MEASURING AND IMPROVING DESIGNER HAZARD RECOGNITION SKILL

By

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University of Colorado at Boulder, 2014

A Thesis submitted to the

Faculty of the Graduate School of the

University of Colorado in partial fulfillment

of the requirements for the degree of

Master of Science in Civil Engineering

Department of Civil, Environmental and Architectural Engineering

2014

This Thesis entitled:

MEASURING AND IMPROVING DESIGNER HAZARD RECOGNITION SKILL

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December 15, 2014

The final copy of this Thesis has been examined by the signatories, and we find that both the content and the form meet acceptable presentation standards of scholarly work in the above mentioned discipline.

Abstract

Hansen, Daniel Cahill (M.S. Civil Engineering)

Measuring and Improving Designer Hazard Recognition Skill

Thesis directed by Professor Matthew R. Hallowell

Although there are several barriers facing the implementation of Construction Hazard Prevention though Design (CHPtD), the most elusive barrier is the capability of designers to identify and mitigate hazards encountered by construction workers. We argue that CHPtD is only effective to the extent that construction hazards are apparent during design (recognizable) **and** designers are capable of hazard recognition (skill). Our research is the first experimental study aimed to measure: (1) the types and quantity of hazards recognizable during design; and (2) the skill of designers at identifying these hazards. In order to systematically measure this, we selected highly modularized building components, observed all hazards present on site during installation, and then tested designers' abilities to recognize these hazards while only providing them with the construction plans, specifications and descriptions of work (the only resources available during the design phase). Among other findings, our study brought forth initial evidence that: (1) 24% of hazards present in the field can be considered *latent* during design; (2) designers can currently recognize 33.5% of the total hazards present in the field; (3) designers with construction experience in the field have significantly higher hazard recognition skills than designers who have never worked in the field; and (4) by introducing an energy mnemonic method, designers experienced an average increase of 30% to their hazard recognition skill. We conclude that with hazard recognition scores this low, even when excluding latent hazards, designers' abilities to influence safety are severely limited in its current state. Nevertheless, we found that it is also possible to dramatically increase designer hazard recognition to mitigate this concern. Since designers' understanding of construction hazards is crucial to their ability to mitigate them, there must be further research to evaluate the potential efficacy of this important concept.

Acknowledgements

Most notably, I would like to thank Professor Matthew R. Hallowell for all of his exceptional guidance and support on this research. I have learned and grown so much in the last 2 years because of his unwavering dedication to meticulous research, construction safety, and his students. This research began as an amazing opportunity and developed into a remarkable journey, and I certainly appreciate all of his patience along the way.

I thank all of the Colorado Construction Safety Laboratory members, especially Josiane Proulx and Marc Prades whose help was crucial in the validation of this study. I also appreciate the guidance from Alex Albert and Antoine Tixier, who have also served as role models when it comes to diligent and thorough research.

I thank all those who helped, supported and contributed to the data collection phases of this project, including all of the contractors, engineers, superintendents, safety professionals, designers and architects.

I acknowledge and thank the CEAE Bridge-Term Fellowship for the financial assistance to complete my graduate degree.

I could not be more grateful to my Mother, Father and Brother for their limitless love and support. I am sincerely grateful for all the resources they have given me to further my education.

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Introduction

Accounting for 3.5% of the US Gross Domestic Product and employing more than 9.1 million workers, the construction industry is one of the largest in the United States (Center for Construction Research and Training 2013). In 2013, there were 796 fatal work injuries in construction, which is the highest number in any industry and amounts to 18.1% of total fatal occupational injuries (BLS 2013). Although construction fatalities have decreased by 36% since 2006 (BLS 2013), substantial progress can still be made. One high potential strategy that has received great attention is Construction Hazard Prevention through Design (CHPtD).

A significant body of research has been devoted to the concept of preventing construction injuries by identifying and removing potential hazards in the design phase of a project. Construction Hazard Prevention through Design (CHPtD) is defined as, "a process in which design professionals explicitly consider construction worker safety while designing a facility" (Toole and Gambatese 2008, pg 225). According to Whittington et al. (1992) and Suraji et al. (2001), a significant proportion of injuries originate from conditions in planning and design, making CHPtD an approach that can considerably improve worker safety. The need for exploring the feasibility and potential benefit of CHPtD is clear since researchers have claimed that approximately 22% of all construction injuries and 42% of fatalities could have been prevented through adjustments made in the design of a construction project (Gambatese et al. 2005, Atkinson and Westall 2010). Other studies support these claims as well. For example, Gibb et al. (2006) studied 100 construction accidents and reported that 47% of these accidents could have been prevented through changes to the final design. Through surveys and statistical analysis, Trigunarsyah (2007) found a powerful correlation between safety performance on projects and safety consideration during design. Additionally, the European Foundation (1991), using injury statistics and surveys, found 60% of fatal construction accidents were linked to decisions during design that could have been decreased or eliminated with thorough safety deliberation from designers. It is clear that designing for safety has potential for tremendous impact on the injury rate experienced by construction workers.

The Hierarchy of Controls shows that eliminating hazards is preferable and more effective than any other type of control (cdc.gov/niosh). While Engineering Controls (put a *barrier* between the worker and the hazard), Administrative Controls (change the process, tool or training by requiring the worker/employer to *do* something) and PPE (require the worker to *wear* something) all reduce the exposure and potential severity of the hazard; the only way to eliminate exposure altogether is by completely removing the hazard. Even though these lower level controls still serve an important role in safety, the optimal way to completely get rid of a hazard is by elimination or substitution in design (osha.gov). The early phases of a project are the most inexpensive and effortless time to affect these changes as well.

It is theorized, but not substantially supported with empirical evidence, that the ability to influence construction safety is significantly greater in the pre-planning and design phase than in the construction phase (Szymberski 1997). Figure 1 illustrates this concept showing that construction worker safety and health decreases exponentially as the project commences. In other words, the conceptual and design phases are the optimal time for improving worker safety and health. According to the theory, by the time the project reaches the construction phase, opportunities to improve worker safety are comparatively limited. In practice, decisions during the design phase of a construction project are typically made by designers and owners with little input from contractors and vendors (Toole and Gambatese 2008). CHPtD has the added benefit of placing safety in the hands of designers, engineers and architects; people with significant education and problem-solving abilities.

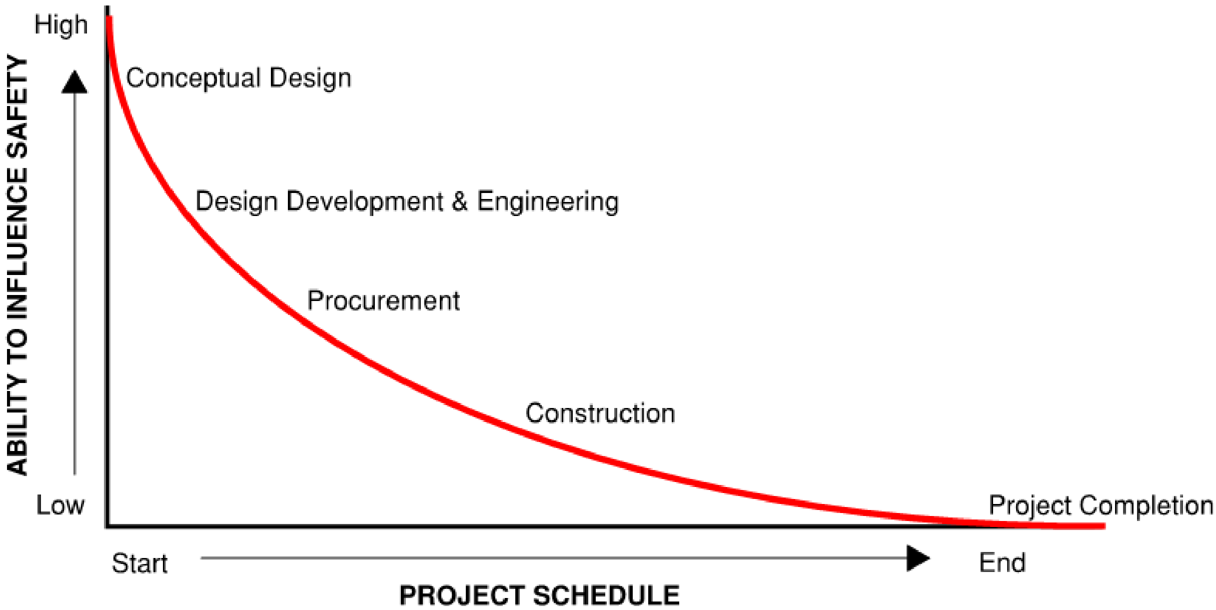

Figure 1: Ability to Influence Safety Curve (Adapted from Szymberski, 1997)

Despite potential benefits, CHPtD has yet to be fully implemented and its current use in the US is minimal to nonexistent (Gambatese et al. 2005). Initial research suggests that the theoretical implementation of CHPtD could be successful in mitigating safety hazards before they even appear in the field; however, the technical principles, tools and processes needed have not been fully defined (Gangolells et al. 2010). Furthermore, the motivation for designers to consider worker safety is completely absent due to OSHA regulations that make safety the sole responsibility of the employer; i.e., the contractor (Maloney and Cameron 2003). Additionally, potentially significant barriers that have yet to receive attention in research are the lack of hazard emergence in design (e.g., detectability) and hazard recognition skill among designers. In order to truly assess and quantify the potential of CHPtD, these barriers must be understood.

When researchers discuss CHPtD, there is an implicit assumption that construction hazards have emerged and are recognizable during the design phase. Logically, CHPtD is only effective to the extent that this is true. If certain hazards are not identifiable early on in the project lifecycle, then they cannot be managed. Also, without strong hazard recognition skills in design, the effectiveness of CHPtD is extremely limited. Although there is a dearth of hazard recognition research in design, researchers have recently focused on hazard recognition skill during construction. Albert et al. (2013) revealed that construction workers are unable to identify over 55% of construction hazards in planning exercises that take place immediately preceding their work. These alarming findings were based on over 100 days of field observations on moderately complex projects. This research begs the question: If workers in the field are unable to successfully identify hazards, what is the level of hazard recognition during design? This is the first study to empirically test and quantify: (1) the extent that construction hazards are apparent or recognizable during design; (2) the hazard recognition skill of designers; and (3) the extent to which hazard recognition skill can be improved in design through training and mnemonics.

Literature Review

This paper builds upon research in the areas of Construction Hazard Prevention through Design (CHPtD), construction hazard recognition, the energy transfer theory and experimental safety research. A brief review of the relevant and salient research in these domains is provided below.

Prevention through Design: Tools and Resources

There are many tools that are readily available to assist designers in CHPtD. These tools take the form of design reviews (Duffy 2004; Hecker et al. 2003; Gambatese 2004), which generally coincide with the main stages of design (Ku and Mills 2010, Gambatese 2000). These segmented stages of design typically have various cost, functionality, and constructability reviews, so including a safety review is not overly burdensome (Toole 2005). Although all CHPtD tools can be generalized in this way, there is a variety of different tools that have various purposes, strengths and weaknesses. These tools fit into 4 categories; hazard recognition checklists, iterative design reviews, risk assessment and decision support, and visualization (Gambatese 2004, Ku and Mills 2010). Definitions of these categories, current and relevant examples with their strengths and weakness are outlined below.

Checklists

The simplest category of tools is Checklists that promote hazard recognition. Checklists are made to help designers recognize hazards that are commonly missed and also to make suggestions for potential ways to alter the design. The first specific CHPtD tool for the construction industry was introduced by Gambatese et al. (1997): the *Design for Safety Toolbox*. This checklist-style method and graphical user interface is to help designers identify and mitigate commonly-encountered hazards. The *Design for Safety Toolbox* takes user input of project characteristics and attributes of the organization and yields a list of design suggestions that guide a design safety review. The generated list of design suggestions can be used to remove hazards or select an alternate design that would mitigate the risk. The authors argued that, since various checklists are used throughout the design process, the *Design for Safety Toolbox* is a viable way to further promote the recognition of site hazards and to develop ways to manage them during design. More than 400 design suggestions make this a powerful tool that is flexible for various project types.

Iterative Design Reviews

Iterative reviews use checklists; however, they are implemented at multiple stages during design. These tools take into account that design is an iterative process and incorporate safety reviews during several phases of design (e.g., conceptual design, design development, drafting of construction documents). In 1998, Australia began mandating use of the Construction Hazard Assessment Implication Review (CHAIR) process on all government projects greater than $3 million in scope. CHAIR is a structured review that helps designers to consider, evaluate and control occupational safety and health (Ku and Mills 2010). As opposed to the toolbox, CHAIR requires a multidisciplinary team and hazard and operability studies to evaluate risks and consider design alternatives (Zhou et al. 2012). This iterative, multidisciplinary process is valuable because building components are constantly modified throughout design. For example, if a building component is reviewed and altered for safety early in design, it may be inadvertently changed during a value engineering review later on. By performing multiple iterations of a design for safety review, the design intent will not be compromised (Ku and Mills 2010). Although a checklist of possible design suggestions is generated, this tool serves as more of a prompt for team discussion.

Risk Assessment and Decision Support

Building upon the checklist-style tools, researchers developed interactive risk assessments that can also compare the risk of various design options in an effort to select the safest design option for construction workers. This technique adds objectivity to the CHPtD process by comparing the level of risk for various alternatives. The Tool for Safety and Health in Design, or ToolSHeD, was developed in order to assess the risk of specific activities or common hazards. The tool generates a report that aids designers with the systematic evaluation and comparison of design alternatives (Ku and Mills 2010). With similar inputs to the Design for Safety Toolbox, ToolSHeD also produces risk report which helps the designer evaluate the risk level associated with falling from height (Cooke et al., 2008). This is particularly helpful when implementing one design alternative could have adverse effects on other design features, thus making that option less desirable. If we take falling from height as an example, the inputs would be any design features that could affect or contribute to the risk of a fall (Cooke et al., 2008). If a designer were to consider alternative roofing membranes that improve traction, ToolSHeD may catch ways that this design alterative increases risk because of ergonomic issues associated with heavier membranes and eye strain from increased reflectivity. ToolSHed is a flexible tool that can be adapted to various projects, but it is limited in its set database of design suggestions and the hazard recognition skill of the designers.

Dewlaney and Hallowell (2012) expanded upon the Design for Safety Toolbox by creating a tool that is specific to Leadership in Energy & Environmental Design (LEED) projects. This tool uses the same format and inputs, but differs in the decision support aspect. Instead of only listing potential design alterations, this LEED tool gives a full risk report that contains all safety risks identified in the database. Another output of the tool is the mitigation report which details the different design alterations or CHPtD strategy that is recommended, given the associated hazards of the project. This tool was rated highly by many designers in the pilot testing, but also received feedback that more detail should be included in the risk report (Albattah et al. 2013).

Visualization through Building Information Modeling

The last category of tool, visualization, uses building information modeling (BIM) to assist designers in recognizing the spatial and temporal safety risk factors. Although no decision support systems exist, researchers have theorized that digital tools enable designers to better visualize the time and location of construction hazards before construction begins (Jung and Joo 2011). Zhang et al. (2013) describes how algorithms may be developed to automatically analyze BIMs to both identify and suggest design alternatives to mitigate fall hazards. Additionally, four-dimensional (4D) models help detect interferences between building components and workspaces. It is proposed that hazard and risk database systems could be linked to building elements and materials to improve hazard predictability. To create such a system, Hammad et al. (2012) generated Dynamic Virtual Fences (DVFs) for fall hazards identified by building information modeling software. These DVFs are placed at optimal locations where the fall hazards most likely exist.

BIM technologies certainly show promise for contributing to the implementation of safety early in the project lifecycle, however there are still many hurdles to be overcome. First, the tools are currently limited to analysis on fall protection around exposed edges (Hammad et al. 2012), which has been shown to be a highly identifiable and controlled hazard during construction (Albert et al. 2013). Second, complete systems would call for a comprehensive hazard or risk database that does not yet exist. Third, there is potential for mindless implementation of the system outputs that would decrease the designers' awareness of hazards. When the focus is completely devoted to accuracy, actual understanding of the risks and how they arise diminishes and hazards are likely to be overlooked (Zhou et al. 2012).

Table 1: CHPtD Tools Organized by Category

Tool	Process	Output	Limitations
Hazard Recognition			
Design for Safety Toolbox (Gambatese et al. 1997)	Input project characteristics and attributes of the organization into a graphical user interface to identify commonly encountered hazards	Generated list of design suggestions	Limited to database of 400 design suggestions
National Institute of Steel Detailing and Steel Erectors Association of America (Toole and Gambatese 2008)	Establishes minimum safe distances for placement and installation of certain components	Defined values for the minimum proximities, clearances, spacings, widths, etc.	Limited to NISD-related scope (steel)
Iterative Reviews			
CHAIR (Zhou et al. 2012; Ku and Mills 2010, Zou et al. 2008)	Iterative process to evaluate safety and health concerns at multiple stages of design	Checklist of design suggestions generated to help facilitate discussion between a multidisciplinary team	Typically a secondary concern to other aspects of design
Peer Review for safety (Toole 2005)	Performed during design reviews where CDM regulations require designers to discuss construction worker safety	Discussion of potential changes to final construction documents	Safety is usually a secondary consideration to cost, functionality, constructability and aesthetics and is sometimes skipped over altogether
Life Cycle Safety process at Intel D1D project (Weinstein et al. 2005)	Discipline-based workgroups evaluate design options	Continual discussion with both contractors and designers to improve safety and constructability	Highly resource and time intensive process
Risk Assessment and Decision Support			
ToolSHeD (Cooke et al. 2008)	Assesses the risk of specific activities and common hazards to compare various design alternatives	Risk report which helps the designer evaluate the risk level	Limited to a set database of design suggestions
LEED adaptation of Design for Safety Toolbox (Dewlaney and Hallowell 2011; Albattah et al. 2013)	Project characteristics and attributes of the contractor are input into a graphical user interface to identify commonly encountered hazards	Full risk report that contains all safety risks identified in the database as well as a mitigation report that provides an objective comparison between design alternatives with respect to the associated hazards of the project	Limited to a set database and lacks detail in the risk report. LEED projects only
Quantitative methodology for risk assessment (Gangolells et al. 2010)	Identifies construction activities at different stages to assesses safety risks and exposure	Overall safety risk level for a project	Output limited to the specific construction activities or trades that are considered
Visualization			
Automatically identify falling and collision risks and generate dynamic virtual fences (Hammad et al. 2012)	Algorithms analyze BIM to detect interferences between building components and workspaces	Automatic generation of dynamic virtual fences to provide real time safety management	Limited in scope of work and in order to fully implement there would need to be a comprehensive hazard database (doesn't exist)
Rule-based systems (Zhang et al. 2013)	Rule-based systems approach system to automatically check, locate and correct identified safety hazards during the design phase	Analyzed BIM model for limited types of hazards	Not ideal for collaboration and understanding of actual hazards is diminished

Table 1 outlines several tools and resources that are currently available to designers. Many of these tools build off one another, especially in terms of databases of hazards that are commonly utilized. An example of this is the LEED tool, developed by Dewlaney and Hallowell (2012), which was built on the *Design for Safety Toolbox* and adapted towards a more specific use; LEED projects. Another trend in these various resources is the limitation of a set database. Even when a database has hundreds of hazards (along with information on when they arise and how to mitigate them), it is limited in regard to those hazards when dynamic environments, such as construction sites, are constantly changing and new hazards continually emerge (Adbelhamid et al. 2011). Some tools, commonly the iterative reviews, have overcome this obstacle by incorporating discussion at various stages of design. This category of tool is generally limited to the effort put in by the review team, however. When the focus at the early stages of design is typically centered on cost, functionality and aesthetics, safety will usually take a secondary role (Toole 2005).

These tools serve a valuable role by integrating safety concerns into the design phase of a project, but it is still unknown how effective they really are. Several studies have claimed the efficacy of one tool or another, but they are all correlation-based studies, which generate anecdotal evidence (Ku and Mills 2010). Although Table 1 outlines the individual strengths and weaknesses for each tool, Ku and Mills (2010, p. 3) state that "there is a need to better understand the impact of these tools on PtD processes". One major limitation to the body of knowledge is the assumption that designers are capable of recognizing construction hazards during the design phase.

Barriers to the Implementation of CHPtD

Despite potential benefits, CHPtD has yet to be embraced in the construction industry and has received a great deal of resistance. Gambatese et al. (2005) interviewed 19 designers and 42% demonstrated overall acceptance of the design for safety concept, while 16% stated they were not willing to implement CHPtD without mandate. More recently, Tymvios et al. (2012) conducted a study and found that only 5.4% of architects and 19.3% of engineers claimed that their firm practiced some form of

Design for Construction Worker Safety. Additionally, this study found that only 78% of the engineers, 53% of the architects, 66% of the owners and 87% of the contractors claimed that they believed that decisions made during the design of a project can help eliminate some construction hazards. These attitudes are driven by a multitude of sociopolitical factors related to opportunity, motivation and capability which greatly limit the overall application of the CHPtD concept (Maloney and Cameron 2003).

Opportunity

Opportunity refers to the collaboration between different entities in the design phase and their ability to communicate concerns to one another (Toole and Gambatese 2008). The absence of communication between designers and contractors on common project delivery methods, such as design-bid-build, contributes to the lack of designers' opportunity to consider safety. In these project delivery methods there is little to no input from the contractor in the design phase, so safety concerns cannot be transmitted (Toole and Gambatese 2008).

In the Design-Bid-Build project delivery method, the owner contracts separately with a designer and a contractor. The design phase is completed in its entirety, the project is bid, and then a contractor builds the facility per the contract documents. The very nature of this project delivery method impedes the integration of design and construction because it fragments the delivery process. Design-Bid-Build delivery separates the designer from the constructor effectively removing opportunity from the designer to create a safer design. When the designer serves as a quality inspector (as is common) the relationship between the designer and the constructor becomes adversarial, further impeding the CHPtD technique. Alternative project delivery methods (design-build, CM/GC, etc) break communication barriers and better facilitate collaboration on topics such as safety (Tymvios 2012).

Motivation

Motivation refers to incentives for designers to address safety concerns. Currently, the US lacks regulations to require designers to consider safety concerns in their work. In the Gambatese et al. (2005)

study, designers ranked construction worker safety last in importance when compared to cost, schedule, quality, aesthetics and end-user safety. OSHA places safety liability on the direct employer of the worker, so the designers who commonly work for a separate entity cannot be held responsible. The specific clause in OSHA 29 Code of Federal Regulations 1926 (below) significantly hinders the use of CHPtD because it removes any liability for construction worker safety from the architects and design engineers;

> "(b) Accident prevention responsibilities.
>
> (b)(1) It shall be the responsibility of the employer to initiate and maintain such programs as may be necessary to comply with this part.
>
> (b)(2) Such programs shall provide for frequent and regular inspections of the job sites, materials, and equipment to be made by competent persons designated by the employers."

Many US architects and engineers fear the increased liability for addressing these concerns, so they resist change and refuse to even consider implementing CHPtD (Tymvios 2012). Outside of the US, mainly in the European Union and Australia, the regulations are different and this concept is (at least to some extent) currently being practiced. In 1992, the European Union Directive 92/57/EEC put legal responsibility on owners and those associated with design to practice CHPtD. The actual implementation of this greatly varied between countries, but the results can be generalized as positive based on the overall reduction of accident rates in participating countries (Martinez Aires et al. 2010). In 2002 in the UK, the role of the designer was further updated to include (HSE 2002):

> "Identify the significant health and safety hazards likely to be associated with the design and how it may be constructed and maintained; consider the risk from the hazards which arise as a result of the design being incorporated into the project; if possible, alter the design to avoid the risk, or where this is not reasonably practical, reduce it."

The success of this specific initiative is difficult to measure, but in a 2010 survey of 258 industry professionals, 90% of respondents felt that CHPtD under the updated EU regulations had a positive effect on construction worker health and safety (Gambatese 2011). In Australia, regulations mandate the elimination of hazards during design per the National OHS Strategy 2002-20012 (NOHSC, 2002). The decision support tool, ToolSHeD, was developed in order to provide Australian designers the means to accomplish this. Although this tool's efficacy is still being evaluated, both designers and the Royal Australian Institute of Architects have provided positive feedback (Cooke et al. 2008).

Although implementation of CHPtD has seen positive results with legislation changes abroad, the US has lagged behind other countries in regulating or mandating this change. Since professional organizations tend to resist change and generally refuse to even consider CHPtD, changes in domestic regulations are unlikely to occur in the US in the near future.

Capability

Capability refers to the designers' ability to accurately identify a potential hazard and then revise a design to overcome a hazard. If the designer does not possess the knowledge or skill to foresee a future concern, the hazard cannot be mitigated. In other words, designer knowledge of construction tasks, sequencing and coordination between different trades is needed to effectively consider safety in design (Toole 2005). Currently, designers lack the education, training and construction experience necessary for CHPtD (Gambatese et al. 2005). In a survey of 75 design engineering firms, only 20% offer their employees some form of training on construction safety (Gambatese 2003). This lack of knowledge can be substantially alleviated by utilizing design for safety tools which have databases of design alternatives to help guide the decision-making process (Toole 2005). Further exacerbating this problem, most universities that have civil engineering programs don't offer any coursework in construction safety (Gambatese 2003). In order to empirically assess this, hypothesis (3) evaluates the hazard recognition skill of two different groups; those with construction field experience and those without.

The barriers categorized by opportunity, motivation and capability all pose significant impediments to the full implementation of CHPtD in the US. Although some of these can be successfully addressed, it is important that future research seeks to eliminate barriers. In this study, we focus on the capability aspect. In a recent survey of 72 designers across 17 different countries, designers claimed relatively high confidence (5.4 out of 7) that they are capable of identifying potentially hazardous design solutions (Öney-Yazıcı and Dulaimi 2014). Although designers may claim to be able to identify hazards, to date there has not been any empirical evidence that supports this claim. To answer this question, hypothesis (2) states that out of all hazards recognizable during design, designers can only recognize less than 50% of them.

Hazard Recognition

In order for any accident to occur, one or multiple people must either not perceive or ignore preceding cues. Hazard recognition, risk perception and effective decision making are important skills for the prevention of construction injuries. Collectively, these skills are known as situational awareness.

Situational Awareness

As defined by McGuiness (2004, p.3), Situational Awareness (SA) refers to "all the situation-specific information and inferences represented in a person's mind which he or she uses to make such decisions." SA has a hierarchy of levels ranging from basic recognition of one's immediate environment to forecasting in new or unfamiliar environments. For example, Level I SA is an individual's perception of what is happening in their immediate physical environment. However, since designers are usually behind a computer, their actual physical environment is less relevant. Level II SA, on the other hand, is more applicable to an engineer or architect since it includes how an individual combines, interprets, stores and retains information (Endsley et al. 2000). More than just perception, Level II is the integration of information with comprehension of that information. Finally, Level III is the highest level of SA and involves the ability to forecast future situation events and dynamics in new and unfamiliar contexts (Endsley et al. 2000). In terms of CHPtD, Level III is by far the most pertinent as it requires designers to project construction operations that have not even been planned. Therefore, a more thorough definition of SA, as it applies to CHPtD, is "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (Endsley et al. 2000, p.98). In CHPtD, the environment is the building itself as it exists virtually in a design and how it will be constructed in the future. Thus, Designers must use Level III SA in order to anticipate the means and methods a contractor will use to construct a given building component. As they project these future events, designers must be able to recognize hazard signals and distinguish them from other noise in the environment.

Haddon's Energy Release Theory

The first step to situational awareness is strong hazard recognition abilities, which can be improved. According to Haddon (1970; 1973), all incidents and injuries originate from the unexpected or unintended release of energy. There are 10 different energy sources which, when released in an unintended manner and exposed to workers, can cause an incident (Albert et al., 2014). In a recent research effort led by Albert (2014), the energy mnemonics method improved hazard recognition of construction workers by 27% with a confidence level of p=0.0001 (Albert 2014). The underlying theory of this mnemonic is that all hazards are related to the undesired release of one or more energy sources.

Figure 2 presents 10 energy sources that have been identified and organized into a mnemonic. For example, if the design of a structure requires construction workers to work adjacent to a leading edge on a roof, then there is a potential for fall and the associated energy source is *gravity*. The value of this mnemonic is that it can be used during a design audit to identify hazards associated with energy sources that wouldn't otherwise be considered by the designer. Examples may include radiation from welding operations, chemicals in confined spaces and biological hazards associated with insects. Although never introduced to designers, a recent study revealed that construction workers were able to identify a higher proportion of construction hazards while using the proposed mnemonic cognitive cues than with traditional methods (Albert et al., 2014). In addition to measuring in situ hazard recognition skill of designers, we also aim to experimentally test the mnemonic on designers with hypothesis (4) that measureable improvements in skill will be realized. Another goal of teaching the mnemonic is to raise the designers' skill in identifing hazards that still may not be recognizable during design (which hazards do designers consistently miss). Hypothesis (1) states that some construction hazards are latent and have not emerged during design.

Figure 2: Energy Mnemonic Wheel (Albert et al. 2014)

Hypotheses and Contributions to the Body of Knowledge

The goals of CHPtD tools and strategies are to identify, assess and control hazards during design. However, the emergence of construction hazards, hazard recognition skills of the designers and methods to improve hazard recognition skills have yet to be empirically or experimentally measured. Without strong hazard recognition skills in design, the effectiveness of CHPtD is limited to checklists, which are ineffective compared with dynamic situational awareness (Albert et al. 2014). Since designers receive little to no formal education on issues of construction worker safety (Gambatese et al. 2005), we hypothesize that the hazard recognition skill of designers is limited.

Our specific hypotheses, stated in their negative, testable form are:

1. Over 30% of construction hazards are latent (i.e. have not emerged) during design.
2. For those hazards that are recognizable, designers' hazard recognition skill exceeds 50%.
3. Designers with construction experience and designers without construction experience are equally capable of identifying construction hazards in design.
4. The Haddon energy mnemonic does not improve construction hazard recognition skill in the designers.

Method

Overview

The data collection encompasses two main phases, the field observations and the experimental testing with designers. These two crucial pieces provide us with the total hazards identified in the field and the hazards identified throughout design.

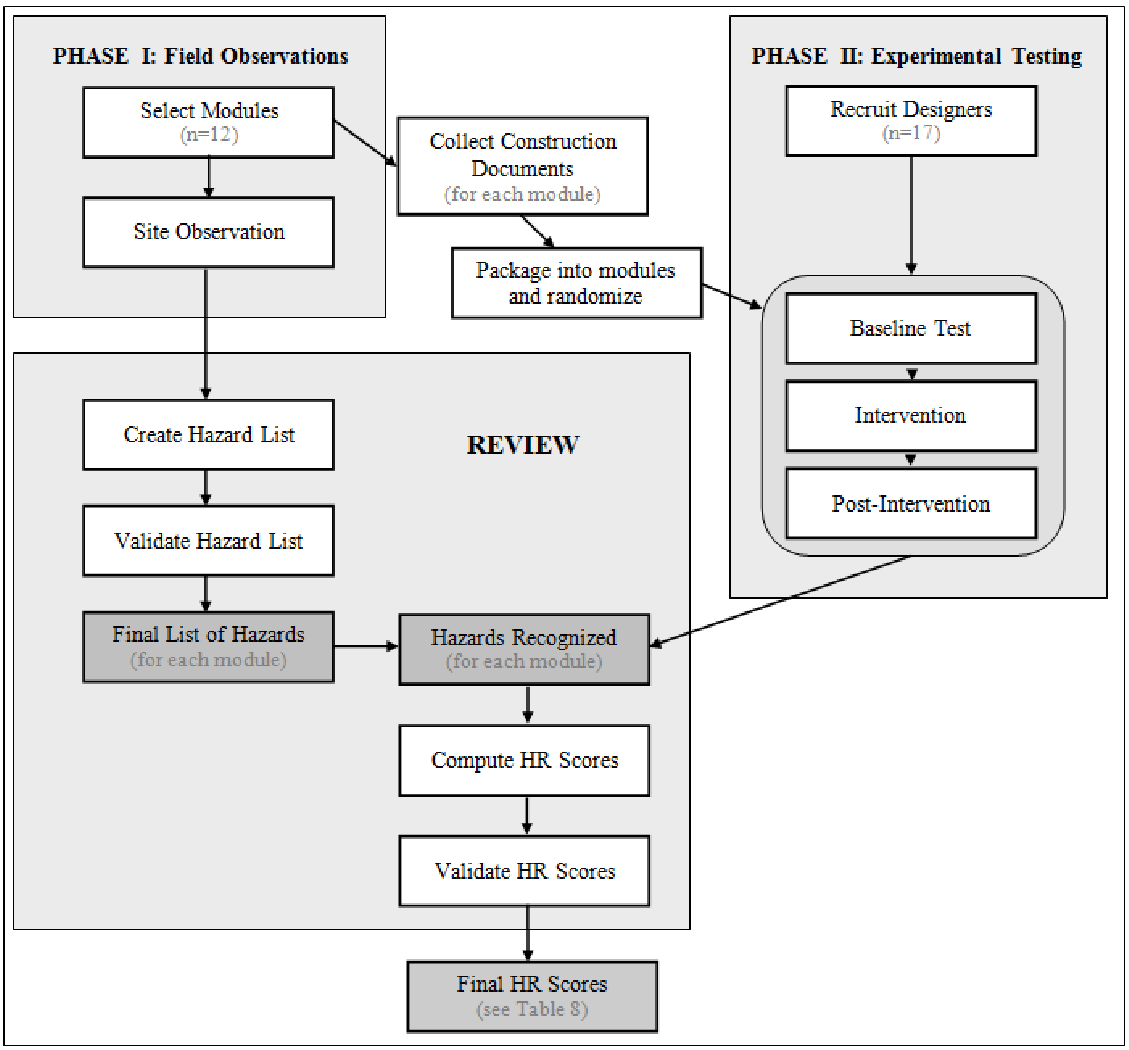

Figure 3: Overview of Method

Phase I: Field Observations

Step 1: Select Construction Process Modules

The first research step required the selection of building construction components to serve as the cases for the experiment. In this step, a total of 12 construction processes were selected from 5 projects in the Denver metropolitan area. A building component, or module, is defined as a discrete building element and the associated activities required for its installation. In order to be included in the study, each module required the following characteristics:

- The module must include a commercial building construction component. Components specific to other types of work (e.g., industrial or heavy civil) were not included in an effort to create appropriate scope.
- The entire installation duration was between 1 and 5 hours and had to be clearly observable. For example, the installation of a caisson meets this criterion, but the duration of a typical concrete pour for a mat foundation would be too long for inclusion.
- Each commercial building component must be discrete in that it is self-contained in plans and specifications and can be evaluated independently of adjacent tasks. For example, painting in a specific location could be included, but a sprinkler system for an entire floor could not because it is a large interconnected system that is difficult to separate out in the plans.
- The module includes activities that are common to a high proportion of building construction projects. For example, a skylight could be included, but an atrium would be too specialized. This requirement was to ensure that most designers who served as experimental participants were familiar with the design of included modules. Highly specialized work, such as electrical and mechanical systems, was excluded for this reason.
- The modules were available on local projects due to resource limitations and data collection feasibility.

Table 2 shows all modules, along with the description of work performed. As will be discussed later, we provided these descriptions to the designers during the experiment to ensure a common understanding of the definition and scope of work associated with each module.

Table 2: Module Descriptions

#	Module	Project	Description
1	**Painting**	Project B	Painting work located on the 3rd floor hallway and closet (walls highlighted in red on attached plans). Includes: preparing workspace and painting. Does not include: Delivery of materials, clean-up, or removal of materials/debris.
2	**Caisson**	Project E	This work involves the construction of caisson # 3255 (DP36A – 12' / 32'). Includes: all work from undisturbed ground through finished concrete caisson. Contractor also tied rebar cage onsite.
3	**Skylight**	Project D	This work involves the construction of a skylight. The framing for the skylight and original roof has previously been demolished and opened up. A temporary cover was installed. Includes: removal of temporary cover and installation of new skylight. Does not include removal of debris or materials.
4	**Soffit Drywall**	Project D	This work involves the construction of a drywall soffit. Includes: all preparatory work and setup, and installation of ceiling and wall drywall.
5	**Tile**	Project C	This work involves the installation of tile on a bathroom wall (see plans for location). Includes: transport of material to workspace and all work required to tile the wall.
6	**Carpeting**	Project B	This work involves the removal of baseboards and installation of carpeting (see plans for location).
7	**Suspended Ceiling**	Project C	This work involves the construction of suspended ceiling in two adjacent restrooms (see plans for location).
8	**Exterior Lights**	Project C	This work involves the installation of 3 exterior light fixtures and conduit (see plans for location).
9	**Interior Vestibule Glazing**	Project C	This work involves the installation of glazing for an interior vestibule. Includes the glazing and metal trim only.
10	**Metal Stud Framing & Sheet Rock**	Project D	This work involves the construction of an interior wall (see plans for location). Includes: vertical members of metal stud framing and installing sheet rock.
11	**Exterior Sheathing**	Project A	This work involves the construction of exterior sheathing (highlighted in red on plans). Includes all work required for installation of gypsum board on the exterior of structure on 1st – 3rd level.
12	**Exterior Framing**	Project A	This work involves the construction of exterior non-load-bearing metal stud framing on the 3rd level (see plans for location). Excludes delivery of materials and clean up.

Step 2: Observe Construction Process Modules

Once identified, the second step of the data collection involved observing the construction of the module. Our goal with these observations was to empirically catalogue the hazards faced by the crew during the construction of each module. To ensure completeness, it was important to conduct direct observations and to solicit input from a variety of individuals involved in construction work and construction oversight. The following sources were used in order to identify all hazards encountered during the work:

1. Observing and recording hazards identified in pre-task safety meetings
2. Reviewing and recording hazards written on job hazard analyses
3. Observing the construction of the module
4. Interviewing workers, foreman and supervisors immediately following the work period

The focus of this task was completeness. The aggregate of the four different approaches ensured that all hazards were captured and this method was consistent with the protocol implemented and validated by Albert (2014).

The Skylight module was an excellent example of how multiple data sources were required for completeness. The primary researcher was present at the pre-task safety meeting where initial concerns were addressed. These conversations focused on fall protection requirements due to work at height. Additionally, the written Job Hazard Analysis (JHA) included other hazards not discussed in the pre-job meeting such as falling material and debris for workers positioned below elevated workspace. Once work began, observations revealed the majority of hazards. Because the hazard recognition skill of any one individual is limited, different resources were used by the researcher, whose sole task was observation and hazard recognition during construction. These resources included: a hazard checklist developed and validated by Albert (2014), which includes 103 hazards identified in over 50,000 worker-hours of observation on six US projects; the Haddon energy mnemonic shown in Figure 2; and a list of 78 risk factors identified from a review of 10,000 construction injury reports (Prades 2014; Desvignes 2014). These 3 separate techniques contributed to the observer's ability to identify hazards.

Following the completion of the work, the observer conducted an interview with the workers and managers involved in the construction of the module to ensure that the list was complete. These individuals were asked the following questions:

1. What are the typical hazards associated with this work?
2. What hazards were unique to this job?
3. What hazards were you especially concerned about for this job?

When no additional hazards were identified and repetition was observed from the various sources, the hazard identification portion of this study was considered complete.

Step 3: Obtain Plans and Specs for each Module

The third data collection step involved obtaining construction documents for each module observed. Construction drawings, shop drawings and specifications were solicited from the contractor's management team. These design documents were used to represent the knowledge available of the module during the design phase. All of the projects that the modules originated from incorporated traditional CAD and paper drawings and weren't using BIM or other advanced modeling technologies. The design documents were packaged for each module, along with a brief description of the work scope (see Table 2). It was important to include a description of the scope of work that was witnessed on site in order to maintain consistency. For example, the scope of the skylight module included the installation of the skylight, but did not include the transport of the materials to the site, demolition of adjacent structures or framing of the opening.

Phase II: Experimental Testing

Experimental testing was comprised of 4 distinct steps. After the participants were recruited (Phase II; Step I), they each took an interview to test their hazard recognition abilities on each module. The remaining three steps were all part of the interview which was a separate process for each participant.

A random set of modules was used to measure the baseline hazard recognition performance, and the remaining set of random modules was used to measure the post-intervention performance. The number in each set varied so the intervention could be introduced at a random point somewhere in the middle quartile to ensure adequate baseline and post-intervention data points were gathered.

The baseline data provides information about the hazard recognition performance and variability in performance prior to the introduction of the intervention. This baseline data is also used to quantify current designer hazard recognition abilities and to extrapolate the baseline phase in the hypothetical case that the intervention was not introduced.

Step I: Recruit Designers (Participants)

In this step, 17 practicing design engineers were recruited to participate in the study. To ensure that the participants had enough knowledge and experience to be a viable candidate, each designer was required to have at least 3 years of practice in designing commercial building projects. Since all modules were for commercial buildings, architects and engineers specializing in this sector of the construction industry were recruited. Although diversity in design backgrounds was preferred, we excluded structural, electrical and mechanical engineering, and other specialty engineering in order to optimize the external validity of our small sample.

In order to verify these personal attributes, we conducted the background survey noted in Appendix A. In addition to demographic and experience questions, we asked designers to indicate which of the 12 modules they may have had significant prior design experience with. Using this information, we could ensure that designers were only given familiar design components during the experiment. Because designers often have very limited or specialized experience, some candidates were rejected because they did not possess adequate knowledge of the various modules, which was the minimum requirement for each subject in the experiment to ensure statistical validity. Table 3 contains the number of participants who were qualified to complete each module.

Table 3: Number of Participants who Completed each Module

Module #	Module Name	Number of Participants
1	Painting	16
2	Caisson	15
3	Skylight	14
4	Soffit Drywall	17
5	Tile	15
6	Carpeting	17
7	Suspended Ceiling	16
8	Exterior Lights	14
9	Interior Vestibule Glazing	15
10	Metal Stud Framing & Sheet Rock	17
11	Exterior Sheathing	17
12	Exterior Framing	17

Step 2: Assess Baseline Hazard Recognition Performance

Module information was organized into packages as previously described and were provided to the designers in a randomized order that was different for each designer. This was done to minimize potential contrast and primacy biases. Each packet contained the module description, plans, specifications and other contract documents produced during design (Appendix E). Each participant was provided with one packet at a time accompanied by a blank hazard identification form (Appendix B). Designers were then asked to review the design documents and identify as many hazards as possible that would be faced by workers in the field. Specifically, they were prompted to *think through the construction processes required to construct this design and list as many hazards as you can find*. It should be noted that the designers were not time-constrained in this process and were encouraged to continue to review the documents until they believed that they had identified all hazards for the module. Such freedom compromises the authenticity of the process; however, our goal was to evaluate hazard emergence and designer hazard recognition skill under ideal conditions.

Step 3: Randomly Introduce Haddon's Energy Mnemonic as an Intervention

In order to teach the Haddon energy mnemonics, a PowerPoint presentation was given to the designer at their randomly assigned point of intervention. This presentation covered the theory behind the mnemonic, a description of each specific energy source and real world pictures of examples where the energy source might occur. All questions were answered so the participant would have a complete understanding of the energy method before continuing.

Step 4: Assess Post-Intervention Hazard Recognition Performance

Using the same protocol described in the baseline phase, the set of modules for the post-intervention phase were prepared for each participant in a random order. Included were all remaining modules with which the designer had experience.

Results

A total of 190 Hazard Identification Forms were collected from 17 participants (average of 11 per participant). We placed each participant into one of two categories: those who have had on-site construction experience and those who did not. For example, some of the designers had prior construction field experience and some designers had none. Additionally, although the majority of participants were recruited from design firms, we recruited two construction professionals to provide breadth of experience in our participant group. Table 4 summarizes the participants' knowledge base and experience as reported in the background survey. In total, 11 participants had only design experience, 2 had only construction experience and 4 had both construction and design experience. Since the biggest gap in performance on hazard identification (discussed later) was between those with experience and those without any experience in the field, participants were split into two groups:

Group A: Participants who currently work for a design, architecture or engineering firm. They have at least 3 years of design experience in building construction, but zero field experience. Visits, tours and observations of construction sites do not qualify as field experience.

Group B: Participants who currently work for either a contractor or a design firm, but have previous field experience in construction with a job function that required on site duties. Any duration of field experience was acceptable.

Table 4: Participant Demographics

Participant #	Years Experience in Building Construction	Experience: Design	Experience: Construction	Group
1	25	x		A
2	11	x		A
3	20	x		A
4	3		x	B
5	23	x	x	B
6	25	x		A
7	25	x		A
8	40	x		A
9	29	x		A
10	22	x	x	B
11	3	x	x	B
12	12	x		A
13	10	x	x	B
14	28	x		A
15	3	x		A
16	6	x		A
17	10		x	B

Out of the 17 participants, 7 were female and 10 were male. The ages ranged from 24 to 60 years old with a median age of 41 years. A maximum of 2 designers per company was used in order to promote diversity. The experience in building construction ranged from 3 to 40 years with a mean experience of 17 years.

Data Analysis

The raw data gathered from the hazard identification forms had to be analyzed to produce the total number of hazards identified. For example, a participant might list 8 items they perceived to be hazards, but some of those hazards were duplicates and others weren't actually present in the module. In addition, some of the answers were vague and required judgment as to whether it qualified as identifying a particular hazard. A method was established to formally assess the situational awareness of the participants by utilizing *hits* and *misses* as part of Signal Detection Theory.

Signal Detection Theory (SDT)

In order for a participant to identify a hazard, they must be able to detect cues from the given description, plans and specs. Signal Detection Theory (SDT) is the way in which a person makes a decision based on information that they classify as relevant or irrelevant. McGuiness (2004, p.8) describes SDT as the process of "discriminating between two types of stimulus, a signal and noise. The task is to detect specific signals, but not confuse them with non-signals and other irrelevant stimuli (noise)." SDT is highly applicable to interpreting the raw data obtained from the designers. Although a participant would make a list of hazards, this list is only the hazards that they perceived to be present. In reality, some of their perceived hazards were present, some were not, some were duplicated or repeated and other actual hazards were entirely missed. Table 5 shows the conventional SDT framework.

Table 5: SDT Framework (adapted from McGuiness 2004, p.8-9)

Term	Definition
Hit	"correct acceptance of a stimulus as a signal"
Miss	"incorrect rejection of a true signal"
False Alarm	"incorrect acceptance of a non-signal"
Correct Rejection	correct rejection of a non-signal
Sensitivity	"the individual's actual ability to discriminate true signals from non-signals"

Construction workers must be able to recognize hazards in order to respond to both perceived and actual risks appropriately (Rasmussen 1994). This concept is equally true for designers; if the designer does not detect hazardous stimuli, they would not be able to respond to the hazard in any manner. In CHPtD, designers must review plans and specifications that contain substantial amounts of stimuli; both signals and lots of background noise (irrelevant information). When reviewing drawings, whether on paper or computer, there is an abundance of information that is not relevant to the specific activity or building component that the designer is considering. The designer must be able to sort through this wealth of information to achieve a hit (correctly identifying a safety hazard). The two possible errors are a miss, when the designer rejects a true signal (fails to notice a hazard), and a false alarm, when he or she mistakes noise for a signal (identifies a hazard that is not actually present). Correct rejection is when the designer accurately dismisses noise for what it is. Since these are innumerable in CHPtD, we will not discuss them (there are an unlimited number of hazards that are not present on site).

This conventional SDT is great for straightforward situations; where a stimuli is either classified as signal or noise. In the unpredictable and dynamic environment of a construction site, there are many uncertainties which make decisions more complicated than a simple hit/miss (Adbelhamid et al. 2011). In response to these challenges (across different industries as well), Parasuraman et al. (2000) developed Fuzzy Signal Detection Theory (FSDT) which is not limited to the dichotomy of either a hit or a miss. Instead, FSDT applies when a "real-world signal has a value that falls in a range between unequivocal presence and unequivocal absence." Simply put, conventional SDT would require a respondent to identify a hazard in a binary fashion (0 or 1), where FSDT allows for any answer in the range between 0 and 1 (Adbelhamid et al. 2011). In order to interpret participants' answers, which varied greatly, a combination of conventional and fuzzy SD was employed.

Handling of Raw Data

Identifying the Total Hazards Present for each Module

There were 2 areas that required some subjective judgment in order to reach the Hazard Recognition Skill. First, the list of total hazards identified on site was the culmination from 4 sources of observation, so many hazards overlapped to some degree or another. This list was generated to ensure all hazards were accounted for and nothing was missed. The two primary researchers carefully went through each module to narrow each list of hazards down to an exhaustive and comprehensive, yet non-redundant list of hazards. Notes, checklists, JHAs and pictures from the site visits made it easy to revisit each module and maintain accuracy. As an example, Table 6 is the comprehensive list of hazards for Module#1, Painting. Tables for the other modules are included in Appendix D.

Table 6: Painting Hazards

Hazard	Probable Resultant	Energy Source
VOC (paint)	Exposure to harmful substance	chemical
Objects on floor (tools, paint bucket, extension cord)	Fall on same level	gravity
Open blade on razor	Struck against	motion
Working at height	Fall to lower level	gravity
Heat stress (no climate control)	Exposure to harmful substance	temperature
Work overhead and bending	Repetitive motion	motion
Electrical cords	Exposure to harmful substance	electrical

Total Hazards Identified by Participants

In order to assess the hazard recognition skill for each participant's review of a module, we needed to use Signal Detection Theory and subjective judgments of the hazards recorded on each participant's data sheets. To compute skill, the lists of hazards identified by each participant were compared with the total number of hazards actually present in each module on site. Each actual hazard was classified as a hit, miss or false alarm based on the whether the participant identified it in their list of perceived hazards. A combination of conventional and fuzzy signal detection was employed; instead of a 0 or 1, or a completely continuous range. Adapted from Jordan (2012), a three-value fuzzy set with discrete values of 0, 0.5 and 1 was used which is an acceptable method to quantify an individuals' hazard perception (Lu et al. 2011, Adbelhamid et al. 2011). Most of the time a participant would either obtain a hit (1) or a miss (0), but the evaluators assigned a value of 0.5 when a participant alluded to a hazard or was unable to explain the full nature of a hazard. For example, one participant wrote "access to building thru construction area" on the Glazing module. The identified hazard in this case was *objects on the floor*. Although he did not recognize that all trades would be walking through the area and stepping over cords and tools, he did recognize that foot traffic in the area could be an issue. In cases like this where lack of specificity was a clear issue, a score of 0.5 was assigned. Another example of a partial hazard identification (score of 0.5) occurred when a participant mentioned "creating sharp edges when cutting framing" on the Exterior Framing module. He received a hit for the *sharp edges on steel* hazard, but only a 0.5 for *sawing steel – sparks & small particles*. Whenever a response was in question, the benefit of the doubt was always given to the designer (a hit was awarded) since the intent of a response couldn't be precisely determined. For example, one participant said "powder activated fasteners" for the Metal Stud Framing module. In reality, a common drill was used but he still received a full hit for *hand tools* since he knew there would be a hazard associated with fastening the framing to the concrete and just assumed the wrong type of tool.

An example hazard identification excerpt in Table 7 shows Participant #13 on the Soffit Drywall module. She scored 5 hits, one partial hit and 5 misses for a total of 5.5 hits. Complete hazard identification tables for each module can be found in Appendix D.

Table 7: Hazard Identification Excerpt for Participant #13 on the Soffit Module

Hazard	#13
Objects on floor	0
Working at height	1
Objects and tools at height	0.5
Electrical cords and tools	0
Small particles (drywall dust)	1
Open blade on razor	1
Work overhead	1
Moving lift	0
Moving/positioning heavy material	0
Hand tools (drill)	0
Sharp metal trim	1
Sound	0

In order to validate the assignment of hits and misses for each hazard, three evaluators and a group study were implemented. In the group study, eleven evaluators were used in a group discussion format to analyze the hazards identified by each participant on 2 distinct modules; Exterior Framing and Skylight. Combining input from a large group with various experience in construction safety led the team to a very accurate assessment of the participants' true hazard identification skill. This step was taken first in order to identify any systematic errors or inconsistencies with the process. This knowledge of prior issues was kept in mind for the second part of the validation.

The 3 different evaluators reviewed all participants' assessments and separately tracked hits and misses for each module of each designer. For each discrepancy, the 3 evaluators would discuss whether or not the participant truly identified the hazard and then would come to a consensus. Different perspectives were used in order to minimize bias from any one evaluator.

Calculating Hazard Recognition Skill

In order to calculate the hazard recognition skill of each participant, both the total number of hazards present on site, as well as the total number of hazards identified (hits) were used. This method, adapted from Carter and Smith (2006), is a tried and trusted approach to calculate the hazard identification levels of all participants. The total numbers of hazards present for each module are identified in Table 10.

$$HR_{skill} = \frac{Total\ Hits}{Total\ Hazards}$$

Equation 1: HR Skill

A separate HR_{skill} was developed for each participant on each module. This HR_{skill} is the fraction of hazards that the participant was able to recognize. The results are summarized below in Table 8.

Table 8: HR Skill

	Participant #																
Module #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	0.29	0.43	0.50	0.29	0.29	0.50	0.29	0.43	0.57	0.14	0.43	0.14	0.29	0.57	x	0.29	0.21
2	x	0.40	x	0.85	0.65	0.45	0.70	0.50	0.40	0.60	0.70	0.00	0.60	0.65	0.70	0.50	0.25
3	x	0.27	x	0.46	0.23	0.15	0.35	0.15	0.31	0.50	0.46	0.15	0.58	0.54	x	0.23	0.15
4	0.42	0.42	0.46	0.50	0.67	0.21	0.67	0.67	0.63	0.71	0.63	0.25	0.46	0.46	0.38	0.54	0.33
5	0.36	0.09	0.23	x	0.41	0.14	0.36	0.41	0.50	0.50	0.32	0.14	0.59	0.27	x	0.41	0.09
6	0.38	0.38	0.25	0.25	0.44	0.00	0.31	0.38	0.63	0.13	0.38	0.00	0.50	0.56	0.38	0.25	0.19
7	0.20	0.45	0.30	x	0.60	0.20	0.40	0.40	0.40	0.60	0.50	0.10	0.55	0.70	0.60	0.50	0.30
8	0.39	0.17	0.56	x	0.67	0.33	0.44	0.56	0.44	0.67	x	0.22	0.22	0.56	x	0.33	0.33
9	0.10	0.00	0.20	x	0.30	0.20	0.40	0.25	0.35	0.40	0.35	0.10	0.40	0.55	x	0.40	0.20
10	0.50	0.23	0.35	0.50	0.50	0.19	0.35	0.38	0.65	0.54	0.42	0.08	0.38	0.50	0.23	0.35	0.31
11	0.27	0.37	0.27	0.53	0.37	0.13	0.43	0.20	0.43	0.57	0.57	0.13	0.33	0.33	0.40	0.53	0.20
12	0.29	0.32	0.32	0.57	0.50	0.14	0.32	0.36	0.50	0.39	0.36	0.14	0.43	0.43	0.43	0.50	0.29

Some of these scores are from the baseline phase and others are from the intervention phase. Note that the rows of the table correspond with the specific module number (from Table 2) and are not in the sequential order that the participant interviewed. An 'x' indicates that the participant did not complete the given module.

Calculating Adjusted Hazard Recognition Skill

Just as HR_{skill} is a measure of the participants' hazard recognition of total hazards, the adjusted hazard recognition skill ($HR_{skill\_adjusted}$) is the fraction of hazards identified out of all hazards that are considered patent during design. First, we must establish what is considered a patent hazard. For the purpose of this study, if 15% or fewer of the participants were able to identify a hazard for a given module, that hazard was labeled *latent* for that particular module.

Table 9: Definitions for Patent and Latent Hazards

Term	Definition
Patent Hazard	An easily or obviously recognizable hazard. More than 15% of participants were able to identify it.
Latent Hazard	A hidden or concealed hazard that has not yet fully emerged in design making it difficult to detect. At least 85% of participants have missed it.

If only 2 or fewer of the 17 participants were able to recognize a given hazard, then it is reasonable to consider the hazard to be latent during design. For example, on the Skylight module the hazard of *heat stress & sun exposure* is deemed latent because only 2 of 14 participants recognized it (detected 14% of the time). This is a very reasonable hazard for participants to miss as they are removed from the work as well as the outdoor elements. Table 10 gives a summary of how many hazards were considered latent for each module.

$$Percent\ Recognized = \frac{\sum Total\ Hits\ for\ a\ Specific\ Hazard}{Number\ of\ Participants}$$

Equation 2: Percent Recognized

Table 10: Total Hazards and Latent Hazards per Module

#	Module	Total Hazards	Latent Hazards
1	Painting	7	1
2	Caisson	10	1
3	Skylight	13	4
4	Soffit Drywall	12	1
5	Tile	11	4
6	Carpeting	8	3
7	Suspended Ceiling	10	1
8	Exterior Lights	9	3
9	Interior Vestibule Glazing	10	4
10	Metal Stud Framing & Sheet Rock	13	4
11	Exterior Sheathing	15	4
12	Exterior Framing	14	2

Similar to the HR_{skill}, the $HR_{skill\_adjusted}$ was calculated for each participant on each module.

$$HR_{skill\_adjusted} = \frac{Total\ Hits}{Total\ Hazards - Unrecognizable\ Hazards}$$

Equation 3: Adjusted HR Skill

Table 11 summarizes all of the $HR_{skill\_adjusted}$ results while accounting for the latent hazards in design for each participant. An 'x' indicates that the participant did not complete that particular module and a 1 indicates that the participant identified as many hazards as are patent.

Table 11: Adjusted HR Skill

Module #	Participant # 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	0.33	0.50	0.58	0.33	0.33	0.58	0.33	0.50	0.67	0.17	0.50	0.17	0.33	0.67	x	0.33	0.25
2	x	0.44	x	0.94	0.72	0.50	0.78	0.56	0.44	0.67	0.78	0.00	0.67	0.72	0.78	0.56	0.28
3	x	0.39	x	0.67	0.33	0.22	0.50	0.22	0.44	0.72	0.67	0.22	0.83	0.78	x	0.33	0.22
4	0.45	0.45	0.50	0.55	0.73	0.23	0.73	0.73	0.68	0.77	0.68	0.27	0.50	0.50	0.41	0.59	0.36
5	0.57	0.14	0.36	x	0.64	0.21	0.57	0.64	0.79	0.79	0.50	0.21	0.93	0.43	x	0.64	0.14
6	0.60	0.60	0.40	0.40	0.70	0.00	0.50	0.60	1.00	0.20	0.60	0.00	0.80	0.90	0.60	0.40	0.30
7	0.22	0.50	0.33	x	0.67	0.22	0.44	0.44	0.44	0.67	0.56	0.11	0.61	0.78	0.67	0.56	0.33
8	0.58	0.25	0.83	x	1.00	0.50	0.67	0.83	0.67	1.00	x	0.33	0.33	0.83	x	0.50	0.50
9	0.17	0.00	0.33	x	0.50	0.33	0.67	0.42	0.58	0.67	0.58	0.17	0.67	0.92	x	0.67	0.33
10	0.72	0.33	0.50	0.72	0.72	0.28	0.50	0.56	0.94	0.78	0.61	0.11	0.56	0.72	0.33	0.50	0.44
11	0.36	0.50	0.36	0.73	0.50	0.18	0.59	0.27	0.59	0.77	0.77	0.18	0.45	0.45	0.55	0.73	0.27
12	0.33	0.38	0.38	0.67	0.58	0.17	0.38	0.42	0.58	0.46	0.42	0.17	0.50	0.50	0.50	0.58	0.33
MEAN	.435	.374	.458	.626	.619	.286	.554	.516	.653	.638	.606	.162	.599	.683	.547	.532	.314
STDEV	.181	.171	.157	.195	.186	.167	.138	.176	.183	.246	.113	.098	.190	.173	.151	.126	.095
VAR	.033	.029	.025	.038	.035	.028	.019	.031	.033	.060	.013	.010	.036	.030	.023	.016	.009

Table 11 contains the adjusted hazard identification abilities from all participants across all modules. When latent hazards are removed, the best designer scored a mean of 0.683 and the minimum was a 0.162. Across designers, the mean was 0.511 (average of the mean row) with a standard deviation of 0.146. (Participant #4 and #17 were excluded from this average because they work for contractors and served as our construction experts. This will be discussed in depth later on.) Three participants were able to score a perfect 1.00; 1 was part of Group A and 2 were part of Group B.

This gives evidence regarding hypothesis (2), stated in its negative; for those hazards that are latent, designers' hazard recognition skill exceeds 50%. In fact, designers' (adjusted) hazard recognition skill is at 51.1% when only accounting for patent hazards.

Aggregated Hazards

In order to get an idea of all hazards present across the different modules, all hazards were combined into Table 24 (Appendix C). The percentage recognized is included below each module that the hazard corresponds to and there is an 'x' if that specific hazard was not present in the module. *Instances* refers to how many modules in which the hazard is present. *Latent in* refers to how many of those modules in which participants identified the hazard less than 15% of the time.

To aggregate hazards across different modules for Table 24, many hazards that were highly similar had to be combined. For example, one hazard of *protruding nails/sharps* had to be made to include hazards of *protruding nails on baseboards* in the Carpeting module as well as *exposed end on rebar & tie wire* in the Caisson module. Some hazards were unlike any others encountered and were left on their own (only one instance), for example, the *open flame* on the Skylight module. All of the aggregated hazards with more than 3 instances were included in Table 12. Aggregated hazards with two or fewer instances had limited data available and are not common hazards present on site across different construction trades, so they were excluded from Table 12 (Table 24 with all of the hazards observed is included in Appendix C).

Equation 4 was used to get an average of the percent recognized across all the modules where a given hazard was present. This gives an overall sense of how well or poorly the participants were able to identify any one hazard over the different modules.

$$\text{Average Identified } = \frac{\sum Percent\ Recognized}{Instances}$$

Equation 4: Average Identified

Participant #4 and #17 were a critical aspect of this analysis. Being individuals whose job responsibilities require them to be on site everyday gives them significant knowledge of construction processes and typical safety concerns pertinent for each module. They were provided the same sets of plans and specifications, making it impossible for them to have insider information on a particular project or task. But having participated in the generic installation of some modules, they also served as construction experts. This helped to find what is truly recognizable and patent during design.

Table 12: Hazards Aggregated from all 12 Modules that have at Least 3 Instances

Hazard	Probable Resultant	Energy Source	Percent Recognized by Module # 1	2	3	4	5	6	7	8	9	10	11	12	Instances	Latent in	Average Identified
Uneven terrain	Fall to same level	gravity	x	27%	x	x	x	x	x	x	x	x	0%	0%	3	2	8.9%
Objects on floor (varies)	Fall to same level	gravity	19%	x	18%	12%	33%	18%	22%	7%	13%	6%	9%	18%	11	5	15.8%
Sound	Exposure to harmful substance	sound	x	20%	x	24%	x	x	x	x	7%	24%	x	x	4	1	18.4%
Heat stress and/or sun exposure	Exposure to harmful substance	temperature	16%	13%	14%	x	x	x	x	x	x	x	35%	29%	5	2	21.6%
Moving man lift	Caught in or compressed	motion	x	x	x	18%	x	x	x	x	x	x	32%	18%	3	0	22.5%
Electrical cords and/or tools	Exposure to harmful substance	electrical	25%	x	21%	44%	10%	0%	34%	86%	7%	15%	18%	24%	11	4	25.7%
Work overhead and/or bending	Repetitive motion	motion	19%	x	x	53%	33%	44%	50%	43%	3%	12%	21%	6%	10	3	28.4%
Open blade on razor	Struck against	motion	6%	x	14%	41%	0%	59%	x	36%	20%	41%	44%	x	9	3	29.1%
Hand tools (varies)	Struck against	motion	x	x	18%	62%	7%	x	25%	7%	33%	82%	44%	71%	9	2	38.8%
Protruding nails/sharps (varies)	Struck against	motion	x	80%	29%	x	7%	56%	38%	x	x	x	x	x	5	1	41.7%
Moving/positioning heavy material	Caught in or compressed	motion	x	x	54%	53%	x	x	x	4%	50%	62%	68%	44%	7	1	47.7%
VOC (varies)	Exposure to harmful substance	chemical	x	70%	29%	x	53%	x	x	x	x	x	x	x	3	0	50.6%
Sharp edge (varies)	Struck against	motion	x	x	x	41%	43%	x	53%	50%	73%	59%	x	47%	7	0	52.4%
Lifting/transporting heavy materials	Overexertion	motion	x	50%	x	x	80%	59%	x	x	x	x	x	32%	4	0	55.3%
Small Particles (varies)	Exposure to harmful substance	chemical	x	x	36%	71%	x	x	56%	x	x	68%	47%	x	5	0	55.5%
Objects and/or tools at height	Struck by	gravity	x	63%	75%	85%	x	x	50%	61%	47%	41%	71%	59%	9	0	61.3%
Working at height (varies)	Fall to lower level	gravity	63%	57%	100%	88%	20%	x	88%	86%	27%	53%	100%	94%	11	0	70.4%

The sum of all latent hazards across all modules compared to the total number of hazards that were identified (all instances) will obtain the percentage of all hazards that are considered latent hazards. By Equation 5, it is discovered that 24% of hazards are considered latent during design. Note that this equation uses the total numbers from Table 24 in order to comprehensively include the hazards that are not as common.

$$\%\ \text{Latent Hazards} = \frac{\sum Latent\ Hazards}{Total\ Instances} = \frac{32}{131} = 24.4\%$$

Equation 5: Percentage of Latent Hazards

This gives evidence regarding hypothesis (1), stated in its negative; over 30% of construction hazards are latent (i.e. have not emerged) during design. In fact, 24.4% of hazards are latent.

It is important to discuss some of the patterns noticed with what hazards were commonly noticed and which were more commonly latent. Hazards related to the condition of the working surface were the least identified. *Uneven terrain* was latent on 2 of the 3 modules it appeared, and *objects on the floor* was undetected by 84% of participants. Environmental factors, such as *sound* and *heat stress/sun exposure* were also commonly omitted as they were missed 82% and 78% of the time, respectively.

Patterns also emerged between patent hazards. Hazards related to height (*working at height* and *objects at height*) were considered patent on every one of the combined 20 modules in which they were present. *Small particles*, also considered patent, was recognized by more than half of participants. These hazards could all be considered trade-specific, since only some construction workers ever deal with heights or small particles. As a whole, these types of hazards appear to be more recognizable in the design phase than other hazards.

Segregating Baseline and Post-Intervention Hazard Recognition Skill

The order modules were presented to the participants was random and different for each person. Table 13 contains the sequence that was used for each participant. For example, Participant#1 received Module#1 as their 8th module. An ‘x’ indicates that the designer did not complete that module.

Table 13: Sequence of Modules

Module #	Participant # 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	8	2	8	12	10	12	2	1	11	9	9	6	5	9	x	7	9
2	x	11	x	7	11	3	9	8	6	1	1	4	7	5	5	6	8
3	x	1	x	5	8	8	10	5	3	2	3	2	8	8	x	3	3
4	10	12	10	2	9	11	8	12	10	12	10	9	2	2	6	5	2
5	6	5	2	x	6	9	7	6	1	6	7	5	10	4	x	12	10
6	9	9	3	4	4	5	11	11	9	3	5	1	4	12	1	4	1
7	4	3	5	x	7	6	4	3	8	7	2	3	12	11	7	10	6
8	5	7	8	x	12	10	3	4	7	8	x	10	3	10	x	2	11
9	1	6	1	x	3	4	5	7	5	5	11	11	1	6	x	9	7
10	7	10	7	1	2	7	1	10	12	10	8	12	6	3	2	1	4
11	2	8	6	6	1	1	12	2	4	11	4	7	11	7	4	11	5
12	3	4	4	3	5	2	6	9	2	4	6	8	9	1	3	8	12

Table 14 defines when the intervention was introduced for each participant (a value of 6 means the intervention was introduced after the sixth module). The intervention was given randomly for each participant between the 4th and 8th module, assigned by Microsoft Excel’s “rand” function.

Table 14: Point of Intervention

Participant #	Intervention After
1	4
2	7
3	6
4	0
5	6
6	5
7	5
8	5
9	5
10	7
11	6
12	5
13	6
14	5
15	4
16	5
17	6

Table 15 breaks out the baseline hazard recognition scores from the rest of the data. An 'x' signifies that specific module was included in the intervention phase or the designer did not participate in that module. Note that Participant #4 only contains scores for the intervention phase since he was already aware and knowledgeable of the energy mnemonic. This individual was left in the data for the aggregated hazards findings since he completed more modules in the intervention phase than any other participant (more data points implies a more valid score) and since he added the perspective of someone who truly understands and has thorough knowledge of the mnemonic. This helped to show what someone with the mnemonic and construction field experience could truly do. Now, however, both Participant #4 and #17 are removed from the analysis in order to focus solely on designer abilities. From here on out, we refer to the participants as designers and these two are excluded from the dataset.

Table 15: Baseline HR Skill

Module #	Participant # 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	x	0.43	x	x	x	x	0.29	0.43	x	x	x	x	0.29	x	x	x	x
2	x	x	x	x	x	0.45	x	x	x	0.60	0.70	0.00	x	0.65	x	x	x
3	x	0.27	x	x	x	x	x	0.15	0.31	0.50	0.46	0.15	x	x	x	0.23	0.15
4	x	x	x	x	x	x	x	x	x	x	x	x	0.46	0.46	x	0.54	0.33
5	x	0.09	0.23	x	0.41	x	x	x	0.50	0.50	x	0.14	x	0.27	x	x	x
6	x	x	0.25	x	0.44	0.00	x	x	x	0.13	0.38	0.00	0.50	x	0.38	0.25	0.19
7	0.20	0.45	0.30	x	x	x	0.40	0.40	x	0.60	0.50	0.10	x	x	x	x	0.30
8	x	0.17	x	x	x	x	0.44	0.56	x	x	x	x	0.22	x	x	0.33	x
9	0.10	0.00	0.20	x	0.30	0.20	0.40	x	0.35	0.40	x	x	0.40	x	x	x	x
10	x	x	x	x	0.50	x	0.35	x	x	x	x	x	0.38	0.50	0.23	0.35	0.31
11	0.27	x	x	x	0.37	0.13	x	0.20	0.43	x	0.57	0.13	x	x	0.40	x	0.20
12	0.29	0.32	0.32	x	0.50	0.14	x	x	0.50	0.39	0.36	x	x	0.43	0.43	x	x
MEAN	.213	.247	.260	NA	.419	.185	.375	.348	.418	.445	.493	.087	.375	.462	.359	.340	x
STDEV	.084	.169	.050	NA	.078	.165	.061	.167	.087	.164	.128	.070	.104	.136	.088	.123	x
VAR	.007	.029	.003	NA	.006	.027	.004	.028	.008	.027	.016	.005	.011	.018	.008	.015	x

Table 16 separates the intervention phase hazard recognition scores from the rest of the data. An 'x' signifies that specific module was included in the baseline phase or the designer did not participate in that module. Table 15 and Table 16 both record the HR skills and similar tables for the Adjusted HR skills, Table 21 and Table 22, are included in Appendix C.

Table 16: Post-Intervention HR Skill

Module #	Participant # 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	0.29	x	0.50	0.29	0.29	0.50	x	x	0.57	0.14	0.43	0.14	x	0.57	x	0.29	0.21
2	x	0.40	x	0.85	0.65	x	0.70	0.50	0.40	x	x	x	0.60	x	0.70	0.50	0.25
3	x	x	x	0.46	0.23	0.15	0.35	x	x	x	x	x	0.58	0.54	x	x	x
4	0.42	0.42	0.46	0.50	0.67	0.21	0.67	0.67	0.63	0.71	0.63	0.25	x	x	0.38	x	x
5	0.36	x	x	x	x	0.14	0.36	0.41	x	x	x	x	0.59	x	x	0.41	0.09
6	0.38	0.38	x	0.25	x	x	0.31	0.38	0.63	x	x	x	x	0.56	x	x	x
7	x	x	x	x	0.60	0.20	x	x	0.40	x	x	x	0.55	0.70	0.60	0.50	x
8	0.39	x	0.56	x	0.67	0.33	x	x	0.44	0.67	x	0.22	x	0.56	x	x	0.33
9	x	x	x	x	x	x	x	0.25	x	x	0.35	0.10	x	0.55	x	0.40	0.20
10	0.50	0.23	0.35	0.50	x	0.19	x	0.38	0.65	0.54	0.42	0.08	x	x	x	x	x
11	x	0.37	0.27	0.53	x	x	0.43	x	x	0.57	x	x	0.33	0.33	x	0.53	x
12	x	x	x	0.57	x	x	0.32	0.36	x	x	x	0.14	0.43	x	x	0.50	0.29
MEAN	.388	.358	.425	x	.517	.246	.449	.420	.531	.525	.457	.156	.513	.544	.558	.447	x
STDEV	.070	.074	.117	x	.202	.128	.165	.131	.113	.225	.118	.068	.108	.108	.166	.087	x
VAR	.005	.005	.014	x	.041	.017	.027	.017	.013	.050	.014	.005	.012	.012	.028	.008	x

Table 17 shows the average hazard recognition skills on each module for the both baseline and post-intervention phases. This includes the Adjusted HR skills as well. Hazard recognition varied on each module as modules contained different numbers of hazards, in addition to some hazards that might be considered easier or more difficult to spot. The lowest skill was 0.257 on the baseline test of module# 6, Carpeting. The highest adjusted HR average of 0.719 was achieved on module# 8, Interior Glazing.

Table 17: Average Designer HR Skill and Adjusted HR Skill per Module

Module #	Mean: HR Skill Baseline	Mean: HR Skill Post-Intervention	Mean: Adjusted HR Skill Baseline	Mean: Adjusted HR Skill Post-Intervention
1	0.357	0.371	0.417	0.433
2	0.480	0.556	0.533	0.618
3	0.297	0.369	0.429	0.533
4	0.486	0.507	0.530	0.553
5	0.305	0.379	0.480	0.595
6	0.257	0.438	0.411	0.700
7	0.369	0.507	0.410	0.563
8	0.344	0.479	0.517	0.719
9	0.261	0.330	0.435	0.550
10	0.385	0.372	0.556	0.537
11	0.313	0.405	0.426	0.552
12	0.368	0.350	0.429	0.408

Comparing Baseline to Post-Intervention

The mean, standard deviation and variance numbers in Table 18 are all calculated from the 'MEAN' rows in Table 15 and Table 16 (Table 21 and Table 22 for the Adjusted HR Skill columns). Percent change is the increase from the baseline mean to the post-intervention mean.

$$Percent\ Change = \frac{|Mean_2 - Mean_1|}{Mean_1}$$

Equation 6: Percent Change

Table 18: Comparison of Baseline and Post-Intervention Results for all Designers

Statistics	HR Skill Baseline	HR Skill Post-Intervention	Adjusted HR Skill Baseline	Adjusted HR Skill Post-Intervention
Mean	0.335	0.436	0.451	0.565
Standard Deviation	0.114	0.113	0.157	0.144
Variance	0.0131	0.0129	0.0246	0.0208
Δ MEAN	0.101		0.113	
Percent Change	30.0%		25.0%	
p-value	3.87E-06		1.91E-05	

Table 18 shows that there is a significant difference between the baseline and post-intervention phase for all designers. On average, a designer would initially identify 33.5% of all hazards present, but after learning the energy mnemonic they could identify nearly 44%. This 30% increase in skill proves the effectiveness of the intervention with a confidence level p=3.87E-06. This is performed using a one-tailed paired t-test because deviation in only one direction is considered possible (increase of skill). A paired test was used because the averages are repeated measurements of the same group. This is a valid statistical measure given the relatively equal variance and assumed normal distribution of the data. This gives evidence regarding hypothesis (4), stated in its negative; the Haddon energy mnemonic does not improve construction hazard recognition skill in the designers. In fact, the designers experienced a 30.0% increase of recognition skill.

From Table 18, another significant finding can be observed in the adjusted scores. Without the intervention, designers can identify only 45% of patent hazards. This means that of all hazards which are reasonably identifiable in design, less than half of them are actually detected by the average designer. By learning the energy mnemonic, designers are able to increase their skill by 25%, to be able to identify 56.5% of patent hazards.

Segregating Group A and Group B Hazard Recognition Skill

In order to make comparisons among designers with various backgrounds in construction field experience, it was necessary to place the designers into groups. Table 19 shows the mean hazard recognition scores for each designer when separated into the baseline and post-intervention phases. This comes from Table 15 and Table 16, which has the average for each designer separated by the intervention. For example, the first data point, 0.213, is the arithmetic mean of Participant#1's average scores for all modules taken during the baseline phase. This number falls under the Group A column because Participant#1 has no field experience to be considered part of Group B. Note that the averages in the Overall column are not the average of the baseline and post-intervention means, but the average of all hazard recognition scores for that participant. The mean, standard deviation and variance numbers in Table 19 are all calculated from their corresponding columns above. Note that Participant #4 and #17 are excluded from this table since they cannot be considered designers. Similar to Table 19, the Adjusted HR Skills are included in Table 23 in Appendix C.

Table 19: HR Skill Averages for Designers (separated by experience type and phase)

	Baseline		Post-Intervention		Overall	
Participant #	**Group A**	**Group B**	**Group A**	**Group B**	**Group A**	**Group B**
1	0.213		0.388		0.318	
2	0.247		0.358		0.293	
3	0.260		0.425		0.343	
4						
5		0.419		0.517		0.468
6	0.185		0.246		0.221	
7	0.375		0.449		0.418	
8	0.348		0.420		0.390	
9	0.418		0.531		0.484	
10		0.445		0.525		0.478
11		0.493		0.457		0.464
12	0.087		0.156		0.122	
13		0.375		0.513		0.444
14	0.462		0.544		0.510	
15	0.359		0.558		0.444	
16	0.340		0.447		0.403	
17						
Mean	0.299	0.433	0.411	0.503	0.359	0.464
Standard Deviation	0.111	0.049	0.124	0.031	0.116	0.014
Variance	0.0124	0.0024	0.0153	0.0010	0.0134	0.0002

Comparing Group A and Group B

Table 19 shows the average baseline scores are 29.9% and 43.3% for Group A and Group B, respectively. These are the most important numbers to take away from this table as they are the hazard recognition scores that we can extrapolate to designers who have not received the intervention by participating in the study. In other words, this is the true hazard identification skill that we can assume for other designers in the industry. The means from Table 19 are displayed graphically with lighter colors in Figure 4 in order to show the change in hazard recognition due to the intervention, as well as the overall abilities of both groups. The combined darker and lighter colors are the Adjusted HR averages from Table 23. This illustrates the fraction of hazards identified when removing the latent hazards.

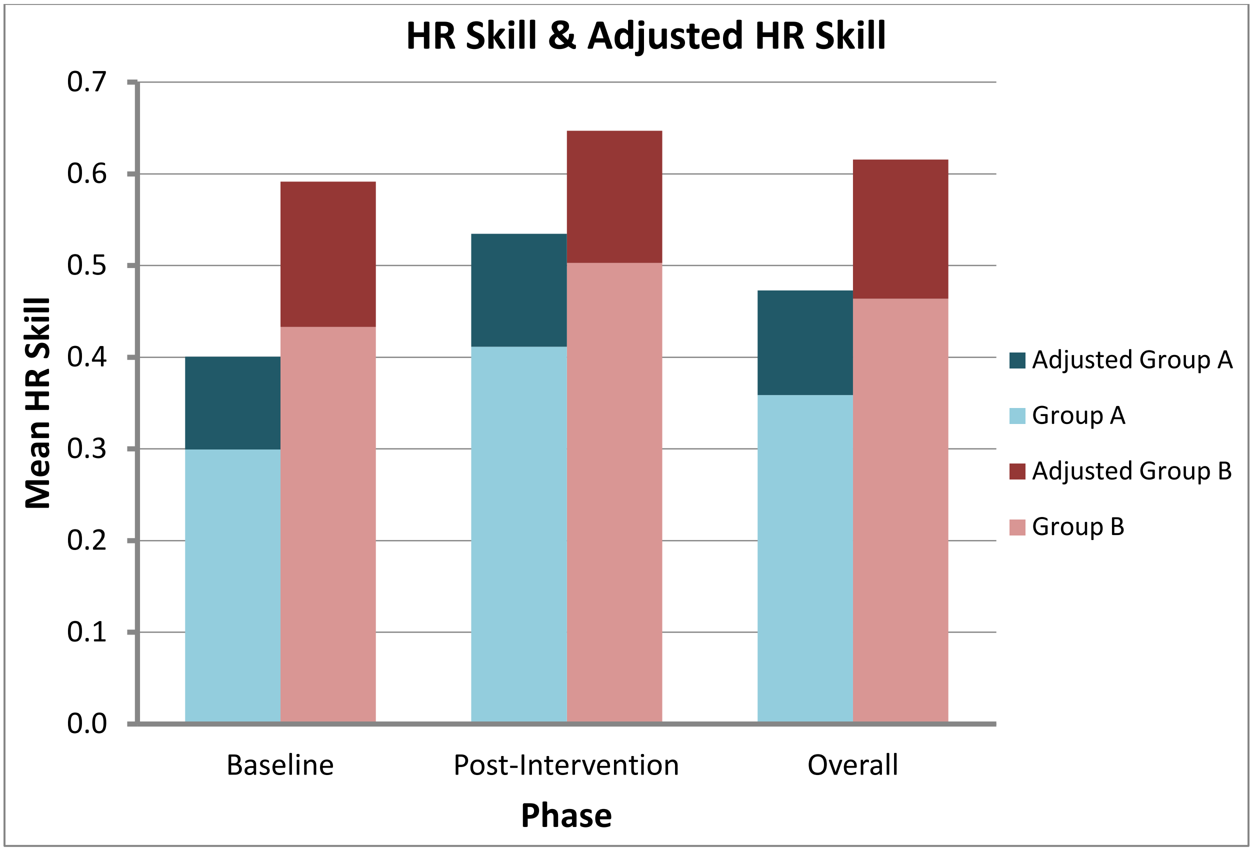

Figure 4: Comparison of HR Skill & Adjusted HR Skill (both Groups A and B)

The left half of Table 20 compares the different columns of Table 19 against one another (each column corresponds to a particular phase for a particular group). The right half of the table does the same thing with the adjusted values from Table 23. The difference in the mean, percent change and p-value are shown for each comparison. The p-values comparing Group A to Group B (top five rows of Table 20) were obtained using a one-tailed, two-sample, equal-variance t-test. A one-tailed test was chosen because the Group B mean is expected to be larger than the Group A mean due to their added experience in the field and knowledge of construction processes. Since A and B contain two different sets of designers, a two-sampled test was required. As shown in Table 19 & Table 23, the variances between the different groups are all low and relatively equal. The p-values comparing the baseline to the intervention phases (bottom two rows of Table 20) were obtained using a similar t-test, except with a paired-design as opposed to a two-sample. Again, the post-intervention mean is expected to be larger than the baseline mean, justifying a one-tailed test; however, a paired test was used because the means are repeated measurements from the same sample of designers.

Table 20: Comparisons between Different Sets of Data

	HR Skill			Adjusted HR Skill		
Comparison	Δ Mean	% Change	p-value	Δ Mean	% Change	p-value
Group A to Group B						
Baseline to Baseline	0.134	44.7%	0.0200	0.191	47.7%	0.0153
Baseline (A) to Intervention (B)	0.203	67.9%	0.0018	0.247	61.6%	0.0040
Baseline (B) to Intervention (A)	0.022	5.1%	0.3702	0.057	9.6%	0.2483
Intervention to Intervention	0.092	22.3%	0.0877	0.113	21.1%	0.0958
Overall	0.105	29.3%	0.0504	0.143	30.2%	0.0472
Baseline to Intervention						
Group A	0.112	37.3%	7.83E-06	0.134	33.4%	1.94E-05
Group B	0.070	16.1%	0.0803	0.055	9.4%	0.1246

The top five rows of Table 20 compare the mean scores of Group A against Group B. For example, Group B scored almost 45% higher than Group A when only comparing the baseline HR average of each group. This is an excellent indicator of the dichotomy between designers who have an understanding of construction processes and field conditions and designers who have not had on-site experience. This particular comparison has a confidence level of p=0.02. This gives evidence regarding hypothesis (3), stated in its negative; designers with construction experience and designers without construction experience are equally capable of identifying construction hazards in design. In fact, designers with field experience were found to be able to recognize 44.7% more hazards than other designers, with 98% confidence. This is especially statistically significant because of the vast difference in skill between the two groups, combined with low variability within the groups. It is imperative to compare the baseline numbers in this case, since the majority of practicing designers do not have an understanding of the energy mnemonic (the post-intervention data would not apply). Another way to look at this comparison would be to analyze the percent change in Adjusted HR Skill. Like the HR Skill, the adjusted average exhibited a similar increase of 47.7%. This increase is slightly more significant with a confidence level of p=0.0153.

Another notable relationship from Table 20 is the baseline phase of Group A to the post-intervention phase of Group B. A difference of almost 68% shows that designers with both field experience and knowledge of the energy mnemonic significantly outperformed their counterparts. This is the greatest difference realized between any of the groupings and the statistical confidence of p=0.0018 assures that there is validity to this sample study. When removing the latent hazards, the percent change for the Adjusted HR Skill drops to a 61.6% increase, but still maintains a confidence level of p=0.004.

The baseline phase of Group B to the intervention phase of Group A makes one of the most interesting comparisons. As seen on Figure 4, the baseline Group A column is nearly equal to the post-intervention Group A column. This means that after teaching the energy mnemonic to designers without field experience, they had a relatively equal HR Skill to the designers with experience. In fact, they outperformed those with experience by only 5.1%, supported by a weak confidence level of p=0.37. Because this is the smallest difference, combined with the lowest level of confidence, it has profound implications. Instead of finding a difference between the groups, we found that these two groups are the most similar. By giving a designer the 10 minute course on Haddon's theory, it has roughly compensated for the lack of years of field experience. Since this comparison has the lowest percent change and highest variability, it asserts that the mnemonic acts as a leveler or equalizer between the groups. It is thus possible to raise the hazard recognition of designers without the hard-to-obtain on-site experience by simply introducing the intervention. The intervention was able to significantly raise their recognition abilities to a level comparable to those with advanced knowledge of construction processes. When looking at the Adjusted HR Skill, Group A designers recognized more than half (53.4%) of the hazards apparent during design (Table 23).

Comparing the adjusted intervention phases between Group A and B, a percent change of 21.1 is observed. This shows that after providing the energy mnemonic to both groups, there is once again a difference between the designers with field experience and those without. Although this change only has a significance level of p=0.0958, the percent change is high enough to reasonably infer that designers who possess both field experience and knowledge of the mnemonic can identify more patent hazards than designers who only understand the mnemonic.

Comparing Baseline to Intervention (separately for each group)

The bottom portion of Table 20 compares the mean scores from the baseline phase against the post-intervention phase, in order to evaluate the effect of the intervention (separately for Group A and Group B). Again, these statistics are derived from the 'MEAN' rows in Table 19 & Table 23. Group A increased their hazard recognition by over 37% due to the intervention, with a high confidence level of p<8E-06 (33.4% for the Adjusted HR with a similar confidence). This is an impressive finding, implying that with just 5-10 minutes of instruction, a designer without field experience can be taught to identify significantly more hazards than before. Group B did not change as considerably, but they were still able to increase their hazard recognition by 16.1%; however, the confidence level dropped to p=0.08, so it is not as statistically significant. The Adjusted HR Skill for Group B changed by 9.4% due to the intervention. Again, the confidence is limited (p=0.1246), although that does not necessarily diminish the implication of this relationship.

Unfortunately, several of the comparisons to be made are somewhat limited due to their lack of statistical significance (p-values). This is due primarily to the small sample size of participants and the variability between each module. As shown in Table 17, some modules can be considered more difficult than others. In addition, some of the higher performing participants scored really low on just a few modules which brought their overall average down (and vice versa). These cases with higher p-values are still relevant (implications are still present despite statistical significance), however, because of the large differences between groups and the low variability within the samples.

Limitations

There are several limitations inherent to the methods performed in this research.

Project Type

Twelve different modules were selected from 5 different projects. Including the obvious limitation on number of projects, all of the project sites were on university campuses in the greater Denver metropolitan area and were LEED accredited. This implies that the specific modules and therefore hazards present may not be applicable to other construction sectors nor can they be construed as representative of the construction industry as a whole. A broad range of modules across different trades were selected to mitigate this concern. The designers were also limited to those familiar with building construction. This means that all data gathered would be limited to that sector as well, although it is reasonable to assume general trends would be consistent across other construction sectors.

Participant Interest and Resistance

There is also the concern of designers' lack of vested interest in the study, contributing to a lack of attention and time spent identifying the hazards for each module. Each interview was completed in one sitting, including the introduction of plans from several different projects, which did not allow participants the time or in-depth knowledge of a project that they would receive in the real world. Resistance to the study was notable as well; both written and verbal pushback was consistently offered by many participants. Designers continually supported the previously mentioned barrier of motivation, citing that they were not liable nor could they adequately address safety since it is the responsibility of the contractor. For example, one designer stated, "I think all of these hazards are driven by construction worker operations, not by the design. I don't see opportunities to change the design to reduce hazards".

Opinion Bias

The list of total hazards present was discussed and decided upon by the two primary researchers. All results were interpreted by evaluators who will inevitably bring some bias into their decision making when assigning hits and misses. Three evaluators were used and every disagreement resulted in a discussion in an attempt to reduce this bias. A group validation exercise with eleven evaluators was also performed for both the lists of total hazards present as well as the evaluation of designer hazard identification.

Small Sample Size

The sample size of participants was fairly small due to time and resource limitations. With only 17 participants and 11 designers with no construction field experience, the sample is too small to make broad claims about the entire industry. Designers from different companies with varying knowledge and experience were selected in order to mitigate this limitation.

The sample size is the largest limitation of the study which makes these results only suggestive of real trends in the construction industry. Further research with a greater population and with participants across different sectors of the industry is needed in order to more categorically support the preliminary evidence revealed in this study.

Experience Did Not Cause Improvement

One initial concern, which turned out to not be a limitation at all, was the varying experience level between different groups. Since a member of Group B was required to have additional on-site construction experience, it stands to reason that they might be older or possess greater experience as a whole. Figure 5 shows there is no correlation between overall construction experience (total # of years in construction) and HR Skill. Slopes are practically non-existent and R squared values are minimal, implying that any difference in skill is attributed specifically to on-site experience, as opposed to more experience in general. Note that the two participants in Group B with only on-site experience were again removed to solely analyze the designers.

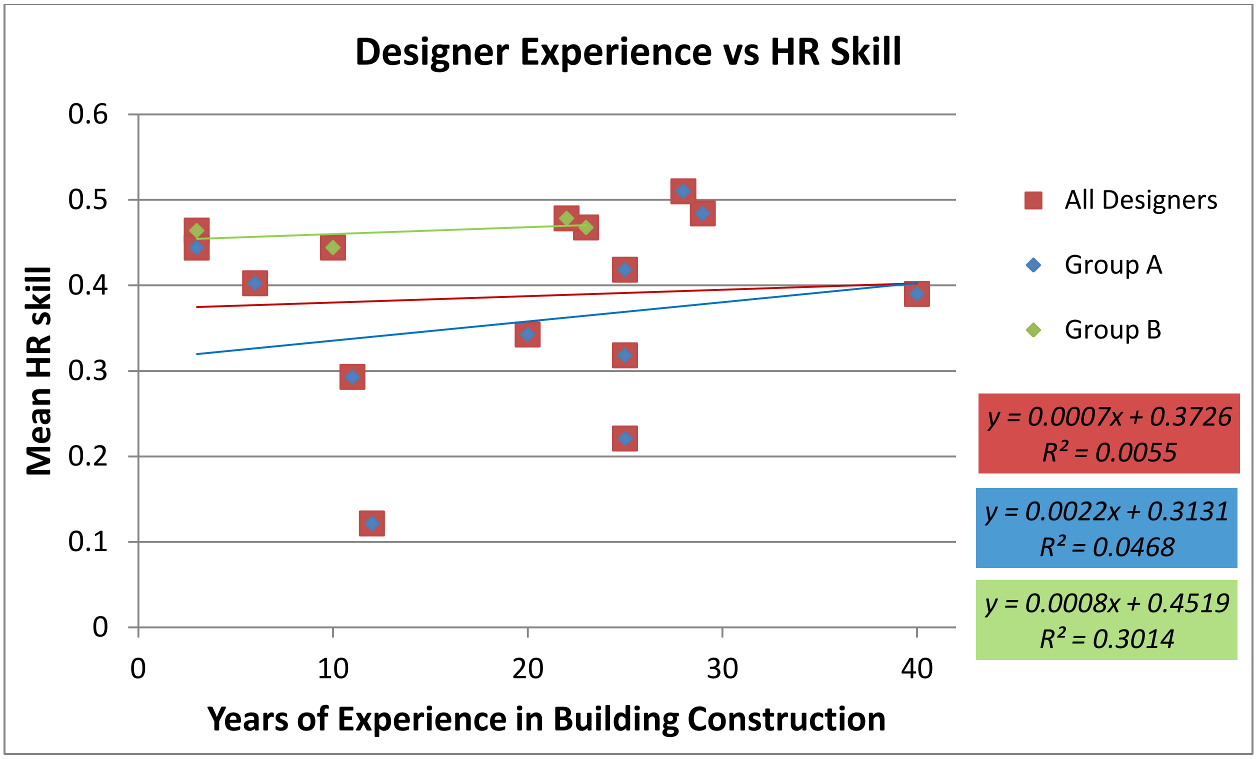

Figure 5: Experience vs. HR Skill

Conclusions

Currently, in the body of knowledge there is a lack of understanding on the capability of designers to implement CHPtD. CHPtD is only effective to the extent that construction hazards are apparent during design (recognizable) and designers are capable of hazard recognition (skill). This research is the first experimental study which measured the capability of designers in order to help evaluate the efficacy of the CHPtD concept.

Hazards related to the condition of the working surface were rarely noticed by designers as *uneven terrain* was latent on 2 of the 3 modules it appeared, and *objects on the floor* was missed by 84% of participants (Table 12). Environmental factors such as sound and *heat stress/sun exposure* were also commonly omitted, as they were missed 82% and 78% of the time, respectively (Table 24). Hazards related to height (*working at height* and *objects at height*) and *small particles*, were always considered patent and were also spotted more than half of the time (Table 12). Szymberski (1997) theorized that the ability to influence construction safety is significantly greater in the pre-planning and design phase than in the construction phase and this belief is widely accepted across the industry. Equation 5 shows that 24.4% of hazards can be considered latent in design, so the true efficacy of CHPtD is restricted to a significant extent. Regardless of the level or scale of implementation, hazards can only be mitigated in design if they can be recognized at that time and our study shows that will be limited to nearly ¾ of its theorized potential.

Designers who do not have field experience can currently foresee 30% of the construction hazards that emerge in the field (Table 19). When only considering designers with construction field experience, hazard recognition is currently at 43% (Table 19). By adjusting the hazard recognition skill to exclude the hazards deemed to be latent during design, the best designer was still only able to identify an average of 68% of the hazards present. The abilities between designers greatly varied as well; the lowest adjusted hazard recognition skill was just 16% (Table 11). This supports previous research claims that designers lack the education, training and construction experience necessary to identify hazards

(Gambatese et al. 2005). With hazard recognition scores this low, even when excluding latent hazards, it stands to reason that designers' ability to influence safety is severely limited in its current state. Overall, designers can detect 45% of hazards when the latent hazards are removed. This could be considered a more appropriate measure of designer skill and ability, since some hazards simply do not manifest until later in the construction process.

After the Haddon energy mnemonic was introduced, designers saw an average increase of 29% to their hazard recognition skill. Group A saw the most dramatic increase at 37%. Although those with field experience only witnessed an increase of 16%, they still maintained higher hazard recognition skill than their counterparts without that experience (Table 20). The overall change is highly similar to the 27% Albert (2014) found when introducing the mnemonic to construction workers. This confirms the success with which the Haddon Mnemonic (Figure 2) can improve hazard recognition, however also demonstrates it can be beneficial to audiences other than construction workers. Another success of the introduction of the mnemonic is shown when designers without field experience were able to increase their hazard recognition skills equal to those with experience. Although there is a slight difference between the two, it is negligible (5.1% with confidence p=.37). This reveals that a 10-minute lesson raises hazard recognition to a level comparable to those who have an advanced understanding of construction processes.

We found that the best ways to improve the average designer's hazard recognition are to (Table 20):

1) Give designers field experience **and** the Intervention: 68% increase,

    (Baseline Group A vs. Post-Intervention Group B);

2) Give a designer field experience: 45% increase,

    (Baseline Group A vs. Baseline Group B);

3) Teach a designer without field experience the Haddon Energy Mnemonic: 37% increase,

    (Baseline Group A vs. Post-Intervention Group B).

Although we found that designer hazard recognition is limited at its current state, we also found that there is significant potential to increase this skill. It is important to note that this study was limited in both sample size and breadth of industry covered. In conclusion, we recommend further research into this essential aspect of construction safety. Several questions remain unanswered such as: would these conclusions hold true across different sectors of the construction industry; would different information formats such as a 3D model or BIM affect designer hazard recognition; and what other hazards could be considered latent with a larger and broader sample of modules and projects? This study was the first of its kind and it can now serve as a baseline and foundation for future research, as the methods and analysis procedures are now well defined.

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Appendix A: Participant Background Survey Form

Participant Background Information Form

Construction Hazard Prevention through Design Research Study

Background Info:
I am a graduate student performing research for CU Boulder on improving hazard recognition in the design phase. The ultimate goal of my project is to assess the ability to recognize construction safety hazards during the design phase. Although Designing for Safety is not current practice in the US, many other countries and owner agencies are starting to require prevention through design (e.g., the CDM regulations in the UK). We are not promoting policy change of any kind; rather, we are examining what hazards are identifiable in design and how they can be recognized and removed without compromising design quality or burdening the design community.

How you're needed:
I am now in the last phase of data collection where I am interviewing designers, architects and engineers in building construction to test a new strategy. The interview takes about one hour and all responses are completely anonymous. The form below will spot if you are a good match for this study and only takes 1 minute. I would really appreciate your help in finishing my thesis and improving construction worker safety.

Name:

Email address:

Phone number:

Gender

- Male
- Female

Age:

How many years of experience in building construction do you have?

What company do you work for?

How many years have you been with this company?

What is your current job function?

What other design functions have you had throughout your career?

Please check all building components that have been designed by you or your design team.

- Metal Stud Framing & Sheet Rock
- Exterior Lights
- Soffit
- Exterior Framing

- ☐ Painting
- ☐ Ceiling/Suspended Ceiling
- ☐ Caisson
- ☐ Skylight
- ☐ Carpeting
- ☐ Exterior Sheathing
- ☐ Glazing
- ☐ Tile

Do you have experience in the field? (ie on a construction site)

- ◯ YES
- ◯ NO

If yes, briefly describe your experience in the field and what you worked on.

Submit

Appendix B: Blank Hazard Identification From

Name : ____

MODULE NAME [ ] SEQUENCE NUMBER [ ]

THINK THROUGH THE CONSTRUCTION PROCESSES REQUIRED TO CONSTRUCT THIS DESIGN

HAZARDS IDENTIFIED (PLEASE LIST AS MANY AS YOU CAN FIND)

HOW MIGHT YOU ALTER THIS DESIGN TO BE SAFER/REDUCE HAZARDS?

Appendix C: Additional Tables

Table 21: Adjusted Baseline HR Skill

Module #	Participant # 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	x	0.50	x	x	X	x	0.33	0.50	x	x	x	x	0.33	x	x	x	x
2	x	x	x	x	x	0.50	x	x	x	0.67	0.78	0.00	x	0.72	x	x	x
3	x	0.39	x	x	x	x	x	0.22	0.44	0.72	0.67	0.22	x	x	x	0.33	0.22
4	x	x	x	x	x	x	x	x	x	x	x	x	0.50	0.50	x	0.59	0.36
5	x	0.14	0.36	x	0.64	x	x	x	0.79	0.79	x	0.21	x	0.43	x	x	x
6	x	x	0.40	x	0.70	0.00	x	x	x	0.20	0.60	0.00	0.80	x	0.60	0.40	0.30
7	0.22	0.50	0.33	x	x	x	0.44	0.44	x	0.67	0.56	0.11	x	x	x	x	0.33
8	x	0.25	x	x	x	x	0.67	0.83	x	x	x	x	0.33	x	x	0.50	x
9	0.17	0.00	0.33	x	0.50	0.33	0.67	x	0.58	0.67	x	x	0.67	x	x	x	x
10	x	x	x	x	0.72	x	0.50	x	x	x	x	x	0.56	0.72	0.33	0.50	0.44
11	0.36	x	x	x	0.50	0.18	x	0.27	0.59	x	0.77	0.18	x	x	0.55	x	0.27
12	0.33	0.38	0.38	x	0.58	0.17	x	x	0.58	0.46	0.42	x	x	0.50	0.50	x	x
MEAN	.271	.308	.360	NA	.608	.236	.522	.455	.598	.595	.632	.122	.531	.575	.495	.465	x
STDEV	.093	.187	.029	NA	.097	.189	.145	.241	.122	.201	.138	.102	.185	.138	.115	.100	x
VAR	.009	.035	.001	NA	.009	.036	.021	.058	.015	.040	.019	.010	.034	.019	.013	.010	x

Table 22: Adjusted Post-Intervention HR Skill

Module #	Participant # 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	0.33	x	0.58	0.33	0.33	0.58	x	x	0.67	0.17	0.50	0.17	x	0.67	x	0.33	0.25
2	x	0.44	x	0.94	0.72	x	0.78	0.56	0.44	x	x	x	0.67	x	0.78	0.56	0.28
3	x	x	x	0.67	0.33	0.22	0.50	x	x	x	x	x	0.83	0.78	x	x	x
4	0.45	0.45	0.50	0.55	0.73	0.23	0.73	0.73	0.68	0.77	0.68	0.27	x	x	0.41	x	x
5	0.57	x	x	x	x	0.21	0.57	0.64	x	x	x	x	0.93	x	x	0.64	0.14
6	0.60	0.60	x	0.40	x	x	0.50	0.60	1.00	x	x	x	x	0.90	x	x	x
7	x	x	x	x	0.67	0.22	x	x	0.44	x	x	x	0.61	0.78	0.67	0.56	x
8	0.58	x	0.83	x	1.00	0.50	x	x	0.67	1.00	x	0.33	x	0.83	x	x	0.50
9	x	x	x	x	x	x	x	0.42	x	x	0.58	0.17	x	0.92	x	0.67	0.33
10	0.72	0.33	0.50	0.72	x	0.28	x	0.56	0.94	0.78	0.61	0.11	x	x	x	x	x
11	x	0.50	0.36	0.73	x	x	0.59	x	x	0.77	x	x	0.45	0.45	x	0.73	x
12	x	x	x	0.67	x	x	0.38	0.42	x	x	x	0.17	0.50	x	x	0.58	0.33
MEAN	.544	.466	.556	x	.630	.321	.577	.559	.693	.698	.594	.203	.666	.761	.618	.581	x
STDEV	.134	.097	.174	x	.258	.154	.139	.114	.217	.313	.075	.083	.186	.159	.189	.126	x
VAR	.018	.009	.030	x	.066	.024	.019	.013	.047	.098	.006	.007	.034	.025	.036	.016	x

Table 23: Adjusted HR Skill Averages for Designers (separated by experience type and phase)

	Baseline		Post-Intervention		Overall	
Participant #	**Group A**	**Group B**	**Group A**	**Group B**	**Group A**	**Group B**
1	0.271		0.544		0.435	
2	0.308		0.466		0.374	
3	0.360		0.556		0.458	
4						
5		0.608		0.630		0.619
6	0.236		0.321		0.286	
7	0.522		0.577		0.554	
8	0.455		0.559		0.516	
9	0.598		0.693		0.653	
10		0.595		0.698		0.638
11		0.632		0.594		0.606
12	0.122		0.203		0.162	
13		0.531		0.666		0.599
14	0.575		0.761		0.683	
15	0.495		0.618		0.547	
16	0.465		0.581		0.532	
17						
Mean	0.401	0.592	0.534	0.647	0.473	0.615
Standard Deviation	0.152	0.043	0.158	0.045	0.154	0.017
Variance	0.0231	0.0018	0.0249	0.0020	0.0237	0.0003

Table 24: All hazards Aggregated from all 12 Modules

Hazard	Probable Resultant	Energy Source	Percent Recognized by Module # 1	2	3	4	5	6	7	8	9	10	11	12	Instances	Latent in	Average Identified
Working at height (varies)	Fall to lower level	gravity	63%	57%	100%	88%	20%	x	88%	86%	27%	53%	100%	94%	11	0	70.4%
Blade on tile cutting board	Struck against	motion	x	x	x	x	67%	x	x	x	x	x	x	x	1	0	66.7%
Auger drilling	Struck by	mechanical	x	63%	x	x	x	x	x	x	x	x	x	x	1	0	63.3%
Objects and/or tools at height	Struck by	gravity	x	63%	75%	85%	x	x	50%	61%	47%	41%	71%	59%	9	0	61.3%
Small Particles (varies)	Exposure to harmful substance	chemical	x	x	36%	71%	x	x	56%	x	x	68%	47%	x	5	0	55.5%
Lifting/transporting heavy materials	Overexertion	motion	x	50%	x	x	80%	59%	x	x	x	x	x	32%	4	0	55.3%
Sharp edge (varies)	Struck against	motion	x	x	x	41%	43%	x	53%	50%	73%	59%	x	47%	7	0	52.4%
VOC (varies)	Exposure to harmful substance	chemical	x	70%	29%	x	53%	x	x	x	x	x	x	x	3	0	50.6%
Moving equipment (varies)	Caught in or compressed	motion	x	87%	x	x	x	x	x	x	x	x	12%	x	2	1	49.2%
Moving/positioning heavy material	Caught in or compressed	motion	x	x	54%	53%	x	x	x	4%	50%	62%	68%	44%	7	1	47.7%
Sawing Steel - hot work w/ sparks	Exposure to harmful substance	thermal	x	x	x	x	x	x	x	x	x	x	x	47%	1	0	47.1%
Protruding nails/sharps (varies)	Struck against	motion	x	80%	29%	x	7%	56%	38%	x	x	x	x	x	5	1	41.7%
Hand tools (varies)	Struck against	motion	x	x	18%	62%	7%	x	25%	7%	33%	82%	44%	71%	9	2	38.8%
Open blade on razor	Struck against	motion	6%	x	14%	41%	0%	59%	x	36%	20%	41%	44%	x	9	3	29.1%
Work overhead and/or bending	Repetitive motion	motion	19%	x	x	53%	33%	44%	50%	43%	3%	12%	21%	6%	10	3	28.4%
Ascending/descending scaffold	Fall to lower level	gravity	x	x	x	x	x	x	x	x	x	x	24%	29%	2	0	26.5%
Electrical cords and/or tools	Exposure to harmful substance	electrical	25%	x	21%	44%	10%	0%	34%	86%	7%	15%	18%	24%	11	4	25.7%
Moving man lift	Caught in or compressed	motion	x	x	x	18%	x	x	x	x	x	x	32%	18%	3	0	22.5%
Unstable/unsupported material (varies)	Struck by	gravity	x	x	x	x	x	12%	x	x	x	32%	x	x	2	1	22.1%
Heat stress and/or sun exposure	Exposure to harmful substance	temperature	16%	13%	14%	x	x	x	x	x	x	x	35%	29%	5	2	21.6%
Sound	Exposure to harmful substance	sound	x	20%	x	24%	x	x	x	x	7%	24%	x	x	4	1	18.4%
Objects on floor (varies)	Fall to same level	gravity	19%	x	18%	12%	33%	18%	22%	7%	13%	6%	9%	18%	11	5	15.8%
Open flame (to heat flashing cement)	Exposure to harmful substance	temperature	x	x	11%	x	x	x	x	x	x	x	x	x	1	1	10.7%
Wire bending tool manipulation	Caught in or compressed	motion	x	x	x	x	x	x	9%	x	x	x	x	x	1	1	9.4%
Uneven terrain	Fall to same level	gravity	x	27%	x	x	x	x	x	x	x	x	0%	0%	3	2	8.9%
Congested work space	Caught in or compressed	motion	x	x	x	x	x	x	x	x	x	0%	12%	x	2	2	5.9%
Slippery surface	Fall to same level	gravity	x	x	x	x	x	6%	x	x	x	x	x	x	1	1	5.9%
Propane tank	Struck by	pressure	x	x	4%	x	x	x	x	x	x	x	x	x	1	1	3.6%

Appendix D: Hazard Identification Tables by Module

#1 - Painting

Hazard	Probable Resultant	Energy Source	Participant #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
			Sequence #	8	2	8	12	10	12	2	1	11	9	9	6	5	9	0	7	9
			Pre/Post Intervention	1	0	1	1	1	1	0	0	1	1	1	1	0	1	3	1	1
VOC (paint)	Exposure to harmful substance	chemical		1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1
Objects on floor (tools, paint bucket, extension cord)	Fall on same level	gravity				0.5					0.5	1					1			
Open blade on razor	Struck against	motion					1													
Working at height	Fall to lower level	gravity		1	1	1			1		1	1		1		1	1		1	
Heat stress (no climate control)	Exposure to harmful substance	temperature							0.5	1	0.5									0.5
Work overhead and bending	Repetitive motion	motion			1			1	1											
Electrical cords	Exposure to harmful substance	electrical				1						1		1			1			

#2 - Caisson

Hazard	Probable Resultant	Energy Source	Participant #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
			Sequence #	0	11	0	7	11	3	9	8	6	1	1	4	7	5	5	6	8
			Pre/Post Intervention	3	1	3	1	1	0	1	1	1	0	0	0	1	0	1	1	1
Exposed end on rebar & tie wire	Struck against	motion					1	1	1	1	1	1	1	1		1	1	1	1	
Rebar cage suspended above ground	Caught in or compressed	gravity					0.5	0.5	0.5	1		1	1	1		1	1	1	1	
Heat stress & sun exposure	Exposure to harmful substance	temperature/radiation					1							1						
Working at height (adjacent to open hole)	Fall to lower level	gravity					1	1	1	1	1		1	0.5			1	1		
Uneven terrain	Fall to same level	gravity					1							0.5		0.5	1		1	
Moving equipment- forklift, jlg, skid, other trucks	Struck by	motion			1		1	1	1	1	1		1	1		1	1	1	1	1
Concrete exposure	Exposure to harmful substance	chemical			1		1	1		1	1	1	1	1		0.5		1		1
Auger drilling	Struck by	mechanical			1		1	1		1		1	1			1	1		1	0.5
Lifting/transporting heavy materials (rebar)	Overexertion	motion					1	1	1	1	1			1			0.5	1		
Sound	Exposure to harmful substance	sound			1											1		1		

#3 - Skylight			Participant #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
			Sequence #	0	1	0	5	8	8	10	5	3	2	3	2	8	8	0	3	3
Hazard	**Probable Resultant**	**Energy Source**	**Pre/Post Intervention**	3	0	3	1	1	1	1	0	0	0	0	0	1	1	3	0	0
Objects and tools at height	Struck by	gravity			1		1	1		1	0.5		1	1		1	1		1	1
Objects on floor (tools, materials, cords,PPE)	Fall on same level	gravity									0.5						1		1	
Working at height	Fall to lower level	gravity			1		1	1	1	1	1	1	1	1	1	1	1		1	1
VOC - Flashing Cement	Exposure to harmful substance	chemical					1			1			1			1				
Moving/positioning heavy material	Caught in or compressed	motion			0.5		1	1	1	0.5			0.5	1		1	1			
Heat stress & sun exposure	Exposure to harmful substance	temperature/radiation					1							1						
Hand tools (drill & hammer)	Caught in or compressed	motion										1		1		0.5				
Small particles (saw dust)	Exposure to harmful substance	chemical			1								1	1		1	1			
Electrical cords and tools	Exposure to harmful substance	electrical					1					1					1			
Open flame (to heat flashing cement)	Exposure to harmful substance	temperature											1		0.5					
Open blade on razor	Struck against	motion								1						1				
Protruding nails/sharps from removed curb	Struck against	motion										1	1			1	1			
Propane tank	Struck by	pressure													0.5					

#4 - Soffit Drywall			Participant #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
			Sequence #	10	12	10	2	9	11	8	12	10	12	10	9	2	2	6	5	2
Hazard	**Probable Resultant**	**Energy Source**	**Pre/Post Intervention**	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	0
Objects on floor	Fall to same level	gravity								1							1			
Working at height	Fall to lower level	gravity			1	1	1	1	1	1	1		1	1	1	1	1	1	1	1
Objects and tools at height	Struck by	gravity		1		1	1	1	1	1	1	1	1	1		0.5	1	1	1	1
Electrical cords and tools	Exposure to harmful substance	electrical		1		1	1	1		1				1					0.5	1
Small particles (drywall dust)	Exposure to harmful substance	motion		1	1	1		1		0.5	1	1	1	1		1	0.5		1	1
Open blade on razor	Struck against	motion		1	1					1	1	1	1			1				
Work overhead	Repetitive motion	motion			1			1		1	1	0.5	0.5	1	1	1			1	
Moving man lift	Caught in or compressed	motion							0.5			1						0.5	1	
Moving/positioning heavy material	Caught in or compressed	motion		1	1		1	1		0.5	1	1	1	0.5				1		
Hand tools (drill)	Caught in or compressed	mechanical				0.5	1	1		1	1	1	1	1	1		1		1	
Sharp metal trim	Struck against	motion						1			1	1	1			1	1	1		
Sound	Exposure to harmful substance	sound				1	1						1	1						

#5 - Tile			Participant #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
			Sequence #	6	5	2	0	6	9	7	6	1	6	7	5	10	4	0	12	10
Hazard	**Probable Resultant**	**Energy Source**	**Pre/Post Intervention**	1	0	0	3	0	1	1	1	0	0	1	0	1	0	3	1	1
Objects on floor	Fall to same level	gravity								1	0.5	0.5	1		0.5	0.5	1			
Working at height	Fall to lower level	gravity				1										1			1	
Blade on tile cutting board	Struck against	motion		1				1		1	1	1	1			1	1		1	1
Open blade on razor	Struck against	motion																		
Protruding nails from floor/wall	Struck against	motion		1																
Work overhead & bending	Repetitive motion	motion						1				1	0.5	1		1			0.5	
Sharp edge on tile	Struck against	motion		1					0.5		1	1	1			1			1	
Hand tool (Grinder)	Struck against	motion												1						
Electrical cords and tools	Exposure to harmful substance	electrical						0.5						1						
Lifting/transporting heavy materials	Overexertion	motion			1	1		1	1	1	1	1	1		1	1	1		1	
VOC -skin irritant - grout	Exposure to harmful substance	chemical		1		0.5		1		1	1	1	1	0.5		1				

#6 - Carpet			Participant #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
			Sequence #	9	9	3	4	4	5	11	11	9	3	5	1	4	12	1	4	1
Hazard	**Probable Resultant**	**Energy Source**	**Pre/Post Intervention**	1	1	0	1	0	0	1	1	1	0	0	0	0	1	0	0	0
Open blade on razor	Struck against	motion		1	1		1	1		1		1	1	1		1	1			
Objects on floor	Fall to same level	gravity		1													1	1		
Electrical cords (on wet floor)	Exposure to harmful substance	electrical																		
Unstable/unsupported material (stacked carpet)	Struck by	gravity						0.5		0.5		1								
Bending in repeated motions	Repetitive motion	motion			1			1			1	1				1	0.5		1	1
Protruding nails on base board	Struck against	motion		1		1					1	1		1		1	1	1	1	0.5
Slippery surface	Fall to same level	gravity																1		
Lifting/transporting heavy materials	Overexertion	motion			1	1	1	1		1	1	1		1		1	1			

#7 - Supsended Ceiling			Participant #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
			Sequence #	4	3	5	0	7	6	4	3	8	7	2	3	12	11	7	10	6
Hazard	Probable Resultant	Energy Source	Pre/Post Intervention	0	0	0	3	1	1	0	0	1	0	0	0	1	1	1	1	0
Objects on floor	Fall to same level	gravity			0.5	1											1	1		
Working at height	Fall to lower level	gravity		1	1	1		1	1	1	1		1	1	1	1	1	1	1	
Tie wire protruding	Struck against	motion						1			1	1	1			1		1		
Work overhead	Repetitive motion	motion			1			1		1		1	1	1		1			1	
Wire bending tool (unpowered- pinch points)	Caught in or compressed	motion														0.5		1		
Electrical cords or tools or existing utilities	Exposure to harmful substance	electrical								1	1			0.5		1	1			1
Sharp material	Struck against	motion				1		1			1	1	1	0.5		1	1		1	
Objects at height	Struck by	gravity			1			1				1	1				1	1	1	1
Hand tools (drill)	Caught in or compressed	mechanical							1					1			1			1
Small Particles	Exposure to harmful substance	chemical		1	1			1		1			1	1			1	1	1	

#8 - Exterior Lights			Participant #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
			Sequence #	5	7	8	0	12	10	3	4	7	8	0	10	3	10	0	2	11
Hazard	Probable Resultant	Energy Source	Pre/Post Intervention	1	0	1	3	1	1	0	0	1	1	3	1	0	1	3	0	1
Objects on floor	Fall to same level	gravity															1			
Working at height	Fall to lower level	gravity		1	1	1		1	1	1	1		1		1		1		1	1
Objects at height	Struck by	gravity		1	0.5	1		1	1		1		1						1	1
Open blade on razor	Struck against	motion				1				1		1	1				1			
Electrical cords and tools	Exposure to harmful substance	electrical		1		1		1		1	1	1	1		1	1	1		1	1
Moving/positioning heavy material	Caught in or compressed	motion		0.5																
Work overhead	Repetitive motion	motion						1	1		1	1	1			1				
Hand tools (drill)	Caught in or compressed	mechanical						1												
Sharp edges on material/conduit	Struck against	motion				1		1		1	1	1	1				1			

#9 - Interior Glazing			Participant #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
			Sequence #	1	6	1	0	3	4	5	7	5	5	11	11	1	6	0	9	7
Hazard	**Probable Resultant**	**Energy Source**	**Pre/Post Intervention**	0	0	0	3	0	0	0	1	0	0	1	1	0	1	3	1	1
Objects on floor	Fall to same level	gravity										0.5		0.5			1			
Working at height	Fall to lower level	gravity				1								1			1		1	
Objects at height	Struck by	gravity						1	1	1		1					1		1	1
Open blade on razor	Struck against	motion								1		1				1				
Electrical cords	Exposure to harmful substance	electrical												1						
Sharp edges on glass	Struck against	motion		1		1		1		1	1	1	1		1	1	1		1	
Sound	Exposure to harmful substance	sound											1							
Hand tools (hammer, other instrument)	Caught in or compressed	motion											1			1	1		1	1
Work overhead and bending	Repetitive motion	motion									0.5									
Moving/positioning heavy material	Caught in or compressed	motion						1	1	1	1		1	1		1	0.5			

#10 - Metal Stud Framing & Sheet Rock			Participant #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
			Sequence #	7	10	7	1	2	7	1	10	12	10	8	12	6	3	2	1	4
Hazard	**Probable Resultant**	**Energy Source**	**Pre/Post Intervention**	1	1	1	1	0	1	0	1	1	1	1	1	0	0	0	0	0
Objects on floor	Fall to same level	gravity															1			
Working at height	Fall to lower level	gravity			1	1		1	1		1	1					1		1	1
Objects at height	Struck by	gravity		1			1	1	0.5			0.5					1		1	1
Electrical cords and tools	Exposure to harmful substance	electrical					1												0.5	1
Congested work space	Caught in or compressed	motion																		
Sharp edge - metal and cutter for metal studs	Struck against	motion		1		1	0.5	1		1	1	1	1	0.5		1	1			
Work overhead	Repetitive motion	motion						1				1								
Moving/positioning heavy material	Caught in or compressed	motion		1	1		1	0.5		1	1	1	1	1		1		1		
Small particles (cutting sheet rock)	Exposure to harmful substance	chemical		1	1	1	1				1	1	1	1		1	0.5		1	1
Unstable/unsupported material	Struck by	gravity					1			0.5			1	1			1	1		
Open blade on razor	Struck against	motion		0.5		0.5		1		1	1	1	1			1				
Hand tools (drill, other cutter/instruments)	Caught in or compressed	motion		1		1	1	1	1	1		1	1	1	1	1	1	1	1	
Sound	Exposure to harmful substance	sound		1								1	1	1						

#11 - Exterior Sheathing			Participant #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
			Sequence #	2	8	6	6	1	1	12	2	4	11	4	7	11	7	4	11	5
Hazard	**Probable Resultant**	**Energy Source**	**Pre/Post Intervention**	0	1	1	1	0	0	1	0	0	1	0	0	1	1	0	1	0
Objects on floor	Fall to same level	gravity		0.5													1			
Uneven terrain	Fall to same level	gravity																		
Working at height	Fall to lower level	gravity		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Objects at height	Struck by	gravity		1	1		1	1		0.5	1	1	1	0.5			1	1	1	1
Electrical cords and tools	Exposure to harmful substance	electrical					1										1		1	
Work overhead	Repetitive motion	motion								0.5		1	1			1				
Moving/positioning heavy material	Caught in or compressed	motion		1	1	1	1	1	1	1		1	0.5	1				1	1	
Moving man lift (pinch points w/ module)	Caught in or compressed	motion					1	0.5		1				1				1	1	
Congested workspace on lift	Caught in or compressed	motion						1						1						
Heat stress & sun exposure	Exposure to harmful substance	thermal					1						1	1		1		1	1	
Accending/decending scaffold	Fall to lower level	gravity		0.5						0.5			1	1						1
Moving equipment (JLG, man lift)	Caught in or compressed	motion												1				1		
Small particles (cutting sheet rock)	Exposure to harmful substance	chemical			1	1					1	1	1	1		1			1	
Open blade on razor	Struck against	motion			0.5	1	1	1		1		1	1			1				
Hand tools (drill)	Caught in or compressed	mechanical			1		1			1		0.5	1		1		1		1	

#12 - Exterior Framing			Participant #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
			Sequence #	3	4	4	3	5	2	6	9	2	4	6	8	9	1	3	8	12
Hazard	**Probable Resultant**	**Energy Source**	**Pre/Post Intervention**	0	0	0	1	0	0	1	1	0	0	0	1	1	0	0	1	1
Objects on floor	Fall to same level	gravity				1											1	1		
Working at height	Fall to lower level	gravity		1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1
Objects at height	Struck by	gravity		1			1	1		1		1	1	1			1		1	1
Electrical cords and tools	Exposure to harmful substance	electrical			1		1											1	1	
Sawing Steel - hot work w/ sparks	Exposure to harmful substance	thermal			0.5		1	0.5		1	1	1	1			1	1			
Moving man lift (pinch points w/ module)	Caught in or compressed	motion					1	0.5								0.5			1	
Work overhead	Repetitive motion	motion												1						
Moving/positioning heavy material	Caught in or compressed	motion		1		0.5		1		1		1	1					1	1	
Sharp edges on steel	Stuck against	motion				1	1	1			1	1	1			1	1			
Heat stress & sun exposure	Exposure to harmful substance	thermal			1									1		1			1	1
Accending/decending scaffold	Fall to lower level	gravity		0.5							1	1				0.5		1		1
Uneven terrain (surface)	fall to same level	gravity																		
Hand tools (drill, powder activated)	Caught in or compressed	mechanical			1		1	1	1		1	1		1	1	1	1	1	1	
Lifting/transporting heavy materials	Overexertion	motion		0.5		1	1	1		0.5		1	0.5							

Appendix E: Sample Construction Documents

RCP NOTES

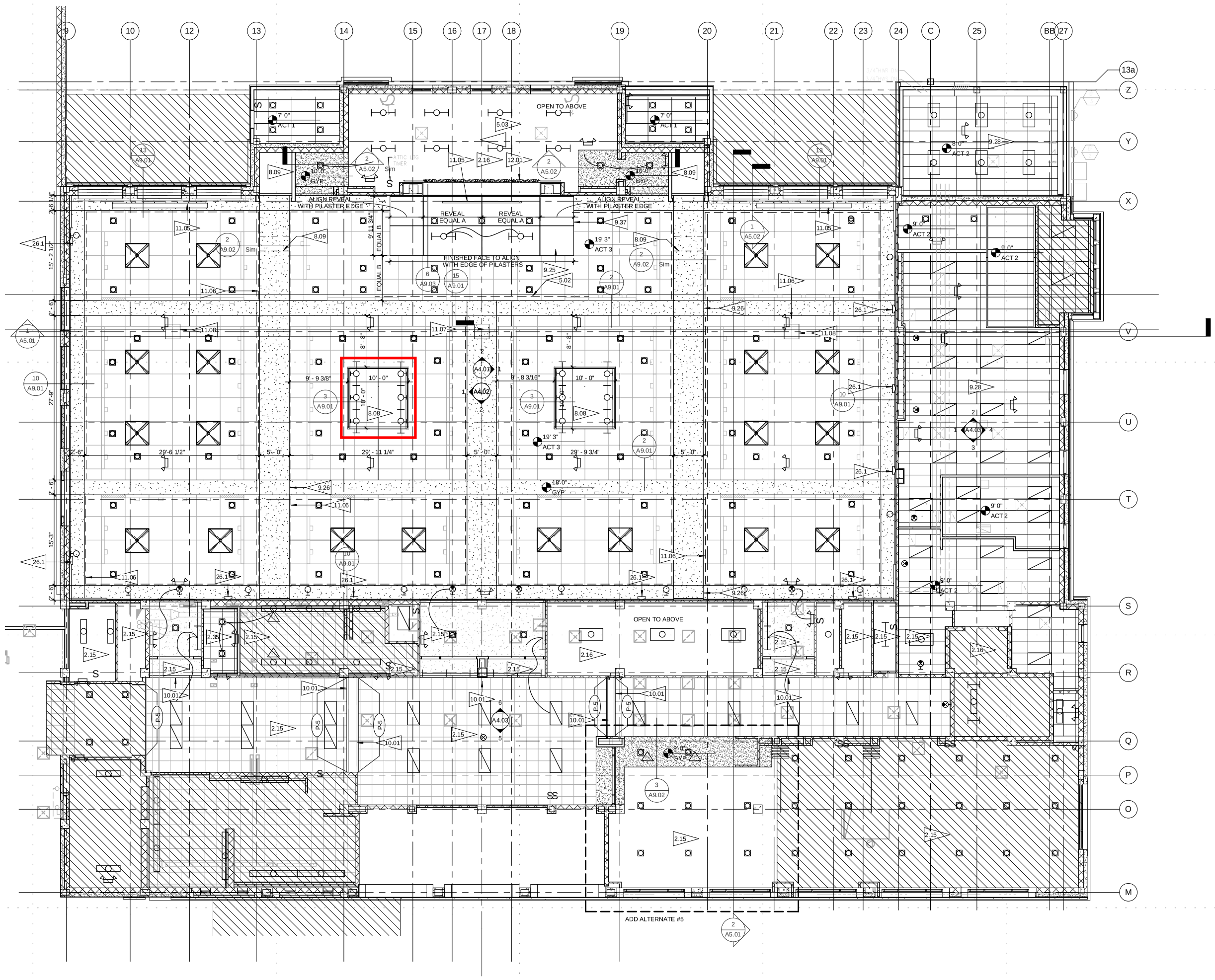
1.	THE REFLECTED CEILING PLAN INDICATES THE LOCATION OF CEILING HEIGHTS, LIGHT FIXTURES, AND ASSOCIATED ITEMS. REFER TO ENGINEERING DRAWINGS FOR ADDITIONAL ELECTRICAL, HVAC, SPRINKLER AND LIFE SAFETY. IN THE EVENT OF DISCREPANCIES BETWEEN THE DESIGNER'S REFLECTED CEILING PLAN AND THE ENGINEERS' PLANS, IMMEDIATELY NOTIFY THE DESIGNER IN WRITING BEFORE ORDERING MATERIALS OR PROCEEDING WITH WORK.
2.	COORDINATE ALL TRADES INVOLVED IN THE CEILING WORK TO INSURE CLEARANCES FOR FIXTURES, DUCTS, PIPING, CEILING SUSPENSION SYSTEMS, ETC., NECESSARY TO MAINTAIN THE FINISHED CEILING HEIGHTS INDICATED ON THE DESIGNERS' DRAWINGS.
3.	ANY ACCESS HATCHES NOT SHOWN ON THE CEILING PLAN BUT REQUIRED BY PLUMBING, MECHANICAL, OR ELECTRICAL SYSTEMS SHALL BE REVIEWED WITH ARCHITECT FOR LOCATION.
4.	CONTRACTOR TO COORDINATE LOCATION OF FIRE SPRINKLER HEADS.
5.	NEW CONSTRUCTION: ALL LIGHT FIXTURES, EXIT SIGNS, SPRINKLER HEADS & OTHER CEILING ELEMENTS SHALL BE LOCATED IN CENTER OF INDIVIDUAL CEILING TILE, U.O.N.
6.	CENTER ALL NEW ACOUSTICAL CEILING GRID WITHIN THE ROOM UNLESS OTHERWISE NOTED.
7.	ALL NEW GYPSUM BOARD SOFFITS AND CEILINGS ARE TO BE PAINTED P-3 UNLESS OTHERWISE NOTED.
8.	PAINT ALL EXPOSED CEILING STRUCTURE & DUCTWORK P-6.1.
9.	DIMENSIONS OF SPECIALTY LIGHT FIXTURES ARE TO CENTER OF FIXTURE, UON
10.	PROVIDE RATED FIXTURES AT ALL CONDITIONS WHERE FIXTURE PENETRATES RATED FLOOR ASSEMBLY
11.	REFER TO ELECTRICAL DRAWINGS FOR SWITCHING AND OR POWER/ZONE

KEYNOTES

2.15	EXISTING CEILING TO REMAIN
2.16	EXPOSED CEILING TO (E) ROOF
2.35	DEMO AND SALVAGE GRID AND TILES FOR REUSE.
5.02	PROVIDE SCH. 40 PIPE MTD TO SIDE OF SOFFIT FOR STAGE LIGHTING.
5.03	SCH 40 PIPE FOR STAGE RIGGING, RE: AV DRAWINGS.
8.08	SKYLIGHT
8.09	THROUGH WALL ACCESS PANEL, 30 X 30 AT EACH FACE OF SOFFIT ABOVE CEILING.
9.13	PROVIDE RIGGING POINTS AT PERIMETER OF ALL FOUR WALLS AND OPERABLE PARTITIONS, AND IN CEILING.
9.25	WD-1 SOFFIT, RE: INTERIOR ELEVATIONS
9.26	CONTROL JOINT TYP AT EACH GYP COFFER.
9.28	VINYL 2 X 4 ACT, RE: FINISH SCHEDULE
9.37	PROVIDE WD-1 AT EDGE OF SOFFIT
10.01	NEW SIGNAGE AT ARCHES AND INTO THE BALLROOM.
11.05	RETRACTABLE PROJECTION SCREEN
11.06	PROVIDE WIRE FOR LIGHTWEIGHT BANNER MOUNTS TYP. AT ALL SOFFITS.
11.07	PROJECTOR MOUNTED TO SCISSORS LIFT TO ABOVE CEILING, RE: AV DRAWINGS. SCISSORS LIFT TO BE ADD ALTERNATE #4.
11.08	PROJECTOR MOUNTED ON FIXED MOUNT TO ABOVE CEILING.
12.01	THEATRICAL CURTAINS
26.1	NEW CUSTOM SCONCES, RE: ELEC

RCP LEGEND

- 2 X 4 ACT TILE ACT-2
- 4 x 4 ACT TILE ACT-3
- GYP BOARD
- CUSTOM 4 X 4 PENDANT LT-2.2
- 10 x 10 SKYLIGHT
- EXISTING 2 X 2 ACT TILE
- EXISTING GYP BOARD

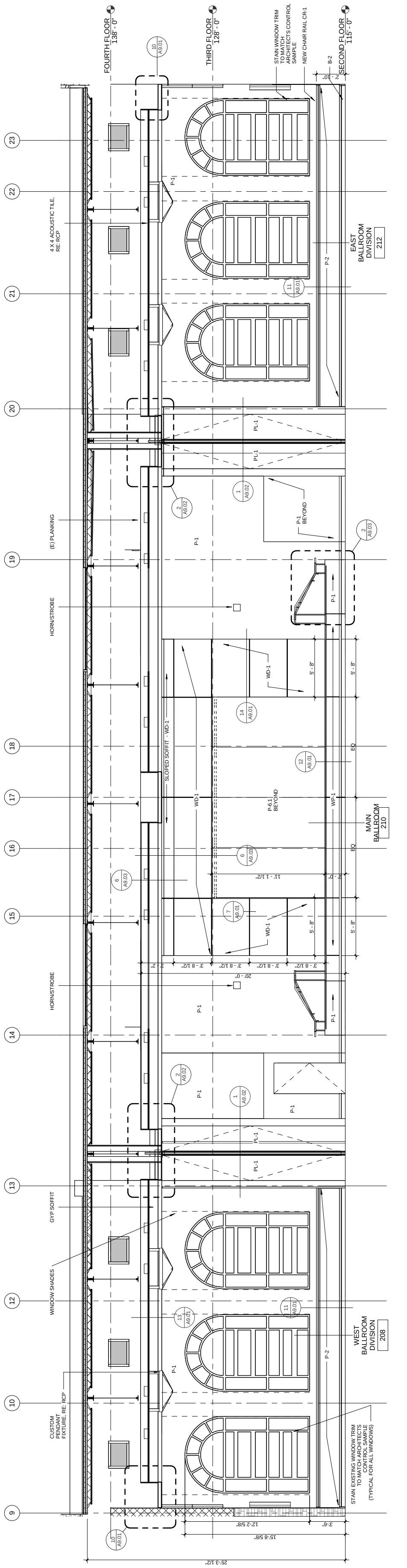


1 LEVEL 2 REFLECTED CEILING PLAN

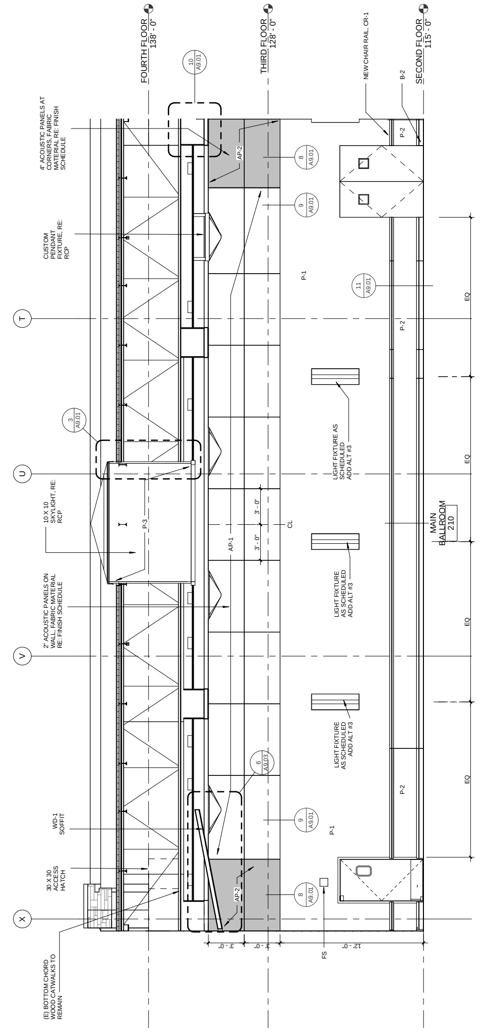
1/8" = 1'-0"

0' 2' 4' 8' 16' 32'

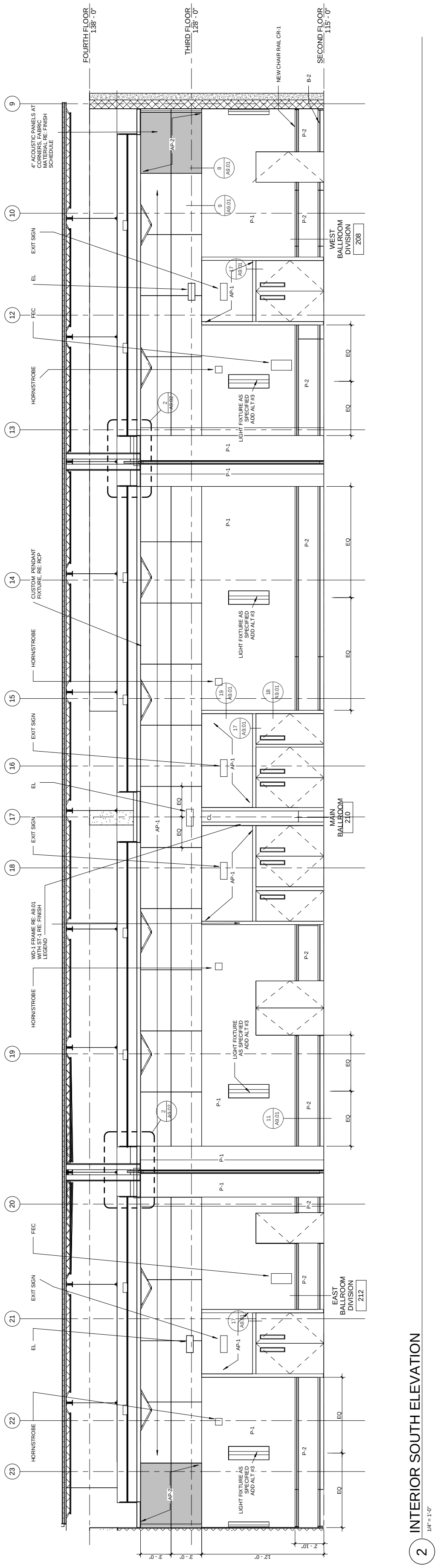
N



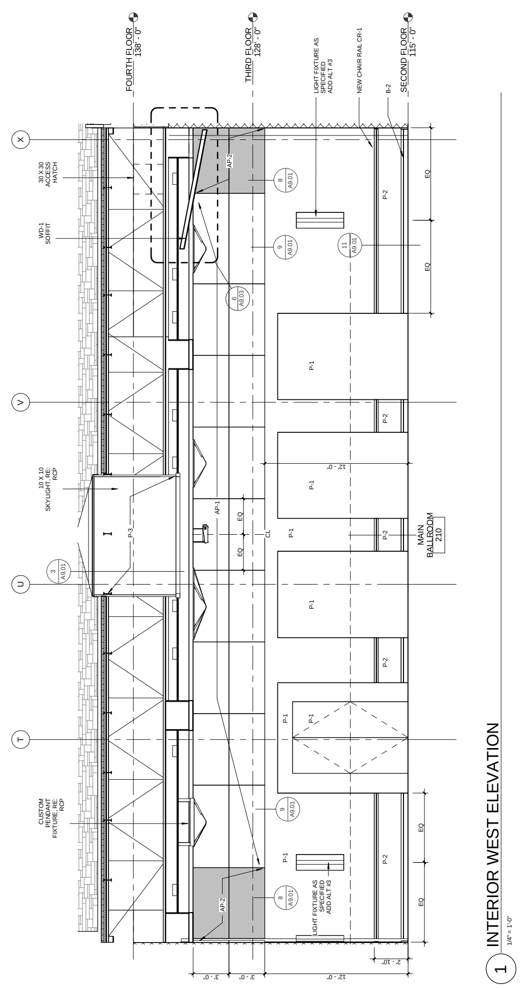
2 INTERIOR NORTH ELEVATION
1/4" = 1'-0"



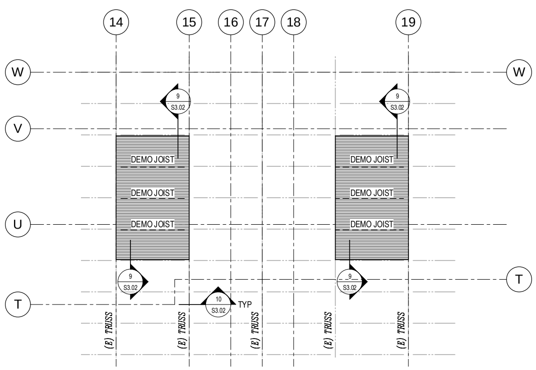
1 INTERIOR EAST ELEVATION
1/4" = 1'-0"



2 INTERIOR SOUTH ELEVATION
1/4" = 1'-0"



1 INTERIOR WEST ELEVATION
1/4" = 1'-0"



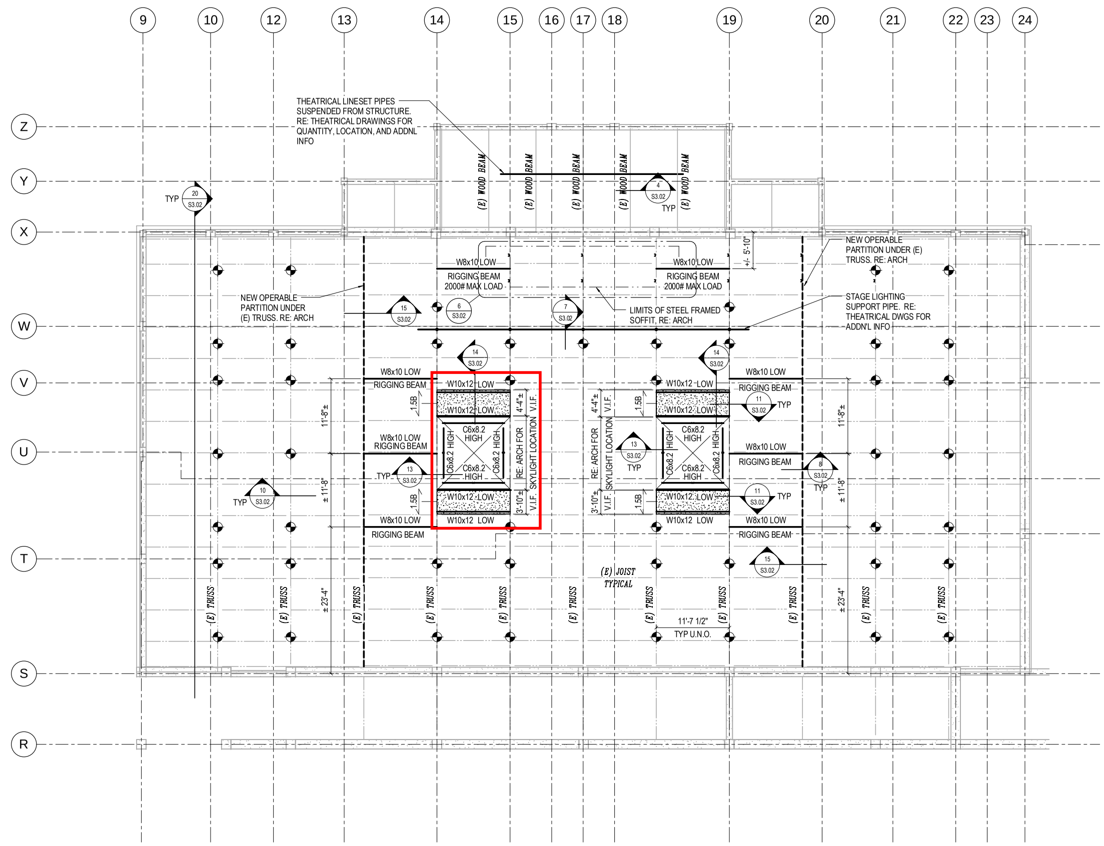
ROOF DEMO PLAN

1/8" = 1'-0"

NORTH

PLAN NOTES:

1. INDICATES LIMITS OF EXISTING WOOD DECKING TO BE REMOVED.



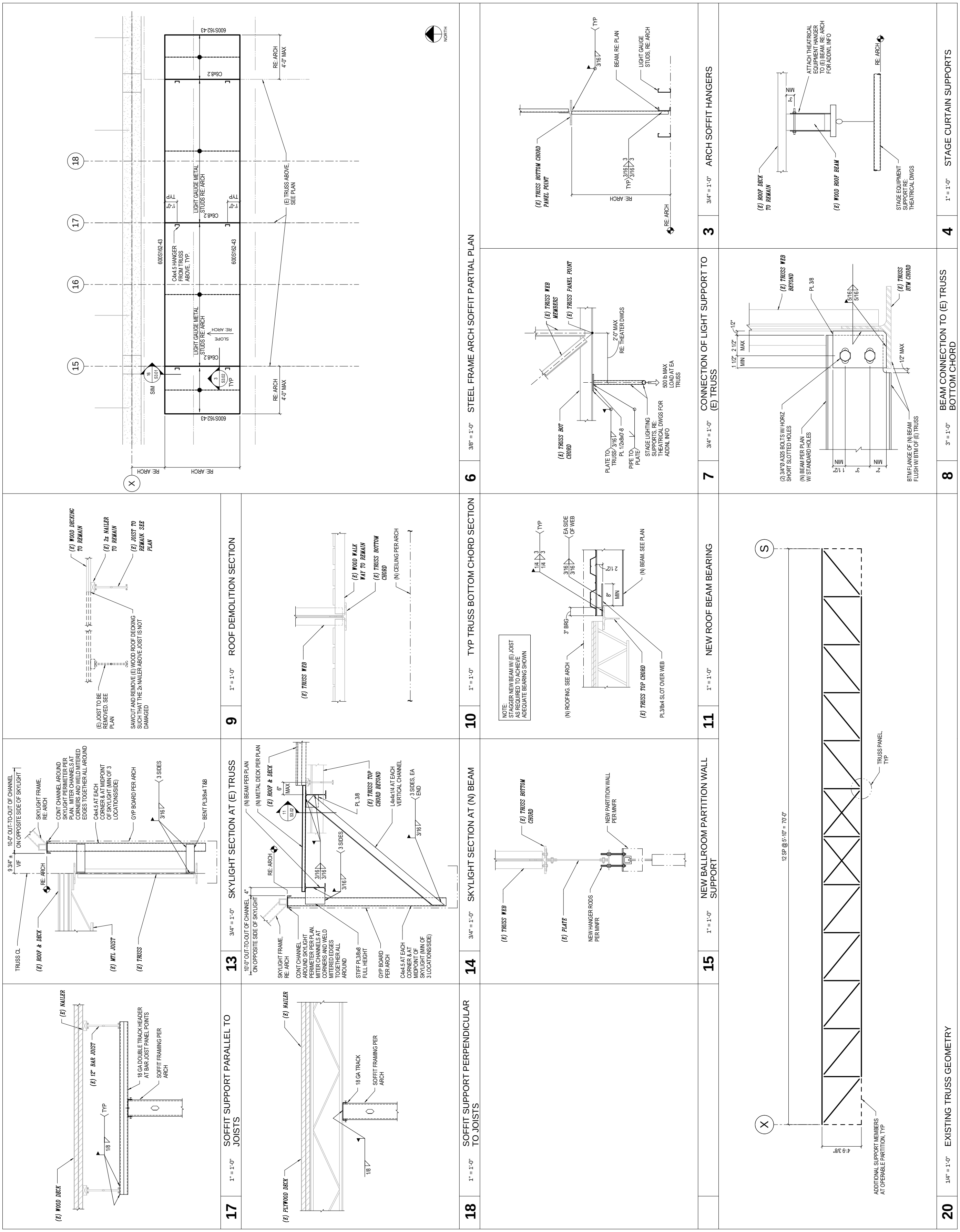
ROOF RECONSTRUCTION PLAN

1/8" = 1'-0"

NORTH

PLAN NOTES:

1. ALL RIGGING BEAMS TO BE LOCATED AT TRUSS PANEL POINTS.
2. RIGGING LOADS OF 500 LBS EACH ARE ALLOWED AT ANY TRUSS BOTTOM CHORD PANEL POINT MARKED AS ⯐ OR ANY LOCATION ALONG THE NEW RIGGINGS BEAM UNLESS NOTED OTHERWISE ON PLAN.
3. CONTRACTOR TO TAKE NECESSARY PRECAUTIONS WHEN WELDING ABOVE CEILING DUE TO COMBUSTIBLE WOOD DECK AND FRAMING.
4. INDICATES EXTENTS OF NEW NETAL DECK INFILL.


17 SOFFIT SUPPORT PARALLEL TO JOISTS 1" = 1'-0"
13 SKYLIGHT SECTION AT (E) TRUSS 3/4" = 1'-0"
9 ROOF DEMOLITION SECTION 1" = 1'-0"
6 STEEL FRAME ARCH SOFFIT PARTIAL PLAN 3/8" = 1'-0"
18 SOFFIT SUPPORT PERPENDICULAR TO JOISTS 1" = 1'-0"
14 SKYLIGHT SECTION AT (N) BEAM 3/4" = 1'-0"
10 TYP TRUSS BOTTOM CHORD SECTION 1" = 1'-0"
3 ARCH SOFFIT HANGERS 3/4" = 1'-0"
15 NEW BALLROOM PARTITION WALL SUPPORT 1" = 1'-0"
11 NEW ROOF BEAM BEARING 1" = 1'-0"
7 CONNECTION OF LIGHT SUPPORT TO (E) TRUSS 3/4" = 1'-0"
4 STAGE CURTAIN SUPPORTS 1" = 1'-0"
20 EXISTING TRUSS GEOMETRY 1/4" = 1'-0"
8 BEAM CONNECTION TO (E) TRUSS BOTTOM CHORD 3" = 1'-0"

PART 1 - GENERAL

1.1 SUMMARY

A. Section Includes:

1. Roof curbs.
2. Equipment supports.

B. Related Sections:

1. Division 01 Section “Sustainable Design Requirements – LEED for Commercial Interiors” for additional LEED requirements.
2. Division 01 Section “Construction Waste Management and Recycling.”
3. Division 07 Section "Sheet Metal Flashing and Trim" for shop- and field-formed metal flashing, roof-drainage systems, roof expansion-joint covers, and miscellaneous sheet metal trim and accessories.
4. Division 07 Section "Roof Specialties" for manufactured fasciae, copings, gravel stops, gutters and downspouts, and counterflashing.
5. Division 08 Section "Unit Skylights."

1.2 PERFORMANCE REQUIREMENTS

A. General Performance: Roof accessories shall withstand exposure to weather and resist thermally induced movement without failure, rattling, leaking, or fastener disengagement due to defective manufacture, fabrication, installation, or other defects in construction.

1.3 SUBMITTALS

A. Product Data: For each type of roof accessory indicated. Include construction details, material descriptions, dimensions of individual components and profiles, and finishes.

B. LEED Submittals:

1. Product Data for Credit MR 4: For products having recycled content, documentation indicating percentages by weight of postconsumer and preconsumer recycled content. Include statement indicating cost for each product having recycled content.

C. Shop Drawings: For roof accessories. Include plans, elevations, keyed details, and attachments to other work. Indicate dimensions, loadings, and special conditions. Distinguish between plant- and field-assembled work.

D. Samples: For each exposed product and for each color and texture specified, prepared on Samples of size to adequately show color.

E. Coordination Drawings: Roof plans, drawn to scale, and coordinating penetrations and roof-mounted items. Show the following:

1. Size and location of roof accessories specified in this Section.
2. Method of attaching roof accessories to roof or building structure.
3. Other roof-mounted items including mechanical and electrical equipment, ductwork, piping, and conduit.
4. Required clearances.

F. Operation and Maintenance Data: For roof accessories to include in operation and maintenance manuals.

1.4 COORDINATION

A. Coordinate layout and installation of roof accessories with interfacing and adjoining construction to provide a leakproof, weathertight, secure, and noncorrosive installation.

B. Coordinate dimensions with rough-in information or Shop Drawings of equipment to be supported.

PART 2 - PRODUCTS

2.1 METAL MATERIALS

A. Zinc-Coated (Galvanized) Steel Sheet: ASTM A 653/A 653M, G90 (Z275) coating designation and mill phosphatized for field painting where indicated. Provide one of the following finishes as directed by Architect.

1. Mill-Phosphatized Finish: Manufacturer's standard for field painting.
2. Factory Prime Coating: Where field painting is indicated, apply pretreatment and white or light-colored, factory-applied, baked-on epoxy primer coat, with a minimum dry film thickness of 0.2 mil (0.005 mm).
3. Exposed Coil-Coated Finish: Prepainted by the coil-coating process to comply with ASTM A 755/A 755M. Prepare, pretreat, and apply coating to exposed metal surfaces to comply with coating and resin manufacturers' written instructions.

   a. Two-Coat Fluoropolymer Finish: AAMA 621. System consisting of primer and fluoropolymer color topcoat containing not less than 70 percent PVDF resin by weight.

4. Baked-Enamel or Powder-Coat Finish: Immediately after cleaning and pretreating, apply manufacturer's standard two-coat, baked-on finish consisting of prime coat and thermosetting topcoat, with a minimum dry film thickness of 1 mil (0.025 mm) for topcoat. Comply with coating manufacturer's written instructions for applying and baking to achieve a minimum dry film thickness of 2 mils (0.05 mm).
5. Concealed Finish: Pretreat with manufacturer's standard white or light-colored acrylic or polyester-backer finish consisting of prime coat and wash coat, with a minimum total dry film thickness of 0.5 mil (0.013 mm).

B. Aluminum-Zinc Alloy-Coated Steel Sheet: ASTM A 792/A 792M, AZ50 (AZM150) coated. Provide one of the following finishes as directed by Architect.

1. Factory Prime Coating: Where field painting is indicated, apply pretreatment and white or light-colored, factory-applied, baked-on epoxy primer coat, with a minimum dry film thickness of 0.2 mil (0.005 mm).
2. Exposed Coil-Coated Finish: Prepainted by the coil-coating process to comply with ASTM A 755/A 755M. Prepare, pretreat, and apply coating to exposed metal surfaces to comply with coating and resin manufacturers' written instructions.

   a. Two-Coat Fluoropolymer Finish: AAMA 621. System consisting of primer and fluoropolymer color topcoat containing not less than 70 percent PVDF resin by weight.

3. Baked-Enamel or Powder-Coat Finish: Immediately after cleaning and pretreating, apply manufacturer's standard two-coat, baked-on finish consisting of prime coat and thermosetting topcoat, with a minimum dry film thickness of 1 mil (0.025 mm) for topcoat. Comply with coating manufacturer's written instructions for applying and baking to achieve a minimum dry film thickness of 2 mils (0.05 mm).
4. Concealed Finish: Pretreat with manufacturer's standard white or light-colored acrylic or polyester-backer finish consisting of prime coat and wash coat, with a minimum total dry film thickness of 0.5 mil (0.013 mm).

C. Aluminum Sheet: ASTM B 209 (ASTM B 209M), manufacturer's standard alloy for finish required, with temper to suit forming operations and performance required. Provide one of the following finishes as directed by Architect.

1. Mill Finish: As manufactured.
2. Factory Prime Coating: Where field painting is indicated, apply pretreatment and white or light-colored, factory-applied, baked-on epoxy primer coat, with a minimum dry film thickness of 0.2 mil (0.005 mm).
3. Clear Anodic Finish: AAMA 611, AA-M12C22A31, Class II, 0.010 mm or thicker.
4. Color Anodic Finish: AAMA 611, AA-M12C22A32/A34, Class II, 0.010 mm or thicker.
5. Exposed Coil-Coated Finish: Prepare, pretreat, and apply coating to exposed metal surfaces to comply with coating and resin manufacturers' written instructions.

   a. Two-Coat Fluoropolymer Finish: AAMA 620. System consisting of primer and fluoropolymer color topcoat containing not less than 70 percent PVDF resin by weight.

6. Baked-Enamel or Powder-Coat Finish: AAMA 2603 except with a minimum dry film thickness of 1.5 mils (0.04 mm). Comply with coating manufacturer's written instructions for cleaning, conversion coating, and applying and baking finish.
7. Concealed Finish: Pretreat with manufacturer's standard white or light-colored acrylic or polyester-backer finish consisting of prime coat and wash coat, with a minimum total dry film thickness of 0.5 mil (0.013 mm).

D. Aluminum Extrusions and Tubes: ASTM B 221 (ASTM B 221M), manufacturer's standard alloy and temper for type of use, finished to match assembly where used, otherwise mill finished.

E. Copper Sheet: ASTM B 370, manufacturer's standard temper.

F. Stainless-Steel Sheet and Shapes: ASTM A 240/A 240M or ASTM A 666, Type 304.

G. Steel Shapes: ASTM A 36/A 36M, hot-dip galvanized according to ASTM A 123/A 123M unless otherwise indicated.

H. Galvanized-Steel Tube: ASTM A 500, round tube, hot-dip galvanized according to ASTM A 123/A 123M.

I. Steel Pipe: ASTM A 53/A 53M, galvanized.

2.2 MISCELLANEOUS MATERIALS

A. General: Provide materials and types of fasteners, protective coatings, sealants, and other miscellaneous items required by manufacturer for a complete installation.

B. Glass-Fiber Board Insulation: ASTM C 726, thickness as indicated.

C. Polyisocyanurate Board Insulation: ASTM C 1289, thickness as indicated.

D. Fasteners: Roof accessory manufacturer's recommended fasteners suitable for application and metals being fastened. Match finish of exposed fasteners with finish of material being fastened. Provide nonremovable fastener heads to exterior exposed fasteners. Furnish the following unless otherwise indicated:

1. Fasteners for Zinc-Coated or Aluminum-Zinc Alloy-Coated Steel: Series 300 stainless steel or hot-dip zinc-coated steel according to ASTM A 153/A 153M or ASTM F 2329.
2. Fasteners for Aluminum Sheet: Aluminum or Series 300 stainless steel.
3. Fasteners for Copper Sheet: Copper, hardware bronze, or passivated Series 300 stainless steel.
4. Fasteners for Stainless-Steel Sheet: Series 300 stainless steel.

E. Gaskets: Manufacturer's standard tubular or fingered design of neoprene, EPDM, PVC, or silicone or a flat design of foam rubber, sponge neoprene, or cork.

F. Elastomeric Sealant: ASTM C 920, elastomeric silicone polymer sealant as recommended by roof accessory manufacturer for installation indicated; low modulus; of type, grade, class, and use classifications required to seal joints and remain watertight.

G. Butyl Sealant: ASTM C 1311, single-component, solvent-release butyl rubber sealant; polyisobutylene plasticized; heavy bodied for expansion joints with limited movement.

2.3 ROOF CURBS

A. Roof Curbs: Internally reinforced roof-curb units capable of supporting superimposed live and dead loads, including equipment loads and other construction indicated on Drawings; with welded or mechanically fastened and sealed corner joints, and integrally formed deck-mounting flange at perimeter bottom.

1. Manufacturers: Subject to compliance with requirements, available manufacturers offering products that may be incorporated into the Work include, but are not limited to, the following:

a. AES Industries, Inc.
b. LM Curbs.
c. Metallic Products Corp.
d. Roof Products, Inc.

e. Thybar Corporation.

B. Size: Coordinate dimensions with roughing-in information or Shop Drawings of equipment to be supported.

1. Height: 12 inches from roof to top of curb.

C. Material: As selected by Architect from manufacturer’s full range.

1. Finish: As selected by Architect from manufacturer’s full range.
2. Color: Match Architect's sample.

D. Construction:

1. Insulation: Factory insulated with minimum 1-1/2-inch- (38-mm-) thick glass-fiber board insulation.
2. Liner: Same material as curb, of manufacturer's standard thickness and finish.
3. Factory-installed wood nailer at top of curb, continuous around curb perimeter.
4. On ribbed or fluted metal roofs, form deck-mounting flange at perimeter bottom to conform to roof profile.
5. Fabricate curbs to minimum height of 12 inches (300 mm) unless otherwise indicated.
6. Top Surface: Level around perimeter with roof slope accommodated by sloping the deck-mounting flange.
7. Sloping Roofs: Where roof slope exceeds 1:48, fabricate curb with perimeter curb height tapered to accommodate roof slope so that top surface of perimeter curb is level. Equip unit with water diverter or cricket on side that obstructs water flow.

2.4 EQUIPMENT SUPPORTS

A. Equipment Supports: Internally reinforced metal equipment supports capable of supporting superimposed live and dead loads, including equipment loads and other construction indicated on Drawings; with welded or mechanically fastened and sealed corner joints, and integrally formed deck-mounting flange at perimeter bottom.

1. Manufacturers: Subject to compliance with requirements, available manufacturers offering products that may be incorporated into the Work include, but are not limited to, the following:

a. AES Industries, Inc.
b. Curbs Plus, Inc.
c. LM Curbs.
d. Milcor Inc.; Commercial Products Group of Hart & Cooley, Inc.
e. Thybar Corporation.

B. Size: Coordinate dimensions with roughing-in information or Shop Drawings of equipment to be supported.

C. Material: As selected by Architect from manufacturer’s full range.

1. Finish: As selected by Architect from manufacturer’s full range.
2. Color: Match Architect's sample.

D. Construction:

1. Insulation: Factory insulated with 1-1/2-inch- (38-mm-) thick glass-fiber board insulation.
2. Liner: Same material as equipment support, of manufacturer's standard thickness and finish.
3. Factory-installed continuous wood nailers minimum 3-1/2 inches (90 mm) wide at tops of equipment supports.
4. Metal Counterflashing: Manufacturer's standard, removable, fabricated of same metal and finish as equipment support.
5. On ribbed or fluted metal roofs, form deck-mounting flange at perimeter bottom to conform to roof profile.
6. Fabricate equipment supports to minimum height of 12 inches (300 mm) unless otherwise indicated.
7. Sloping Roofs: Where roof slope exceeds 1:48, fabricate each support with height to accommodate roof slope so that tops of supports are level with each other. Equip supports with water diverters or crickets on sides that obstruct water flow.

2.5 GENERAL FINISH REQUIREMENTS

A. Comply with NAAMM's "Metal Finishes Manual for Architectural and Metal Products" for recommendations for applying and designating finishes.

B. Appearance of Finished Work: Noticeable variations in same piece are not acceptable. Variations in appearance of adjoining components are acceptable if they are within the range of approved Samples and are assembled or installed to minimize contrast.

PART 3 - EXECUTION

3.1 EXAMINATION

A. Examine substrates, areas, and conditions, with Installer present, to verify actual locations, dimensions, and other conditions affecting performance of the Work.

B. Verify that substrate is sound, dry, smooth, clean, sloped for drainage, and securely anchored.

C. Verify dimensions of roof openings for roof accessories.

D. Proceed with installation only after unsatisfactory conditions have been corrected.

3.2 INSTALLATION

A. General: Install roof accessories according to manufacturer's written instructions.

1. Install roof accessories level, plumb, true to line and elevation, and without warping, jogs in alignment, excessive oil canning, buckling, or tool marks.
2. Anchor roof accessories securely in place so they are capable of resisting indicated loads.
3. Use fasteners, separators, sealants, and other miscellaneous items as required to complete installation of roof accessories and fit them to substrates.

4. Install roof accessories to resist exposure to weather without failing, rattling, leaking, or loosening of fasteners and seals.

B. Metal Protection: Protect metals against galvanic action by separating dissimilar metals from contact with each other or with corrosive substrates by painting contact surfaces with bituminous coating or by other permanent separation as recommended by manufacturer.

1. Coat concealed side of uncoated aluminum or stainless-steel roof accessories with bituminous coating where in contact with wood, ferrous metal, or cementitious construction.
2. Underlayment: Where installing roof accessories directly on cementitious or wood substrates, install a course of felt underlayment and cover with a slip sheet, or install a course of polyethylene sheet.
3. Bed flanges in thick coat of asphalt roofing cement where required by manufacturers of roof accessories for waterproof performance.

C. Roof Curb Installation: Install each roof curb so top surface is level.

D. Equipment Support Installation: Install equipment supports so top surfaces are level with each other.

E. Seal joints with elastomeric or butyl sealant as required by roof accessory manufacturer.

3.3 REPAIR AND CLEANING

A. Galvanized Surfaces: Clean field welds, bolted connections, and abraded areas and repair galvanizing according to ASTM A 780.

B. Touch up factory-primed surfaces with compatible primer ready for field painting according to Division 09 painting Sections.

C. Clean exposed surfaces according to manufacturer's written instructions.

D. Clean off excess sealants.

E. Replace roof accessories that have been damaged or that cannot be successfully repaired by finish touchup or similar minor repair procedures.

END OF SECTION 077200

PART 1 - GENERAL

1.1 SUMMARY

A. This Section includes assemblies incorporating fiberglass sandwich panels and aluminum frame systems as follows:

1. Skylight assemblies.

B. Related Sections include the following:

1. Division 01 Section “Sustainable Design Requirements – LEED for Commercial Interiors” for additional LEED requirements.
2. Division 01 Section “Construction Waste Management and Recycling.”
3. Division 05 Section "Structural Steel Framing" for steel framing that supports skin-system assemblies.
4. Division 07 Section "Thermal Insulation" for insulation materials field installed with assemblies.
5. Division 07 Section "Sheet Metal Flashing and Trim" for metal flashings installed at perimeters of assemblies.
6. Division 07 Section "Joint Sealants" for sealants installed at perimeters of assemblies.

1.2 PERFORMANCE REQUIREMENTS

A. Provide assemblies, including anchorage, capable of withstanding, without failure, the effects of the following:

1. Structural loads.
2. Thermal movements.
3. Movements of supporting structure.
4. Dimensional tolerances of building frame and other adjacent construction.

B. Failure includes the following:

1. Deflection exceeding specified limits.
2. Water leakage.
3. Thermal stresses transferred to building structure.
4. Noise or vibration created by wind and thermal and structural movements.
5. Loosening or weakening of fasteners, attachments, and other components.
6. Delamination of fiberglass-sandwich-panel faces from panel cores.

C. Structural Loads:

1. Wind Loads: As indicated by structural design data on Drawings
2. Snow Loads: As indicated by structural design data on Drawings
3. Concentrated Live Loads on Overhead Assemblies: 300 lbf (1334 N) applied to assemblies at locations that will produce greatest stress or deflection.
4. Load Combinations: Calculate according to requirements of applicable code indicated on Drawings.

D. Thermal Movements: Allow for thermal movements from ambient and surface temperature changes. Base engineering calculation on surface temperatures of materials due to both solar heat gain and nighttime-sky heat loss.

1. Temperature Change (Range): 120 deg F (67 deg C), ambient; 180 deg F (100 deg C), material surfaces.

1.3 PERFORMANCE TESTING

A. Provide assemblies that comply with test-performance requirements indicated, as evidenced by reports of tests performed on manufacturer's standard assemblies by a qualified independent testing agency.

1. Owner will engage a testing agency to perform preconstruction tests on laboratory mockups of assemblies.
2. Build laboratory mockups at testing agency facility using personnel, materials, and methods of construction that will be used at Project site.
3. Notify Architect seven days in advance of the dates and times when laboratory mockups will be constructed.
4. Preconstruction Testing Sequence: Perform specified tests on laboratory mockups in the following order:

a. Structural-performance preloading (ASTM E 330).
b. Air infiltration (ASTM E 283).
c. Water penetration under static pressure (ASTM E 331).
d. Water penetration under dynamic pressure (AAMA 501.1).
e. Water penetration, wind-driven rain (ICBO ES AC07).
f. Structural performance at design load (ASTM E 330).

B. Structural-Performance Test: ASTM E 330.

1. Performance at Design Load: When tested at positive and negative wind-load design pressures, assemblies do not evidence deflection exceeding specified limits.
2. Performance at Maximum Test Load: When tested at 150 percent of positive and negative wind-load design pressures, assemblies, including anchorage, do not evidence material failures, structural distress, and permanent deformation of main supporting members exceeding 0.2 percent of span.
3. Test Durations: As required by design wind velocity but not less than 10 seconds.

C. Air-Infiltration Test: ASTM E 283.

1. Minimum Static-Air-Pressure Difference: 6.24 lbf/sq. ft. (300 Pa).
2. Maximum Air Leakage: 0.06 cfm/sq. ft. (0.30 L/s per sq. m).

D. Test for Water Penetration under Static Pressure: ASTM E 331.

1. Minimum Static-Air-Pressure Difference: 20 percent of positive wind-load design pressure, but not less than 10 lbf/sq. ft. (479 Pa).
2. Water Leakage: None.

E. Test for Water Penetration under Dynamic Pressure: AAMA 501.1.

1. Dynamic Pressure: 20 percent of positive wind-load design pressure, but not less than 15 lbf/sq. ft. (718 Pa).
2. Water Leakage: None, as defined by AAMA 501.1. Water controlled by flashing and gutters that is drained to exterior and cannot damage adjacent materials or finishes is not considered water leakage.

F. Water-Penetration, Wind-Driven-Rain Test: Wind-driven-rain test in ICBO ES AC07, "Special Roofing Systems."

1. Water Leakage: None.

1.4 SUBMITTALS

A. Product Data: Include construction details, material descriptions, dimensions of individual components and profiles, and finishes for assemblies.

B. LEED Submittals:

1. Product Data for Credit IEQ 4.1: For sealants used inside the weatherproofing system, documentation including printed statement of VOC content.

C. Shop Drawings: For assemblies. Include plans, elevations, sections, details, and attachments to other work.

1. Include structural analysis data signed and sealed by the qualified professional engineer responsible for their preparation.

D. Samples for Verification: For each type of exposed finish required, in manufacturer's standard sizes.

E. Fabrication Sample: Of each frame system intersection of assemblies, made from 12-inch (300-mm) lengths of full-size components and showing details of the following:

1. Joinery.
2. Anchorage.
3. Expansion provisions.
4. Fiberglass sandwich panels.
5. Flashing and drainage.

F. Product Test Reports: Based on evaluation of comprehensive tests performed by a qualified testing agency, for assemblies.

G. Preconstruction Testing Program: For assemblies, developed specifically for Project. Include plans, elevations, sections, and details of laboratory mockup.

H. Preconstruction Test Reports: For assemblies.

I. Field quality-control test reports.

J. Warranties: Special warranties specified in this Section.

K. Maintenance Data: For assemblies to include in maintenance manuals.

1.5 QUALITY ASSURANCE

A. Installer Qualifications: Entity capable of assuming engineering responsibility, including preparation of Shop Drawings, and performing work of this Section and who is acceptable to manufacturer.

B. Manufacturer Qualifications: For fiberglass sandwich panels, a qualified manufacturer whose facilities, processes, and products are monitored by an independent, accredited quality-control agency for compliance with applicable requirements in ICBO ES AC04, "Sandwich Panels."

C. Testing Agency Qualifications: An independent agency qualified according to ASTM E 699 for testing indicated.

D. Product Options: Information on Drawings and in Specifications establishes requirements for assemblies' aesthetic effects and performance characteristics. Aesthetic effects are indicated by dimensions, arrangements, alignment, and profiles of components and assemblies as they relate to sightlines, to one another, and to adjoining construction. Performance characteristics are indicated by criteria subject to verification by one or more methods including testing conducted by an independent testing agency and in-service performance.

1. Do not modify intended aesthetic effects, as judged solely by Architect, except with Architect's approval. If modifications are proposed, submit comprehensive explanatory data to Architect for review.

E. Fire-Test-Response Characteristics: Where fire-test-response characteristics are indicated for assemblies and components, provide products identical to those tested per test method indicated by an independent testing and inspecting agency acceptable to authorities having jurisdiction.

F. Welding: Qualify procedures and personnel according to AWS D1.2, "Structural Welding Code - Aluminum."

G. NFRC Certification: Provide fiberglass sandwich panels that are certified for U-factors indicated according to NFRC 100 and listed in its "National Fenestration Council Incorporated - Certified Products Directory."

H. Mockups: Build mockups to demonstrate aesthetic effects and set quality standards for fabrication and installation.

1. Build mockup of typical assembly area as shown on Drawings.
2. Field testing shall be performed on mockups according to requirements in Part 3 "Field Quality Control" Article.
3. Approved mockups may become part of the completed Work if undisturbed at time of Substantial Completion.

I. Preinstallation Conference: Conduct conference at Project site to comply with requirements in Division 01 Section "Project Management and Coordination."

1.6 PROJECT CONDITIONS

A. Field Measurements: Indicate measurements on Shop Drawings.

1.7 WARRANTY

A. Special Fiberglass-Sandwich-Panel Warranty: Manufacturer's standard form in which manufacturer agrees to replace panels that exhibit defects in materials or workmanship.

1. Defects include, but are not limited to, the following:

a. Fiberbloom.
b. Delamination of coating, if any, from exterior face sheet.
c. Discoloration of exterior face sheet of more than 8.0 units Delta E when measured according ASTM D 2244.
d. Delamination of panel face sheets from panel cores.

2. Warranty Period: 20 years from date of Substantial Completion.

PART 2 - PRODUCTS

2.1 MANUFACTURERS

A. Available Manufacturers: Subject to compliance with requirements, manufacturers offering products that may be incorporated into the Work include, but are not limited to, the following:

1. Kalwall Corporation.
2. Major Industries, Inc.
3. Skywall Translucent Systems; Vistawall Group (The).
4. Structures Unlimited, Inc.

2.2 ALUMINUM FRAME SYSTEMS

A. Aluminum: Alloy and temper recommended in writing by manufacturer for type of use and finish indicated.

1. Sheet and Plate: ASTM B 209 (ASTM B 209M).
2. Extruded Bars, Rods, Profiles, and Tubes: ASTM B 221 (ASTM B 221M).
3. Extruded Structural Pipe and Tubes: ASTM B 429.

B. Components: Manufacturer's standard extruded-aluminum members of thickness required and reinforced as required to support imposed loads.

1. Construction: Thermally broken; framing members are composite assemblies of two separate extruded-aluminum components permanently bonded by a material of low thermal conductance.

C. Exposed Flashing and Closures: Manufacturer's standard aluminum components not less than 0.060 inch (1.524 mm) thick.

D. Frame-System Gaskets: Manufacturer's standard.

E. Frame-System Sealants: As recommended in writing by manufacturer.

1. Sealants used inside the weatherproofing system shall have a VOC content of 250 g/L or less when calculated according to 40 CFR 59, Subpart D (EPA Method 24).

F. Anchors, Fasteners, and Accessories: Manufacturer's standard, corrosion-resistant, nonstaining, and nonbleeding; compatible with adjacent materials.

1. At closures, retaining caps, or battens, use ASTM A 193/A 193M, 300 series stainless-steel screws.
2. Where fasteners are subject to loosening or turning out from thermal and structural movements, wind loads, or vibration, use self-locking devices.
3. At movement joints, use slip-joint linings, spacers, and sleeves of material and type recommended in writing by manufacturer.

G. Concrete and Masonry Inserts: Hot-dip galvanized cast-iron, malleable-iron, or steel inserts complying with ASTM A 123/A 123M or ASTM A 153/A 153M requirements.

H. Anchor Bolts: ASTM A 307, Grade A (ASTM F 568M, Property Class 4.6), hot-dip zinc coating, ASTM A 153/A 153M, Class C.

I. Frame System Fabrication:

1. Fabricate components before finishing.
2. Fabricate components that, when assembled, have the following characteristics:

a. Profiles that are sharp, straight, and free of defects or deformations.
b. Accurately fitted joints with ends coped or mitered.
c. Internal guttering systems or other means to drain water passing joints, condensation occurring within components, and moisture migrating within the assembly to exterior.

3. Fabricate sill closures with weep holes and for installation as continuous component.
4. Reinforce components as required to receive fastener threads.
5. Weld components in concealed locations to greatest extent possible to minimize distortion or discoloration of finish. Remove weld spatter and welding oxides from exposed surfaces by descaling or grinding.

2.3 FIBERGLASS SANDWICH PANELS

A. Panel Construction: Assembly of uniformly colored, translucent, thermoset, fiberglass-reinforced-polymer face sheets bonded to both sides of a grid core and complying with requirements applicable to panel materials in ICBO ES AC04, "Sandwich Panels."

1. Face-Sheet, Self-Ignition Temperature: 650 deg F (343 deg C) or more per ASTM D 1929.
2. Face-Sheet Burning Extent: 1 inch (25 mm) or less per ASTM D 635.
3. Face-Sheet, Smoke-Developed Index: 450 or less per ASTM E 84.
4. Interior Face-Sheet, Flame-Spread Index: Not more than 50 per ASTM E 84.

B. Panel Thickness: 2-3/4 inches (70 mm).

C. Panel U-Factor: Not more than 0.23 (1.31), measured in Btu/sq. ft. x h x deg F (W/sq. m x K) according to NFRC 100 or ASTM C 1363 using procedures described in ASTM C 1199 and ASTM E 1423.

D. Panel Strength Characteristics:

1. Maximum Panel Deflection: 3-1/2 inches (89 mm) when a 4-by-12-foot (1.2-by-3.6-m) panel is tested according to ASTM E 72 at 34 lbf/ sq. ft. (1.6 kPa), with a maximum 0.090-inch (2.3-mm) set deflection after 5 minutes.
2. Panel Support Strength: Capable of supporting, without failure, a 300-lbf (1334 N) concentrated load when applied to a 3-inch- (76-mm-) diameter disk according to ASTM E 661.

E. Grid Core: Mechanically interlocked extruded-aluminum I-beams, with a minimum flange width of 7/16 inch (11.1 mm).

1. Extruded Aluminum: ASTM B 221 (ASTM B 221M), in alloy and temper recommended in writing by manufacturer.
2. I-Beam Construction: Thermally broken; two separate extruded-aluminum components permanently bonded by a material of low thermal conductance.
3. Grid Pattern: As indicated on Drawings.

F. Exterior Face Sheet:

1. Thickness: 0.070 inches (1.778 mm).
2. Color: Crystal.
3. Color Stability: Not more than 3.0 units Delta E when measured according to ASTM D 2244 after outdoor weathering in southern Florida according to procedures in ASTM D 1435 with panels mounted facing south and as follows:

   a. Panel Mounting Angle: Not more than 5 degrees from horizontal.
   b. Exposure Period: 60 months.

G. Interior Face Sheet:

1. Thickness: 0.045 inch (1.143 mm).
2. Color: White.

H. Fiberglass-Sandwich-Panel Adhesive: ASTM D 2559.

1. Compatible with facing and core materials.
2. Tensile and shear bond strength of aged adhesive ensures permanent adhesion of facings to cores, as evidenced by testing according to ASTM C 297 and ASTM D 1002 after accelerated aging procedures that comply with aging requirements for adhesives with high resistance to moisture in ICBO ES AC05, "Sandwich Panel Adhesives."

I. Panel Fabrication: Factory assemble and seal panels.

1. Laminate face sheets to grid core under a controlled process using heat and pressure to produce straight adhesive bonding lines that cover width of core members and that have sharp edges.

   a. White spots indicating lack of bond at intersections of grid-core members are limited in number to 4 for every 40 sq. ft. (3.7 sq. m) of panel and limited in diameter to 3/64 inch (1.2 mm).

2. Fabricate with grid pattern that is symmetrical about centerlines of each panel.
3. Fabricate panel to allow condensation within panel to escape.

4. Reinforce panel corners.

2.4 ACCESSORY MATERIALS

A. Insulating Materials: Specified in Division 07 Section "Thermal Insulation."

B. Bituminous Paint: Cold-applied asphalt-mastic paint complying with SSPC-Paint 12 requirements except containing no asbestos, formulated for 30-mil (0.762-mm) thickness per coat.

2.5 ALUMINUM FINISHES

A. General: Comply with NAAMM's "Metal Finishes Manual for Architectural and Metal Products" for recommendations for applying and designating finishes.

B. Finish designations prefixed by AA comply with the system established by the Aluminum Association for designating aluminum finishes.

C. Class II, Clear Anodic Finish: AA-M12C22A31 (Mechanical Finish: nonspecular as fabricated; Chemical Finish: etched, medium matte; Anodic Coating: Architectural Class II, clear coating 0.010 mm or thicker) complying with AAMA 611, unless otherwise noted on Drawings.

PART 3 - EXECUTION

3.1 EXAMINATION

A. Examine areas, with Installer present, for compliance with requirements for installation tolerances and other conditions affecting performance of work.

1. Proceed with installation only after unsatisfactory conditions have been corrected.

3.2 INSTALLATION

A. General:

1. Comply with manufacturer's written instructions.
2. Do not install damaged components.
3. Fit joints between aluminum components to produce hairline joints free of burrs and distortion.
4. Rigidly secure nonmovement joints.
5. Install anchors with separators and isolators to prevent metal corrosion and electrolytic deterioration and to prevent impeding movement of moving joints.
6. Weld aluminum components in concealed locations to minimize distortion or discoloration of finish. Protect glazing surfaces from welding.
7. Seal joints watertight, unless otherwise indicated.

B. Metal Protection: Where aluminum components will contact dissimilar materials, protect against galvanic action by painting contact surfaces with bituminous paint or by installing nonconductive spacers as recommended in writing by manufacturer for this purpose.

C. Install continuous aluminum sill closure with weatherproof expansion joints and locked and sealed or welded corners. Locate weep holes at rafters.

D. Install components to drain water passing joints, condensation occurring within aluminum members and panels, and moisture migrating within assembly to exterior.

E. Install components plumb and true in alignment with established lines and elevations.

F. Install insulation materials as specified in Division 07 Section "Thermal Insulation."

G. Erection Tolerances: Install assemblies to comply with the following maximum tolerances:

1. Alignment: Limit offset from true alignment to 1/32 inch (0.8 mm) where surfaces abut in line, edge to edge, at corners, or where a reveal or protruding element separates aligned surfaces by less than 3 inches (76 mm); otherwise, limit offset to 1/8 inch (3.2 mm).
2. Location and Plane: Limit variation from true location and plane to 1/8 inch in 12 feet (3.2 mm in 3.7 m); 1/2 inch (13 mm) over total length.

3.3 FIELD QUALITY CONTROL

A. Testing Agency: Owner will engage a qualified independent testing and inspecting agency to perform field tests and inspections and prepare test reports.

B. Testing Services: Testing and inspecting of representative areas to determine compliance of installed assemblies with specified requirements shall take place as follows and in successive stages as indicated on Drawings. Do not proceed with installation of the next area until test results for previously completed areas show compliance with requirements.

1. Water Penetration under Static Pressure: Before installation of interior finishes has begun, areas shall be tested according to ASTM E 1105.

   a. Test Procedures: Test under uniform and cyclic static air pressure.
   b. Water Penetration: None.

2. Water-Spray Test: Before installation of interior finishes has begun, assemblies shall be tested according to AAMA 501.2 and shall not evidence water penetration.

C. Repair or remove work where test results and inspections indicate that it does not comply with specified requirements.

D. Additional testing and inspecting, at Contractor's expense, will be performed to determine compliance of replaced or additional work with specified requirements.

END OF SECTION 084523