where

$F$  = Future value,

$P$  = Present value,

$i$  = Interest rate, and

$n$  = time period

Eight of the twelve participants recruited for this study reported that each of their respective companies incurred two or more accidents in the last year. The calculations done above are hypothetical and based on information gained from past years from BLS. If the information of amount of days lost and the monetary loss due to days away from work is assumed to be true for this sample of participants, then the monetary loss for the participants due to injuries would be \$3,114. Considering the total benefit stated above, it would be feasible for government organizations like OSHA and NIOSH to



implement the training system as suggested in this study using the CD methodology. Thus, the small construction industry would collectively save \$6,205,130, increase productivity, and most importantly, save the lives of construction workers.

Considering the sample of this study, the perceived value of the training system for a small construction company would be \$3,114, which is the amount of productivity lost by a small construction company due to the injuries. Therefore, the training system would be required to be priced by the developers taking into account the perceived value of the training system. Some of the other determining factors of the price would be the potential market size, the additional amount invested in product development, and other costs such as promotion and maintenance. The amounts mentioned above are computed to provide hypothetical cost/ benefit information. The estimates show that the implementation of this training system would reduce monetary losses for the workers and increase productivity for the small construction companies. But, at the end, if this training program achieves its primary goal of saving lives, then the result is invaluable in terms of money and productivity.

#### **6.4. Limitations of CD**

Although the CD methodology was helpful in identifying the design requirements of the small construction companies, there were some weaknesses and limitations to its application. Partly, the limitations were due to the fact that the application of CD is new in the field of construction safety. Even though the process is guided by the insight of the users, in the end it relies highly on the interpretation of the data by the interviewer. Some researchers may see it as an advantage, assuming that this aspect was intentionally left open, while others might argue that the process is vague. For example, the founders of CD have not suggested a rule for determining the time for observation during the CI. It might be best that this is determined based on available resources. In this study, the participants were observed only for an hour. Construction jobs are

different from office jobs. Construction jobs are considered one of the most hazardous jobs in the U.S. (Minchin et al., 2006). It is difficult to interrupt the persons while they are performing their work activities. The information gained by this observation session was limited. Two questionnaires and a semi-structured interview were added to gain the required information that was not available through the observation sessions.

Furthermore, the information gained during the observation session was limited to the participant that was being observed. However, to understand the culture, workflow, and other aspects of the work system, it is important that the organization is analyzed as a whole. During the CI, information was gained on the workflow, roles, responsibilities, sequence of work, artifacts, and the safety climate, but with focus on the user being observed and interviewed, not the entire organization.

In terms of the design of the training system, the CD methodology helped identify the user requirements for safety training. However, in this study of designing a training system for small construction companies, the innovation in the design was limited. The CD methodology has been found to be beneficial in developing software applications for corporations such as SAP (Holtzblatt, 2003), which is different than implementing CD in informal work systems like small construction companies. The small construction industry is different from formalized work systems in terms of work dynamics, environmental factors, and workforce.

## **6.5. Applying CD for Construction Research**

The fourth and final research question was about how the CD methodology could be implemented in construction research. The CD methodology was overall found to be effective for the design of the training system. But certain alterations and modifications were made to the process of CD in order to meet the requirements of this study. As explained earlier, the changes were made to the CI stage and the User Interface Design

and Mockup stage. The following are some of the notes based on the experience gained during this research project that could be considered while applying the CD methodology for construction research.

- **Observation of the participant:** Since construction jobs are among of the most hazardous of all jobs (Minchin et al., 2006), the observation sessions were different. The interviewer was not able to interrupt the participants due to the hazardous nature of the construction jobs. Furthermore, the participants worked on heights also. In such a case, the interviewer was not able to follow the participant on the roof. This is an important point to be noted, as the information gained through CI is highly dependant on the observation sessions.
- **The cultural model:** According to Beyer and Holtzblatt (1998), the cultural model is developed based on the information gained from the participant being observed. Hence, the information gained is from the perspective of the participant being observed and interviewed, and is specific to that time frame. This is considered more as *climate* than *culture* of the organization as it is subject to change (Zhang et al., 2002). Organization culture refers to the values, beliefs, goals, and mission that are commonly shared by all the members of the organization (Zhang et al., 2002).
- **Time:** Another important aspect of conducting the CI is time. In this study, the observation session was conducted for an hour for each participant. As mentioned above, the information gained through an hour-long observation might not yield the required information. Besides, if the participants are being compensated, then the number of observation hours becomes even more critical in terms of budget.
- **Questionnaires:** As mentioned earlier, the observation of the construction workers was different as their jobs are high-risk. For this study, two questionnaires (demographic and safety) were used in addition to the

observation session. The questionnaires were found to be useful since the one-hour observation did not provide the participants' background information, which was addressed by the demographic questions. The safety questionnaire consisted of questions about worksite safety, workers' attitudes towards safety, supervisor attitudes, risk perception, hazard recognition and prevention, and work practices. It is important to consider the information that is required to conduct research and decide whether one would require questionnaires to gain supplemental data to achieve the research goals.

- **Semi-structured interviews:** Similar to questionnaires, the semi-structured interviews were used to gain some of the information that was not gained through the one hour long observation session. The semi-structured interview allowed the interviewers to probe the participants about their work practices, safety training methods, and most importantly receive suggestions for the design of the training system prototype. Holtzblatt (2003) suggests that the interviewer should not go with a structured interview, but let the participant lead the interview. However, keeping the time factor under consideration, it is important that the interviewers go to the construction site with a semi-structured interview script so that required information can be retrieved from the CI.
  
- **Organizational structure:** Even though it has been established that small construction work systems in the U.S. are typically not formalized through incorporation (BLS, 2001), the CD methodology does not clearly address this issue. The consolidated flow model discusses roles and responsibilities of the people in the organization. However, it does not clearly define whether the organization is formalized. To address that issue, a technique suggested by Hendrick and Kleiner (2002) in the MEAD framework can be incorporated- Construct Role Networks. This technique, as suggested by Hendrick and Kleiner (2002) can be incorporated with the flow model of the CD methodology to gain a clear perspective on the lines of formalism that exist in the organization between people.

In terms of applying the CD methodology to conduct research in the construction field, the above-mentioned notes can help the researchers to plan the research project more systematically. Certain issues relevant to this research might not be relevant to another construction research project if its end goals are different. The researchers should analyze and map the steps so that the goals of the research are met and apply the CD methodology accordingly. The CD methodology is a design methodology and it can be applied within other frameworks also to conduct construction research.

## **6.6. Relationship of CD to MEAD**

Following up on the discussion of the previous section, and as discussed earlier in the Literature Review section, the CD methodology can be used as a design methodology, and it can also be applied within other frameworks such as MEAD. This section provides a brief overview of some of the phases of the MEAD framework developed by Hendrick and Kleiner (2001) that can utilize the CD methodology towards designing the work system. The explanation provided below is a brief overview and not a detailed explanation. The aim is to show that CD can also be used in conjunction with other system design frameworks.

The first step of CD, CI, can be used as a data collection tool in the MEAD framework with minor modifications such as questionnaires and a semi-structured interview. The CI also incorporates an observation session, which is an added benefit as it allows the researchers to gather data that is in the context of the work environment (Holtzblatt, 2003). The next two steps of CD, interpretation and work modeling, and affinity and work model consolidation, can be used to facilitate information in different phases of the MEAD framework.

The information gained from the consolidated flow model and the cultural model,

as defined by Beyer and Holtzblatt (1998), can be utilized in the first phase of MEAD-Scanning Analysis. Phase one of MEAD is aimed to identify the mission, vision, and values of the work system. In this study, it was found that the generalized mission of the small construction companies is to perform a high quality job and develop a good reputation to earn further business from the customers. Information gained from the second and third stages of CD can be used for environmental scan as defined in MEAD, and different sub-environments can be recognized. In this study, one of the sub-environments recognized is the political sub-environment, and the main stakeholders identified are the insurance agencies, and the city and state government. However, insurance agencies are the main stakeholders in terms of safety. The city and state government address building codes and ethics more than safety. In terms of the economic sub-environment, the high emphasis on speed of work and money makes safety less important.

The consolidated flow model from CD resembles the organizational chart that is prepared in the first phase of MEAD. The only difference is that in CD the consolidated flow model emphasizes the flow of work within the hierarchy of the organization. Comparatively, MEAD clearly defines and maps the levels of hierarchy in the organizational chart. The flow model from this study revealed that the small construction company workers typically perform more than one type of job. These workers are mostly specialized in certain jobs such as framing, painting, or plumbing. However, due to the small size of the companies, they do have to perform different jobs. This information can be used in phase two of the MEAD- production system type and performance analysis where Hendrick and Kleiner (2001) define system type in terms of complexity, centralization, and formalization.

In phases four, five, and six of MEAD, the variance data is collected, key variances are identified, and role networks are constructed to control the variances (see Hendrick and Kleiner, 2001). A *variance* is defined as an unexpected or unwanted deviation from standard operating conditions, specifications, or norms (Hendrick and Kleiner, 2001). The CD methodology used in this study does not particularly address

these phases of MEAD. The analysis conducted in these phases of MEAD is more in-depth, more detailed, and more focused, compared to the information that CD provides in terms of variances and role networks. However, CD does provide some information that can be used for these phases of the MEAD framework. In this study, the affinity diagram and the consolidated models helped to recognize some of the variances for lack of safety in small construction companies. They are: lack of training due to the small size of the company, speed of work, and emphasis on money. Most experienced workers did not feel the need for safety training and also did not recognize their jobs to be hazardous. Also, the emphasis on safety training was low as speed of work and the amount of money earned were emphasized more than safety. The MEAD framework conducts a much more detailed analysis of variances and methods to control them in phases four, five, and six. Evidently, CD is an informational tool that can be used to gain information that can be applied at a much deeper level depending on the needs and requirements, and the focus and scope of the study.

Phases seven (Function Allocation and Joint Design) and eight (Roles and Responsibilities) of MEAD can take advantage of the stages four (Visioning and Storyboarding) and five (User Environment Design) of the CD methodology. Visioning and storyboarding are concerned with ideas about the design of the system based on the information from the interpretations sessions of CD. Phase seven of the MEAD framework is concerned with function allocation, developing organizational design for the system, and designing personnel changes. Phase eight of the MEAD is concerned with evaluating roles of the personnel in terms of perception and providing training and support to the personnel. In these phases of the MEAD, information from preceding phases is used to control the variances with appropriate allocation of functions between personnel. Similarly, for the CD method in this study, the design ideas to increase safety at the workplace were generated from the information gained from the interpretation sessions. In this study, during the visioning and storyboarding, design ideas considering roles of personnel were suggested. The owners' and supervisors' responsibilities were increased in terms of receiving training and then providing it to their respective companies. The roles and responsibilities of tradespersons were improvised by

implementing the buddy system for on-site safety and toolbox talks for on-the-job training.

Stage five of CD, the UED (user environment design), particularly emphasizes the structure and sequence of the training system to enhance safety for small construction companies. Information from this stage can be useful in MEAD phase nine (Design/ Redesign) where support subsystems, interfaces and functions, and internal environment are designed or redesigned.

Following the user environment design, the last stage of CD was implemented: user interface design and mock-up. In this stage, the first paper prototype of the training system as suggested by Beyer and Holtzblatt (1998) was prepared. This prototype was evaluated by two experts and two users. Beyer and Holtzblatt (1998) suggest iterating the design and evaluating it with users until the design goals are achieved and the needs and requirements of the users are met. However, due to limitations and restrictions in this study, the iteration was done only once. This technique can be used in the last phase of MEAD, where Hendrick and Kleiner (2001) have suggested implementing, iterating, and improving the design of the work system.

Overall, the CD methodology would have to be applied more extensively if it were adapted in the MEAD framework to gain an understanding of the work system. The CD methodology is typically used for developing software applications (Holtzblatt, 2003) for corporations with formalized work systems. Its implementation for designing a training system for informal work systems such as small construction companies may require modification. In this study, the CD methodology was useful in requirements acquisition, which is important to gain an understanding of the users of the system. However, in order to design and implement a system, a more detailed analysis of the work system is required, which can be provided by frameworks such as MEAD. For example, the organizational analysis performed by MEAD is more detailed when compared to the CD methodology. Every methodology has strengths and weaknesses. CD's strength lies in the emphasis that it places on the context of the work. It is recommended that future



research should take advantage of the CD methodology and apply it in conjunction with other frameworks such as MEAD based on the research goals. The founders of CD have suggested that CD should be modified and applied based on research goals (Holtzblatt, 2003), which makes CD a strong Macroergonomics tool to conduct a needs analysis of the users of a work system and to design systems efficiently.

## 7. CONCLUSION

### 7.1. Future work and lessons learned

Since the application of the CD methodology to designing a safety training system for small construction companies is new, certain lessons were learned. There were lessons learned during the research, leading to suggestions about applying CD in the future in construction research. Some of the limitations and restrictions of this study were also discussed in preceding sections.

CD involves observation of participants as they perform their everyday work activities. In this study, different trades were observed within a sample of twelve participants. The power of its effectiveness can be elevated to a higher level by using the methodology to answer one trade-specific question. For example, what are the causes for the high amount of falls in the construction industry? Then, the researchers would be able to observe people working on heights in particular, and gain an insight. Since the observation of the participants is so vital to the CI, the activity observed has to be the focus of the research. In this study, the participants were observed as they performed work activities. However, the observation session did not provide all the insight necessary for this research, such as the culture of the organization, existing training methods, suggestions for the design of the training system, and relationship dynamics outside of work. To a certain extent, the information was supplemented using questionnaires and semi-structured interviews. For future research, it is recommended that semi-structured interviews and demographic questionnaires be used to gain more information in addition to what is observed during the observation session.

The results of this study, consistent with Zohar's (1980) past findings, suggested that owners, supervisors, and forepersons had a significant influence on their employees. Future studies can build on this information, use the existing data from this

study, and explore that particular area to a greater extent for improving safety in the construction industry. For design implications, the study puts forth all the different ideas and recommendations coherently made by the people that work in the small construction companies. The design ideas are not new, but the coherent nature of the training system that brings them together in the form of training would be beneficial.

Another important suggestion for future research deals with the evaluation component of the existing framework of CD. Currently, CD suggests that users should evaluate the system for as long as the design requirements are met—an iterative design process. In this study, the first prototype was evaluated by only two expert evaluators and two users. The feedback was insightful, but the suggestions made were different based on the evaluators' backgrounds. A few more iterations of the prototype design would have provided an understanding of positive and negative features of the design of the training system. Furthermore, the most effective evaluation process in the case of a training system would be to eventually recruit an experimental small construction company to implement the training system, and compare it with another small construction company that does not particularly implement the training system recommended by this research. The results can be compared in terms of money spent on training, number of injuries in a year, and the attitude toward safety of the employees.

Future research can address some of the issues that were faced in this research and perform a study to compare the consistency of the results. Furthermore, suggestions from the experts and users about the design of the training system should also be considered for future research. In this study, only three of twelve participants reported using computers. However, computer-based online training has been found to be beneficial for safety training at high-risk workplaces (Liebeskind, 2005). Hence, it is recommended that future studies should explore computer-based training in small construction companies to improve safety at the workplace.

## 7.2. Research conclusion

In the conclusion of this thesis project, some important findings need to be noted. Safety training for small construction companies requires attention at a higher level than what currently exists. In this sample of twelve participants from six different companies, it was found that most of the participants have had accidents in the past. In the safety questionnaire, the participants rated lack of training and speed of work as leading factors associated with injuries at the work place. In terms of training, nine of the 12 participants agreed that formal safety training would be helpful. However, it was found that speed of work was emphasized more than safety at the work place.

The observation sessions revealed that the people working in small construction companies did not adequately use the appropriate PPE. This again is an indicator of a lack of resources and a reason for accidents in small construction companies. The affinity diagram revealed that working with family and friends can be difficult. At the same time, it was also found that working with family and friends makes people more concerned about each other's safety. The problem is that even though they are concerned about safety, familial relationships make it difficult to exert authority for safe working procedures. Additionally, the emphasis on speed of work and money, and the lack of resources due to the small size of the companies make it difficult for small construction companies to implement formalized safety training systems. Hence, it is important that safety training systems are designed in alignment with the requirements of small construction companies so that safety can be improved at the workplace.

In terms of the design of the safety training system, the CD methodology was helpful in identifying the training requirements of small construction companies. To improve safety at the workplace, the majority of the participants suggested safety meeting, followed by their recommendation of demonstration of work practices. In terms of innovation in the design of the training system, the CD methodology was limited in this research. The methodology was useful in requirements acquisition, which is important in order to design a training system. However, in this study the aim was to

design a training system for small construction companies, which is different than designing software applications. The CD methodology is traditionally implemented in an office work environment with a formalized work system, which is different than implementing CD in informal work systems like small construction companies. According to Holtzblatt (2003), the CD methodology is flexible in its application and should be implemented based on the goals of the research. For construction research, it is recommended that the CD methodology be used with other frameworks such as MEAD.

Overall, the findings of this research, such as workflow, structure, and social environment of small construction companies, enabled the design of the safety training system prototype. Furthermore, with the primary focus on safety, the method also provided a comprehensive overview of the small construction work systems. With the information gained from this research about safety and small construction companies in general, future research can address the issue of safety in small construction companies to a greater extent and thus participate in the effort of reducing the number of fatalities in the construction field.

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## Appendix A: Demographic information questionnaire

Demographic Information Sheet                      Participant #: \_\_\_\_\_

1). Company name (optional) / Type (family owned, govt., other)

\_\_\_\_\_

2). What department of construction field do you work in? Job duties?

\_\_\_\_\_

3). The owner(s) is your    \_\_\_ Friend    \_\_\_ Relative    \_\_\_ Sibling    \_\_\_ Parent  
 \_\_\_ Spouse    \_\_\_ Daughter/ Son    \_\_\_ N/A (I am the owner of the company)

4). Are you related to any of your co-workers(s)?    \_\_\_ Yes    \_\_\_ No

5). The co-worker(s) is your    \_\_\_ Friend    \_\_\_ Relative    \_\_\_ Sibling    \_\_\_ Parent  
 \_\_\_ Spouse    \_\_\_ Daughter/ Son    \_\_\_ N/A (Not related in anyway)

6). What is the size (# of employees) of the company? \_\_\_\_\_

7). Age: \_\_\_\_\_

8). Gender:    \_\_\_ Male                      \_\_\_ Female

9). Ethnicity:

- |                      |                         |
|----------------------|-------------------------|
| a) African American  | e) Hispanic/ Latino     |
| b) American Indian   | f) Pacific Islander     |
| c) Asian             | g) Non – resident Alien |
| d) Caucasian / white | h) Other _____          |

10). Any disabilities?    \_\_\_ Yes                      \_\_\_ No

If yes, explain: \_\_\_\_\_

11). Education:

- |                         |                       |
|-------------------------|-----------------------|
| a) Some high school     | d) College graduate   |
| b) High school graduate | e) College graduate + |
| c) Some college         | f) Other _____        |

Continue on back page.....

12). What is your marital status?

- a) Single                                  c) Divorced  
b) Married                                d) Widowed                              e) Other\_\_\_\_\_

13). How long have you been working in this company?

- a) Under 1 month                        e) 1 – 4 years  
b) Under 3 months                      f) 5 – 10 years  
c) 3 – 6 months                         g) 10 – 20 years  
d) 6 – 12 months                        h) over 20 years

14). Does your work involve safety hazards? \_\_\_\_\_Yes                                  \_\_\_\_\_No

If yes, explain: \_\_\_\_\_

15). How many accidents have you had in the past while doing construction jobs?

\_\_\_\_\_

16). Briefly explain an accident that you experienced in the past.

\_\_\_\_\_

\_\_\_\_\_

17). Number of construction work accidents at your workplace in the last year?

\_\_\_\_\_

18). Do you use computers, cell phones, PDAs or other electronic equipment? If yes, what?

\_\_\_\_\_

*Please rate the following questions based on the given scale starting from 1 being the lowest to 10 being the highest.*

19). Satisfaction with current construction job

(Not satisfied)

1      2      3      4      5      6      7      8      9      10

(Fully satisfied)

20). How likely are you to get injured during work at your construction job? (*Perceived vulnerability to injury*)

(Least likely)

1

2

3

4

5

6

7

8

9

(Most likely)

10

## Appendix B: Safety Questionnaire

### SAFETY QUESTIONNAIRE

PARTICIPANT #: \_\_\_\_\_

**1. What are the factors/conditions associated with injuries in your workplace?**

- |  |   |                                   |
|--|---|-----------------------------------|
| <input type="checkbox"/> Speed of work       | <input type="checkbox"/> Time pressures       | <input type="checkbox"/> Weather  |
| <input type="checkbox"/> Slippery surface    | <input type="checkbox"/> Task too heavy       | <input type="checkbox"/> Coworker |
| <input type="checkbox"/> Lack of help        | <input type="checkbox"/> Housekeeping         | <input type="checkbox"/> Fatigue  |
| <input type="checkbox"/> Wrong tool for task | <input type="checkbox"/> Storage of materials | <input type="checkbox"/> Lighting |
| <input type="checkbox"/> Lack of training    | <input type="checkbox"/> Other: _____         |                                   |

**2. In your company, employees/ workers have problems in communicating with the managers/ supervisors.**

Strongly disagree      Disagree      Neutral      Agree      Strongly agree

—————  —————  —————  —————

**3. What are the onsite safety controls enforced by your company? (Check all that apply.)**

- |   |   |   |
|---|---|---|
| <input type="checkbox"/> Designated safety person         | <input type="checkbox"/> Hazard communication plan              | <input type="checkbox"/> Fall protection plan |
| <input type="checkbox"/> Safety manual                    | <input type="checkbox"/> Wearing personal protective equipments |   |
| <input type="checkbox"/> Tool Box Talks (Safety Meetings) |   |   |
| <input type="checkbox"/> Other _____                      |   |   |

**4. Please rank the following items from 1 (least appropriate) to 4 (most appropriate) in terms of possible safety measures to increase safety at workplace.**

- \_\_\_\_\_ Management enforcing safety
- \_\_\_\_\_ Safety training/education (classes, meetings)
- \_\_\_\_\_ Using computers, videos and other technology to distribute safety information
- \_\_\_\_\_ Suggest appropriate working postures

**5. Please rank the following items, from 1(least important) to 4(most important).**

- \_\_\_\_\_ Having extra time after completing a task/project is important to me
- \_\_\_\_\_ The amount of money I make from a project is important to me
- \_\_\_\_\_ Having breaks during work shifts is important to me
- \_\_\_\_\_ Worksite safety is important to me

**6. You know how to improve safety at your construction site.**

Strongly disagree      Disagree      Neutral      Agree      Strongly agree

—————  —————  —————  —————

**7. You are responsible for your employees' health and work safety.**

Strongly disagree      Disagree      Neutral      Agree      Strongly agree

—————  —————  —————  —————

**8. You tell your employees to follow the safe working procedures when they are**





## Appendix C: Semi-structured interview script

### Contextual Inquiry semi-structured interview

Items check list before beginning the interview

1. Informed consent
2. Tax sheet
3. Demographic Information sheet
4. Safety Questionnaire
5. Observation session notes, recording, etc

*Note for the interviewer:* As the interviewer observes the participant doing his/her work, some questions should be noted down. The semi structured interview should add as supplemental material to the contextual inquiry. Hence, certain questions cannot be pre-determined. The observer/ interviewer should make some questions based on the observations, only then will the context of work receive focus in the interview. These questions can be about the work activities, body language of the participant while working, gestures, habits, etc.

#### *Purpose of Study:*

This phase of the study is called the Contextual Inquiry. It is the first step of the six steps followed in Contextual Design. Contextual Design is considered to be a state-of-the-art approach of understanding how users interact with the environment, while keeping the social factors also under consideration. In this stage we are trying to see how the construction workers actually work in the natural work environment. Data collected here will be further analyzed to make recommendations about training in small construction companies.

**Questions drafted during observation:** (*Write questions in the space provided*)

**Question:**

What is your responsibility in this company? Explain.

**Probe:** *Responsibility in terms of doing a job, practicing safety and communicating with others?*

**Question:**

What does your company emphasize the most in relation to your job?

**Probe:** *How does it emphasize? Explain.*

**Question:**

What motivates you the most in this job? (OR) What is your motivation in doing this job? Explain.

**Question:**

Who influences you the most on this job? Why?

**Probe:** *How does this affect your work habits? Explain.*

**Question:**

When you hear the word “safety” on the job, what are the first thoughts that come to your mind?

**Question:**

What are some safety rules you are aware of? Prompt: For your job, could you give me some examples of the safety practices or rules you have to follow?

**Question:**

Do you get safety training from your company? Or have you received training from other places in the past?

**Yes probe:** Can you describe the types of training you have had?

- Who does the training? Anyone specific?
- How did they train you?
- Do you use computers or any other technology for safety training?

*Probe regardless: Explain?*

**No probe:** Why do you think you did not receive any safety training? What problems do you see in your company that makes it hard to do safety training? Please be specific.

**Question:**

What tools and equipment do you use commonly at workplace? Explain

**Probe:** How can any of the tools enhance workplace safety?

**Question:**

What are some of the advantages of working in a small construction company with your family or friends?

**Regardless of answer, probe:** Why?

**Question:**

What are some of the disadvantages of working in a small construction company with your family or friends?

**Regardless of answer, probe:** Why?

**Question:**

If you had a choice, what kind of safety training would you like to receive?

**Prompt:** What things would you like to be trained in to avoid accidents and injuries based on your experience?

- a. Probe: Can you describe to me in more detail what you think you need to know to protect yourself from injuries?

**Question:**

If you could design your own training program for people who work in small family-owned or friend-owned businesses, what would it be like? For example, some people have classes, some put things on computer and you can do it on site during a break, some give you things to read. In your environment, what would be easiest for you? **Prompt:** How would you like safety and health information to be given to you if you could receive training?

**Question:**

Sometimes you just learn to be safe as you are working. You watch out for each other, are careful yourself, practice caution, and don't do anything that can cause an accident.

**Prompt:** Do you still think formal training sessions or training program can help you at work to be safe? Explain.

**Prompt:** If you think training in this environment does not fit, explain.

Is there anything else you would like to add that relates to safety and training in small construction companies?

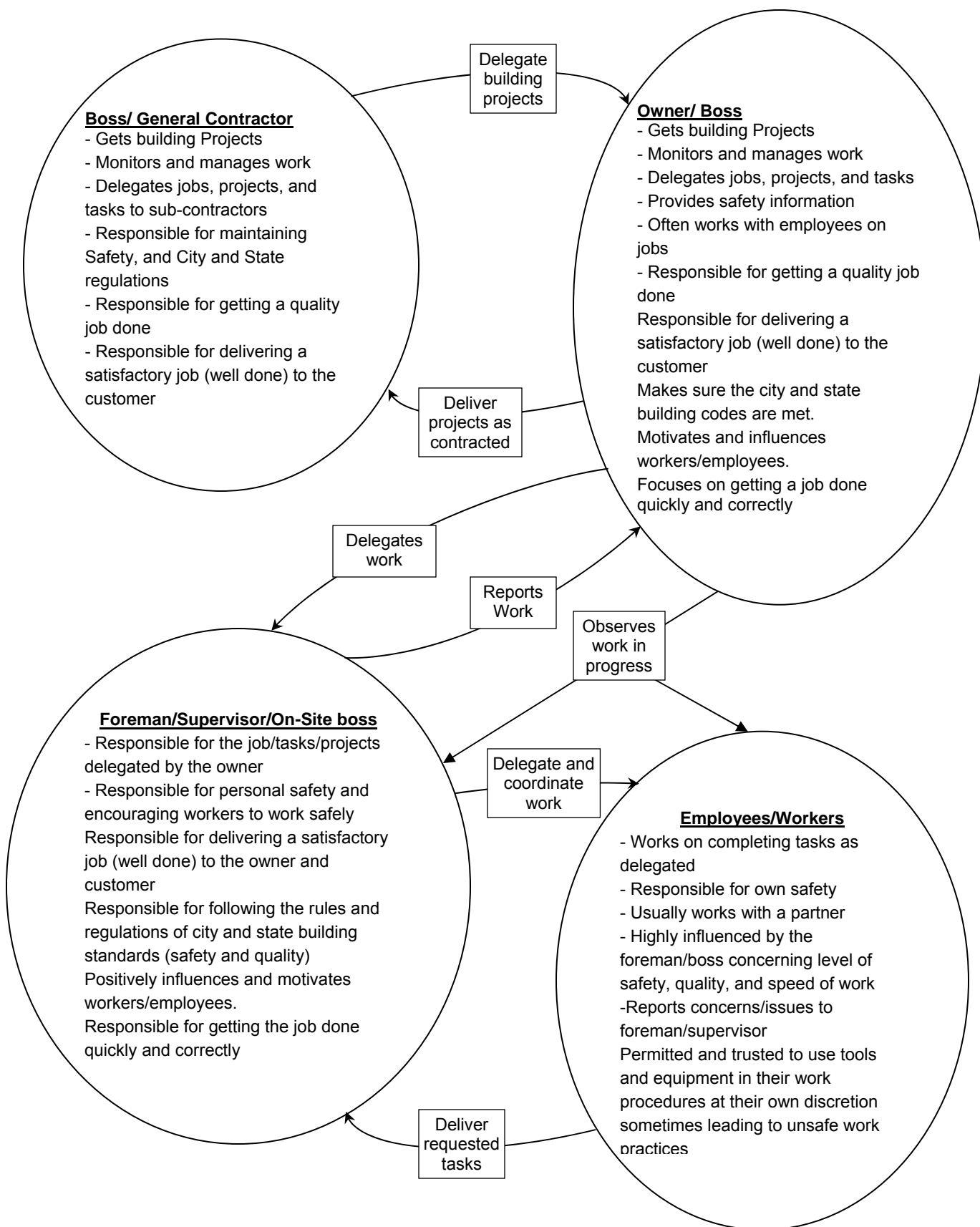
*Pause. Turn off tape recorder when done.*

**Interviewer:** Thank you for participating in this interview! This information will be used to design safety training systems for workers in small construction companies and to better understand the problems faced by small construction companies. If you have any questions or are curious about what we find at the end of this study, you may contact Darshan Baldev, Dr. Tonya Smith-Jackson or Dr, Woodrow Winchester. Contact information is on the informed consent copy that you have.

I'll need to compensate you for your time.

*Pay and get signature.*

### Appendix D: CONSOLIDATED FLOW MODEL



### Appendix E: CONSOLIDATED SEQUENCE MODEL

<u>ACTIVITY</u>	<u>INTENT</u>	<u>ABSTRACT STEP</u>
<b>PLAN TASK</b>	<ul style="list-style-type: none"> <li>• To do a good job</li> <li>• Work fast</li> <li>• Be safe</li> </ul>	<ul style="list-style-type: none"> <li>• Understand the job that is needed to be done</li> <li>• Organize team members for the job</li> <li>• Gather tools and equipment for the job</li> <li>• Gather materials to start work</li> <li>• Get PPE</li> </ul>
<b>PERFORM TASK</b>	<ul style="list-style-type: none"> <li>• Work fast and safe</li> <li>• Decide action to be taken</li> </ul>	<ul style="list-style-type: none"> <li>• Use the tools and equipment to start the job and execute the operations</li> <li>• See if the material gathered is adequate</li> <li>• Get more material as required</li> </ul>
<b>CO-ORDINATE JOB</b>	<ul style="list-style-type: none"> <li>• Co-ordinate work to get it done fast</li> <li>• Watch out for co-workers safety while on the job</li> </ul>	<ul style="list-style-type: none"> <li>• Ask co-worker/partner to get material</li> <li>• Simultaneously work on a task if needed</li> <li>• Give instructions to do the job (delegate)</li> <li>• Receive instructions to on how to do the job (Assist)</li> </ul>
<b>RECEIVE HELP/PROVIDE HELP</b>	<ul style="list-style-type: none"> <li>• Decide if additional assistance is required to help the flow of work on the site</li> </ul>	<ul style="list-style-type: none"> <li>• Help out co-workers to fix a problem and complete a task or a job</li> <li>• If more help is needed on a task or job ask co-workers to help finish that part of the job or task</li> <li>• Resume operation with co-worker/partner working in coordination</li> </ul>
<b>CONTINUE TASK UNTIL FINISHED</b>	<ul style="list-style-type: none"> <li>• Finish the job as planned</li> </ul>	<ul style="list-style-type: none"> <li>• Repeat the process of performing the task until the job is done or finished</li> </ul>

**JOB:** A broad duty on a larger scale. (e.g. finish framing the house)

**TASK:** A small part of the job. A sub-part of the job. (e.g. Frame a wall that goes on the garage foundation)

## **Appendix F: CONSOLIDATED ARTIFACT MODEL**

### **Tools and Equipment Commonly Used by Construction Trades people**

- Tool Bag
- Hammer, mallet
- Power circular saws
- Small hand saws
- Ladder (Step and Extension)
- Nail gun
- Screw gun
- Floor cleat nailer
- Level
- Speed square
- Tape measure
- Framing pencil
- Compressor
- Generator

### **PPE not seen to be used commonly**

- Hard Hat
- Gloves
- Steel toe boots
- Face mask
- Shirt (often workers remove shirts)
- Ear plugs (most jobs observed did not require)

### **Communication and Organization**

- Radio (2-way)
- Planner
- Cell phone
- PDA (Mainly Supervisors)

### **Transportation**

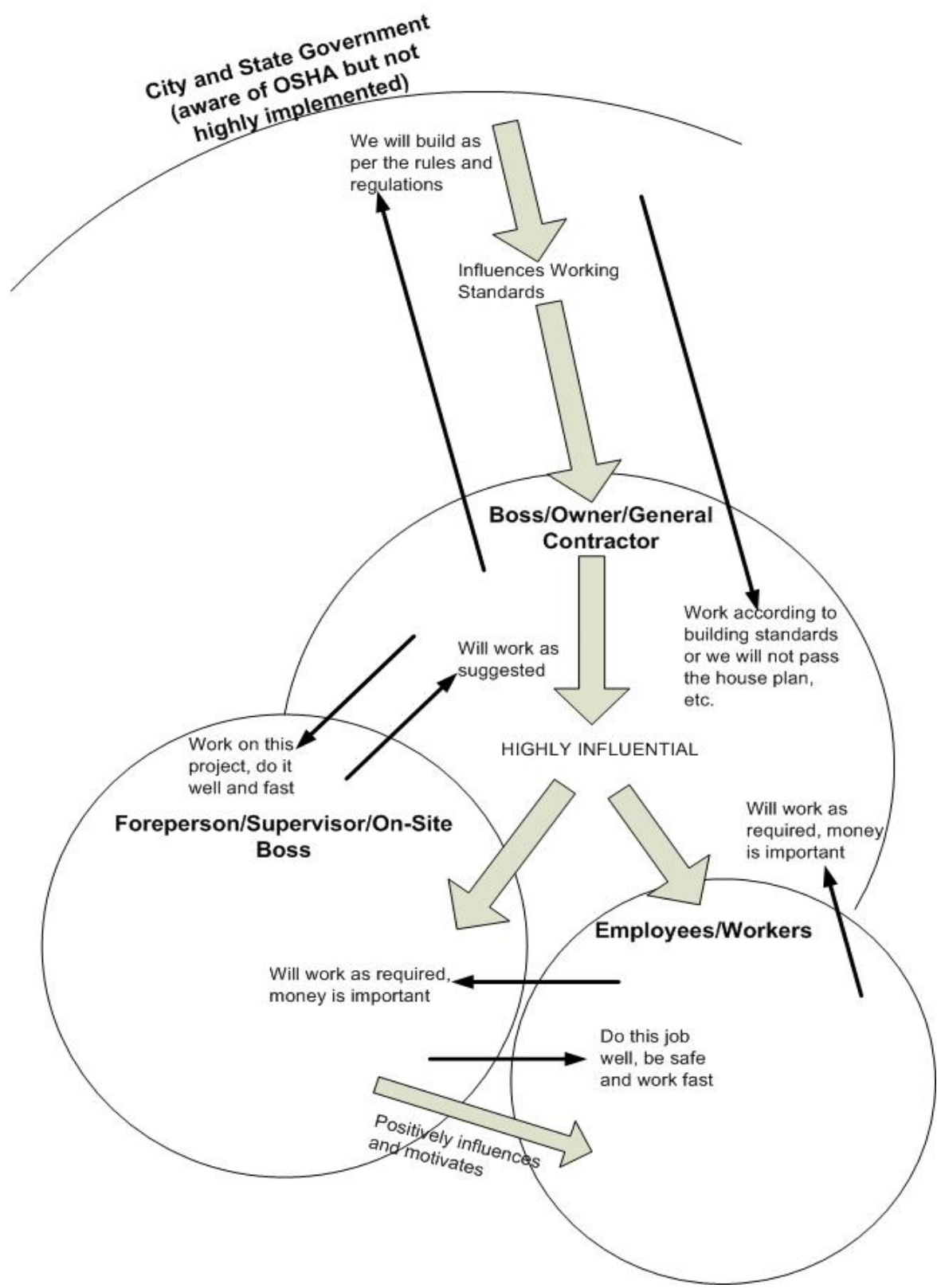
- Work truck
- Excavator
- Cars



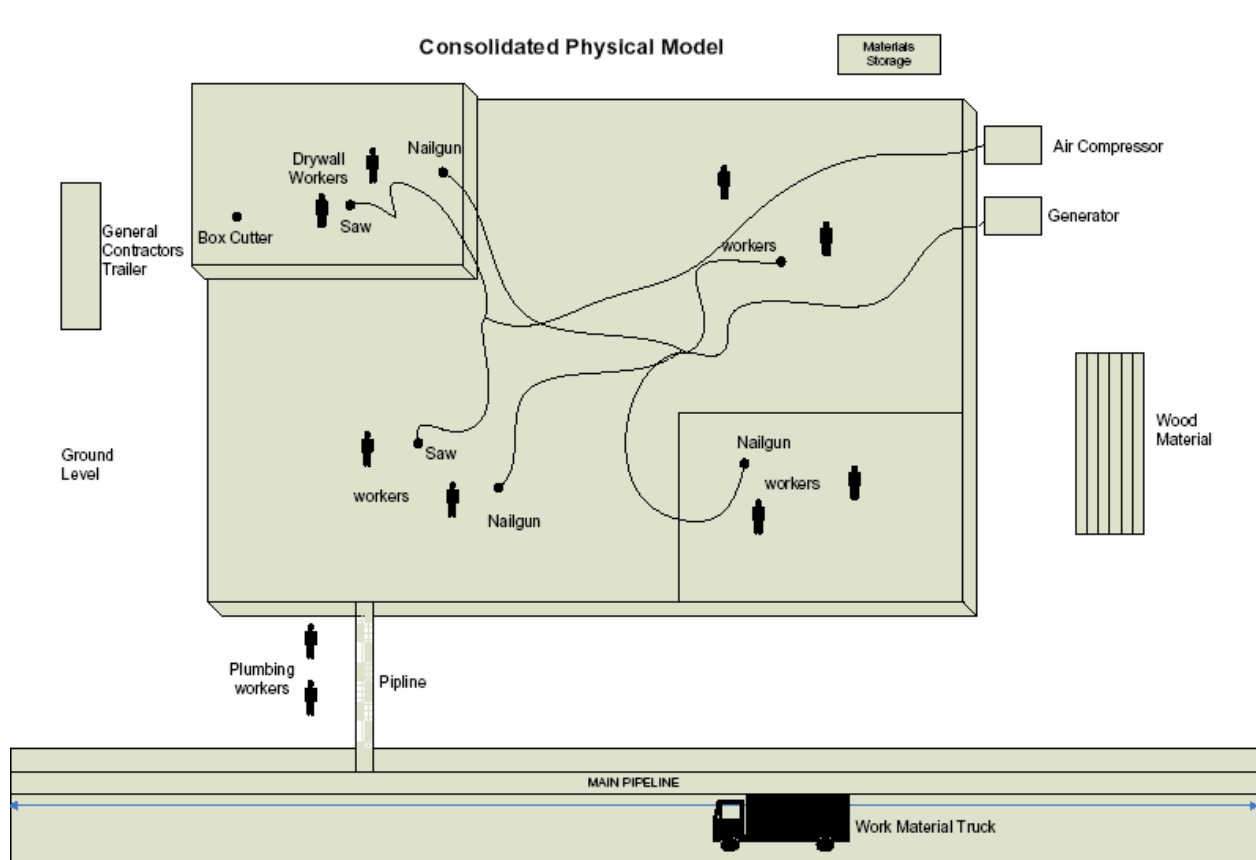
**PPE Used**

- Eye Protection (Sunglasses used commonly)
- Ear Plugs (In heavy noise environment)
- Hard Hat

### Appendix G: CONSOLIDATED CULTURAL MODEL



### Appendix H: CONSOLIDATED PHYSICAL MODEL



### Appendix I: Evaluation form

EVALUATION FORM
-----------------

Name: \_\_\_\_\_

1. The structure of the training system design.

<i>Very Poor</i>	<i>Poor</i>	<i>Fair</i>	<i>Good</i>	<i>Very Good</i>
1	2	3	4	5

**Comments:**

2. The organization of the various components of the training system demonstrated in the prototype.

<i>Very Poor</i>	<i>Poor</i>	<i>Fair</i>	<i>Good</i>	<i>Very Good</i>
1	2	3	4	5

**Comments:**

3. The functionality of the Training System.

<i>Very Poor</i>	<i>Poor</i>	<i>Fair</i>	<i>Good</i>	<i>Very Good</i>
1	2	3	4	5

**Comments:**

4. How do you rate the contextual design method as applied in this project for designing a safety training system for small construction companies?

<i>Very Poor</i>	<i>Poor</i>	<i>Fair</i>	<i>Good</i>	<i>Very Good</i>
1	2	3	4	5

**Comments:**

Other Comments and Suggestions regarding the training system design:

## Appendix J: Semi-structured interview data

	FREQUENCIES
<b>Safety Responsibility</b>	
I am responsible for my safety at the workplace	8
Owner/ Supervisor responsible for safety	4
Company is responsible for safety	1
<b>Emphasis</b>	
Work fast (time)	8
Safety	6
Do a good job (quality)	5
Workers given incentives for PPE	2
Budget	1
<b>Motivation</b>	
Job Satisfaction (Like the job, enjoy working)	6
Money	5
Don't want people to get hurt	1
<b>Who Influences</b>	
Boss/ supervisor	8
co-workers	3
Self	1
Client	1
None	1
<b>First thing that comes in mind with when hear about safety</b>	
Fall protection (working on heights)	4
Wear PPE	3
Clean work area	2
Pay attention	1
Weather	1
Use own good judgment	1
Responsibility	1
Tools and equipment	1
<b>Safety Attitude</b>	
Just be careful	4
Don't take it seriously till it happens to me	1
Make sure the job is safe for everybody	1
Very serious about safety	1
<b>Safety Rules</b>	
Wear harness (fall protection)	4
Not aware of rules	4
Wear PPE	3
OSHA rules	2
Clean-up after work	1

Use ladders	1
<b><i>Safety training in the past</i></b>	
Received while working in the past	3
Safety meetings	3
Toolbox meetings	2
Seminar by insurance company	2
Manual	1
None	1
<b><i>Current Method of Safety training</i></b>	
Safety meetings	7
Manuals/ Handouts in meetings	3
None	3
Insurance company demonstration	2
Boss monitors and checks on safety on-site	2
Toolbox talks	2
Boss uses computers	1
Person-to-person communication	1
First aid training	1
<b><i>PPE</i></b>	
Harness	4
Eye glass	4
Hard Hats	2
Ear protection	2
Boots	1
Never asked to wear hard hats, steel toe boots, etc	1
<b><i>Advantages of working with family and friends</i></b>	
Get along well (like a family)/ comfortable due to strong relationship	6
Flexibility due to family and friends	3
No advantages	2
Have control over the situation	1
Awarding	1
Personal attention	1
<b><i>Disadvantages of working with family and friends</i></b>	
Family and friends can give problems	4
None	3
Spending too much time together	2
Low pay	1
Personal attention	1
Family and Friends does not affect safety at workplace	5
Working with family and friends makes you more concerned	2
Safety not emphasized due to family and friends working together	2

***Desired method of training***

Meetings (in groups, classes)	9
Have someone demonstrate the right way to do things	6
Computer-based training	3
Tool box talks	3
Teach them to pay attention	2
Use videos for demonstration	2
Common sense	1
Have the lead person emphasize on safety	1

***Formal safety training is necessary***

Yes it is helpful	10
Yes for new people	2
No	1

***Miscellaneous***

Don't need safety training due to experience	3
Don't use computers personally for training	3
No training due to small size of the company	2
Accidents are always going to happen	1
A lot of safety programs out there are not practical	1

***Reasons for accidents in the past***

Personal mistake	3
Not wearing PPE	2



## **Appendix K: Informed consent**

### **Informed Consent Form**

Virginia Polytechnic Institute and State University

Title of Project: Training Needs Analysis of Informal Work Systems (a)

Principal Investigator: Tonya L. Smith-Jackson, Ph. D.

Co-Principal Investigator: Brian M. Kleiner, Ph. D.

Additional Investigators: Woodrow Winchester, Ph. D., Darshan Baldev, Sharnnia Artis, Yu-Hsiu Hung & Patrick Bieli

#### **I. THE PURPOSE OF THIS PROJECT**

You are invited to participate in a study on health and the safety environments for workers in small construction firms that are family-owned and/or employ workers with other strong social ties. This project will examine how you think about working with family and friends and how those relationships influence safety and health in the work setting.

#### **II. PROCEDURES**

You will be asked to complete a set of questionnaires. After the questionnaires, the interviewer will observe your work activities and intervene when necessary. Following the observation session, a face-to-face interview will be conducted. During the interview or discussion session you will discuss safety related incidents that you have experienced or witnessed in the workplace, preferences for safety and health information, types of training tools that would be most beneficial, and advantages and disadvantages of working in construction sites with family or friends. Your description of these events may include information on conflicts related to family member or friendship roles, access to safety information, and use of personal protective equipment. The session will last for a period of 2 hours (120 minutes).

#### **III. RISKS**

Participation in this project does not place you at more than minimal risk of harm.

#### **IV. BENEFITS OF THIS PROJECT**

You will be compensated for your participation, and you will be given information to contact the principal investigator to get information about the outcomes of the study. You will also benefit from knowing that you have participated in worthwhile research that will make a real difference for the safety and health of other construction workers.

#### **V. EXTENT OF ANONYMITY AND CONFIDENTIALITY**

The results of this study will be kept strictly confidential. No one outside the research team will be able to connect any data with your name. The information you provide will have your name removed and only a three digit participant number will identify you during analyses and any written reports of the research. An audio recording will be made of the interview session. No reference will be made in oral or written reports that could link you to the data nor will you ever be identified as a participant in the project.

**VI. COMPENSATION**

You will be paid at the rate of \$10 per hour for participation in this research.

**VII. FREEDOM TO WITHDRAW**

You are free to withdraw from this study at any time for any reason.

**VIII. APPROVAL OF RESEARCH**

This research project has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Department of Industrial and Systems Engineering.

**IX. PARTICIPANT'S RESPONSIBILITIES**

It is very important that you keep the activities and information discussed confidential, since others will be participating in this research.

**X. QUESTIONS**

If you have questions, or do not understand information on this form, please feel free to ask them now.

**XI. PARTICIPANT'S PERMISSION**

I voluntarily agree to participate in this study, and I know of no reason I cannot participate. I have read and understand the informed consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project. If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project

\_\_\_\_\_  
Signature

\_\_\_\_\_  
Date

\_\_\_\_\_  
Name (please print)

\_\_\_\_\_  
Contact: phone

**XII. PARTICIPANT'S PERMISSION TO USE EXCERPTS FROM AUDIO TAPED SESSIONS**

I have read and understand the manner in which audiotapes will be used for subsequent analyses of information related to this study. I grant permission to researchers to present this information as necessary in the manner described on this form to others who are on the research team.

\_\_\_\_\_  
Signature

\_\_\_\_\_  
Date

I **do not** grant permission to researchers to present this information as necessary in the manner described on this form.

\_\_\_\_\_

\_\_\_\_\_

Signature

Date

**XIII. CONTACT**

If you have questions at any time about the project or the procedures, you may contact the principal investigator, Tonya Smith-Jackson at (540)231-4119 or [smithjack@vt.edu](mailto:smithjack@vt.edu) (519-H Whittmore).

If you feel you have not been treated according to the descriptions in this form, or your rights as a participant have been violated during the course of this project, you may contact Dr. David Moore, Chair of the Institutional Review Board Research Division at (540)231-4991.