SAFETY RISK QUANTIFICATION AND MITIGATION FOR HIGH PERFORMANCE SUSTAINABLE BUILDING CONSTRUCTION

by

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ABSTRACT

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Safety Risk Quantification and Mitigation for High Performance Sustainable Building Construction

Thesis directed by Professor Matthew R. Hallowell

Recent studies have found that LEED buildings have a higher injury rate than non-LEED buildings and there are fourteen LEED credits that increase risk for construction workers. The present study had two main goals: 1) quantify the perceived percent increase in safety risk resulting from the design strategies and construction methods implemented to earn specific LEED credits and 2) identify risk mitigation strategies and construction safety management techniques for high performance sustainable projects. The results indicate that fourteen LEED credits for new construction increase the frequency of injuries or exposure to known risks. The results also provide feasible prevention through design and construction safety management strategies to mitigate safety risk for design and construction methods used to achieve the LEED credits. Practitioners may use findings to enhance safety for construction workers, an aspect of sustainability that is not currently addressed in the LEED program.

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A recent study found that LEED certified buildings have a recordable injury rate that is 9 percent higher than traditional, non-LEED buildings. Additionally, a follow-up study showed that there are distinct aspects of the design elements and means and methods of construction used to achieve LEED certification that have negative impacts on worker safety. This research builds on the study that distinguished twelve LEED credits to have an increase in hazard by actually quantifying the perceived percent increase in safety risk resulting from the design strategies and construction methods implemented to earn specific LEED credits. This will determine the relative magnitudes of risk associated with each credit so that they can be weighed against each other. A total of twenty-six interviews were conducted with designers and contractors who had completed, on average, 4 LEED projects, 100 traditional projects, and averaged eighteen years of experience in the industry. The results indicate that fourteen of the 49 LEED credits for new construction increase the frequency of injuries or exposure to known high risk environments. The most significant impacts are a 36% increase in lacerations, strains and sprains when recycling construction materials; a 24% increase in falls to lower level during roof work because of the installation of on-site renewable energy (e.g., PV panels); a 19% increase in eye strain when installing reflective roof membranes; a 14% increase in exposure to harmful substances when installing innovative wastewater technologies; and a 13% increase in overexertion injuries when lifting sustainable roof membranes. These results can be used to better understand the safety impacts of sustainable building design that will enhance designer awareness and help contractors to better prioritize safety resources.

CHAPTER TWO: MANUSCRIPT ONE: RISK QUANTIFICATION

1.0 Abstract

A recent study found that LEED certified buildings have a recordable injury rate that is 9 percent higher than traditional, non-LEED buildings. Additionally, a follow-up study showed that there are distinct aspects of the design elements and means and methods of construction used to achieve LEED certification that have negative impacts on worker safety. This research builds on the study that distinguished twelve LEED credits to have an increase in hazard by actually quantifying the perceived percent increase in safety risk resulting from the design strategies and construction methods implemented to earn specific LEED credits. This will determine the relative magnitudes of risk associated with each credit so that they can be weighed against each other. A total of twenty-six interviews were conducted with designers and contractors who had completed, on average, 4 LEED projects, 100 traditional projects, and averaged eighteen years of experience in the industry. The results indicate that fourteen of the 49 LEED credits for new construction increase the frequency of injuries or exposure to known high risk environments. The most significant impacts are a 36% increase in lacerations, strains and sprains when recycling construction materials; a 24% increase in falls to lower level during roof work because of the installation of on-site renewable energy (e.g., PV panels); a 19% increase in eye strain when installing reflective roof membranes; a 14% increase in exposure to harmful substances when installing innovative wastewater technologies; and a 13% increase in overexertion injuries when lifting sustainable roof membranes. These results can be used to better understand the safety impacts of sustainable building design that will enhance designer awareness and help contractors to better prioritize safety resources.

2.0 Introduction

The United States Green Building Council (USGBC) was formed to promote the construction of buildings that are cost-efficient and energy-saving (USGCB 2006). The USGBC developed a green building rating system called Leadership in Energy and Environmental Design (LEED), which was first implemented in 1998. LEED is a voluntary, consensus-based national standard that is used as a standard to certify high performance sustainable buildings. There are nine different versions of the LEED rating system. LEED for new construction is the most commonly used system and has a point system with six different categories: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Material and Resources, Indoor Environmental Quality, and Innovation in Design (USGBC 2010). Buildings are formally certified at the following levels, depending on the proportion of the 69 possible credits that can be achieved: Certified, Silver, Gold, and Platinum. LEED was used as the framework because it is the most widely used green building accreditation program in the US.

The popularity of green buildings has grown rapidly due to a perceived decrease in negative environmental impact and monetary savings through decreased utility costs (Eicholtz et al. 2008; Fuerst et al. 2008; Miller et al. 2008). Though there are apparent benefits to the LEED program, general contractors claim that LEED projects tend to be more complex and require additional time to complete (Schaufelberger et al. 2009). Previous research on the construction impacts of sustainable building design has focused primarily on the schedule, quality, and cost implications. However, one study conducted by Rajendran et al. (2009) found that LEED certified projects had a mean recordable injury rate (RIR) of 6.12 injuries per 200,000 worker-hours while non-LEED projects had a mean RIR of 5.63. Rajendran et al. hypothesized that this increase in safety risk is tied to an increase in work at height and the installation of new building elements such as photovoltaic (PV) panels. Rajendran (2006) explained that LEED offers a negligible consideration for the safety of construction workers. Consequently, the authors argued that, to be labeled as “sustainable,” buildings must be safe to construct.

Another study conducted by Fortunato (2010) identified the new safety risks resulting from the design and construction strategies implemented to achieve LEED certification. The case studies revealed that a total of twelve credits increased safety risks when compared to traditional projects. For example, to achieve the LEED credit for material recycling, construction workers on several projects entered dumpsters to retrieve and sort recyclable materials due to a lack of education and training in understand the front end requirements for recycling. Such work was found to result in an increased frequency of lacerations, strains, and sprains. The results reported by Fortunato (2010) and Rajendran et al. (2009) provide compelling evidence that sustainable high performance buildings are more dangerous to construct than their non-green counterparts.

Researchers have projected that the value of green building will increase by $60 billion over the next decade, resulting from the construction of over one million LEED certified buildings. Though this rapid growth is exciting, it is essential for designers and constructors to identify, analyze, manage, and respond to the increased safety risks associated with sustainable design and construction. The objective of this present research is to quantify the relative increase in safety risk resulting from the design elements and construction means and methods implemented to achieve LEED credits. The authors expect that this increase in knowledge is essential for identifying the highest risk design elements and construction activities and for prioritizing safety resources that must ultimately be allocated to respond to these risks.

3.0 Literature Review

Literature related to safety risk quantification and categorization of risk as well as comparative risk was completed. Additionally, literature related specific to the safety of sustainable building design and construction was reviewed.

3.1 Safety Risk Assessment

The research framework for this study was established on a strong foundation in risk quantification. The most common method of safety risk quantification involves separately measuring the following three components: frequency, severity, and exposure. The relationship among these variables is illustrated in Equation 1. In this relationship, frequency refers to the number of events per unit of time, severity is the magnitude of the potential outcome of an event, and exposure is the duration of contact with a potentially hazardous condition. This risk quantification strategy has been used as an analytical technique in several safety studies (e.g., Jannadi and Almishari (2003); Barandan and Usmen (2006); and Hallowell and Gambatese (2009)). Brauer (1994) used this method of quantifying risk by classifying the frequency of the occurrence of different events and severity levels. Likewise, Everett (1999) quantified the frequency and severity of ergonomic risks associated with different construction processes using a Likert scoring system. Jannandi and Almishari (2003) aimed to formalize the safety quantification process by developing a model to determine risk scores for construction activities.

Safety Risk = Frequency x Severity x Exposure **Equation 1**

Quantifying frequency, severity, and exposure values can be a very difficult task because data can be difficult to collect due to underreporting, poor recordkeeping, and insufficient archival databases (Hallowell and Gambatese 2009). There is a level of liability issues that occur with over-documentation which also adds to the difficult of collecting safety data. Data are also rarely collected for low-severity outcomes such as near misses, persistent pain, and first-aid injuries. To address this limitation, relative risks have been quantified using expert opinion surveys and interviews. These studies have shown that highly qualified industry professionals are capable of accurately quantifying relative safety risks for specific tasks and work environments (Hallowell and Gambatese 2010). Several researchers have used Equation 1 and input from experienced professionals to perform comparative risk analysis for various work environments and trades. For example, Baradan and Usmen (2006) compared safety risks for various trades, Larsson and Field (2002) asked respondents to rate the difference in frequency of injuries based on a merger of worker's compensation data from the public works fund Victorian Workcover Authority from 1996-1998, and Zou (2009) compared industry practitioner's recognition of safety risk factors in order to pinpoint the most impactful risks. The study by Zou aimed to understand how construction personnel perceive safety risks in China as compared to Austalia. In the present study, a comparative risk assessment was performed by directly comparing the design and construction strategies employed to achieve individual LEED credits with the traditional building strategies identified by Fortunato (2010).

3.2 Risk Categories

To classify the risk comparisons, the research team utilized risk classification schemes developed in previous studies. The Bureau of Labor Statistics, the Occupational Safety and Health Administration (OSHA), and a construction-specific accident classification system developed by Hinze and Russell (1995) have been created to categorize injury types. The ten mutually exclusive and all-inclusive safety risk classifications described by these studies are as follows: (1) struck by; (2) struck against object; (3) caught in or compressed; (4) fall to lower level; (5) fall to same level; (6) overexertion; (7) repetitive motion; (8) exposure to harmful substances; (9) transportation accidents; and (10) other. For the purpose of this study, the "other" category will encompass all miscellaneous safety risks on a construction site including, but not limited to muscle sprains, eye strain, lacerations, and abrasions. During a comprehensive review of literature, the writers identified many publications that utilized a similar risk classification system (Hinze and Russell 1995; Jannadi and Almishari 2003; Zou and Zhang 2009)

3.3 Safety and LEED

The body of literature that describes the relationship between safety and LEED is extremely small despite the significant increases in safety risk that have been connected to the construction of high performance sustainable buildings. As previously indicated, Fortunato (2010) conducted a series of case studies on LEED projects to identify and describe the safety risks associated with the design and construction strategies implemented to achieve specific LEED credits. The study revealed that there are fourteen credits that cause and increase in safety risk when compared to traditional methods. Because the present study builds directly upon this work, the salient credits, the common design and construction strategies used to achieve them as described in USGBC 2009), and the risks identified by Fortunato (2010), Gambatese et. al (2009) and Rajendran et al. (2009)), are highlighted in Table 1.

Table 1 – Safety hazards associated with LEED credits

	Design and construction strategies employed to achieve LEED credit (USGBC 2009)	Increased hazards when compared to traditional designs and means and methods of construction (Fortunato 2010, Gambatese et. al. 2009, Rajendran, Gambatese 2009)
Sustainable Sites		
Stormwater Quality Control	Reduce impervious cover, promote infiltration, and capture/treat storm water runoff from 90% of the average annual rainfall using pervious pavers, rain gardens, rainwater recycling, detention ponds, wetlands, and/or vegetated filters.	Increased exposure to on-site excavation and trenching, which may increase the number of falls and trench collapses.
Heat Island Effect-Roof	Specify thermoplastic polyolefin (TPO) materials that have a solar reflectance index (SRI) equal to or greater than 78 for low-sloped roofs (slope less than or equal to 2:12) or 29 for steep-slope roofs (slope greater than 2:12).	TPO membranes tend to be heavy, slippery, and 'blindingly' bright when compared to ethylene propylene diene monomer (EPDM) These material properties were found to lead to slips, trips, falls to lower levels, and eye strain
Water Efficiency		
Innovative Wastewater Technologies	Reduce the use of potable water building sewage by 50% through water-conserving fixtures or the use of non-potable water (e.g. captured rainwater, recycled gray water, on-site treated wastewater)	These methods increase in the time that workers are installing electrical and mechanical systems at height, which increase the exposure to falls from working at height and on ladders.
Energy & Atmosphere		
Optimize Energy Performance	Reduce energy use by optimizing efficiency of window and mechanical systems, heat exchangers, LED light fixtures, and mechanical window shades.	Such systems increase the volume of mechanical, electrical, and plumbing (MEP) work that typically occurs at height or in confided spaces and workers may be exposed to chemicals used in the on-site filtration process.
On-Site Renewable Energy	Specify photovoltaic (PV) panels or the requisite infrastructure for future installation of PV panels.	PV panels tend to be installed on roof surfaces, which increase the time that work with heavy and unwieldy objects is performed near exposed edges.
Enhanced Commissioning	Begin the commissioning process early in the design process and execute additional activities after systems performance verification has been completed.	On-site visitors who may not be familiar with the specific means and methods of construction, increasing the probability of injury for such individuals.
Materials and Resources		
Construction Waste Management	Prevent debris from being disposed in landfills and incineration facilities by redirecting recyclable and reusable materials to nearby recycling centers	Sorting materials involves 'dumpster diving' where workers enter into waste and recycling containers to retrieve and sort recyclable materials. In such an environment workers are exposed to sharp, heavy, and unstable materials and experience muscle sprains, lacerations, and abrasions at a higher rate.

Indoor Environmental Quality

Outdoor Air Delivery Monitoring	Install monitored ventilation systems that maintain optimum airflow. These systems are generally accompanied by visual alert systems that inform occupants when airflow is impeded or when allowable air quality tolerances have been violated.	Workers constructing these systems must install additional wiring and controls at height.
Construction IAQ Management Plan	Install covers over open ducts during construction, avoid operating diesel equipment indoors, suppress dust, and protect stored materials against moisture damage.	Tasks and constraints result in increased exposure to fall hazards because workers must ascend and descend ladders more frequently and spend additional time working at height.
Low-Emitting Materials-Adhesives/Sealants	In an effort to reduce noxious and volatile indoor air contaminants, all adhesives and sealants must have a volatile organic compound content that complies with the South Coast Air Quality Management District (SCAQMD) Rule #1168	These low emitting adhesives and sealants have been shown to involve more rework due to quality issues. Since reworking these materials involves grinding and sanding, workers are exposed to wood dust, silica, and other known carcinogens.
Indoor Chemical and Pollutant Source Control	Specify permanent entryways that are at least 10 feet long and separate exhaust systems for each space that may include harmful chemicals (e.g. coffee rooms and janitor's closets).	These systems involve installing additional overhead ductwork and piping that exposes workers to additional work at height with sharp and heavy materials.
Controllability of Systems- Lighting	75% or more of all regularly occupied spaces much have daylight luminance levels of at least 25 footcandles and a maximum of 500 footcandles. These luminance levels are achieved by specifying skylights, atriums, and curtain walls.	Not only are fall hazards increased, but the number of overexertion injuries may also increase due to work overhead.

The present study aims to build upon the current body of literature by quantifying the impact of each of the identified hazards on the frequency, severity, and exposure components of safety risk. Though safety risks associated with LEED design and construction strategies have been previously identified, there has yet to be a formal study that quantifies their impacts on safety risk during the construction process. LEED was used to develop the underlying framework for this study because it is clear, standardized, and is the most commonly used green building certification program. Because each credit in this study was addressed individually, the results can be applied to not only projects attempting to achieve LEED but to any project with eh sustainable designs or construction methods discussed. This is important because many local governments (e.g., the City of Boulder, Colorado) have their own 'green' certification programs that supplement LEED.

4.0 Point of Departure

After a thorough review of current literature on sustainable building construction as related to the increase in risk due to specific LEED credits, it was evident that there is a need to establish relative magnitudes of risk through quantification of increase or decrease in risk associated with LEED. Researchers have identified the safety issues with the design techniques and construction methods implemented to achieve LEED certification, however no research has been performed to actually quantify these risks and the present study aims to bridge this gap.

5.0 Research Methods

The objective of the research was to quantify the perceived percent increase or decrease in safety risk for each of the LEED credits highlighted in Table 1. For each credit, the perceived percent increase in risk was quantified for each of the ten injury classifications published by Hinze and Russell (1995) using interviews with experienced design and construction professionals. Structured interviews were selected as the primary research method because archival injury data do not yet exist for LEED certified projects and it is unrealistic to obtain the requisite empirical data through case studies. Interviews also provided the research team with the opportunity to obtain perception ratings form a large number of diverse professionals who have many years of experience with sustainable design and construction. Furthermore, the research team was able to systematically obtain and record data using a reasonably exhaustive system in a relatively short timeframe with the resources available.

Though most interviewees reside in Colorado, most represent national firms that complete projects throughout the US. Ultimately, 11 architects, 13 general contractors, and 2 subcontractors were interviewed. To ensure that interviewees were able to compare LEED and traditional projects with respect to safety, it was of the utmost importance that the interviewees had extensive experience with both LEED and traditional projects. On average, the 26 interviewees had completed 96 traditional projects, 4 LEED certified projects, and had been working in the industry for 18 years at the time of the interview. This highly experienced pool promoted the external validity of the results.

In addition to experience, it was also important that the interviewees had an unbiased perspective on both sustainability and safety. Thus, the research team targeted the lead architect rather than the LEED coordinator for architect representatives and superintendents rather than safety managers for the general contractors. Superintendents and project managers were found to have the most holistic perspective and were able to discuss safety impacts in the context of other project management functions (e.g., quality and productivity management).

Each interview began with a thorough description of the research objectives and the structure of the interview questions. The twelve credits that were the focus of the study were described and the results from previous literature were reviewed. Additionally, the injury classification code system was reviewed and a definition of the frequency, severity, and exposure elements of risk were provided. For each credit, interviewees were then asked to quantify the percent increase or decrease in frequency, severity, and exposure for each of the ten injury classifications. The percent increase for each LEED credit was quantified relative to the traditional design elements or means and methods of construction. For example, for LEED credit 7.2 (heat island effect for roofs) the interviewee was asked to compare thermoplastic polyolefin (TPO) roofing membranes, the prevailing method used to reduce the solar reflectance index, to traditional *ethylene propylene diene monomer* EPDM rubber membranes.

Interviewees were given the opportunity to provide both positive and negative ratings and were encouraged to identify additional hazards or refute the data reported from previous studies. The research team continued to conduct interviews until replication was observed in the results as suggested by Guest (2006). Replication was said to occur when interviewees no longer identified new impacts to the frequency, severity, or exposure to any of the ten injury classifications. Replication was achieved after approximately 25 interviews.

The interview process was carefully designed using guidance provided by Taylor et al. (2009), Eisenhardt (1989), and Yin (2003) to enhance the reliability and internal, external, and construct validity of the results. Data were carefully monitored and cross referenced to identify repetition and patterns to establish internal validity. Reliability and construct validity were preserved by pre-defining a replication strategy, conducting interviews until a predetermined criterion was achieved, and using a structured interview script that is based upon previous literature. Finally, external validity was promoted by conducting interviews with 26 highly experienced professionals who, collectively, had completed projects nationwide.

6.0 Results

Once the interviews were completed, the data were aggregated by determining the mean and median ratings for each frequency, severity, and exposure for each injury classification and each credit. The resulting matrix of values is reported in Table 2. This table only includes values that represent the aggregation of five or more ratings. Categories that were only rated by four or fewer interview were omitted from the results as they were not adequately substantiated by other participants. Struck by, struck against object, caught in or compressed, repetitive motion, and transportation are not shown in Table 2 as they received no ratings from designers or contractors during the data collection process. A risk classification was omitted from Table 2 if there were no impacts to that category for any of the credits.

It should be noted that during the interview process, two additional credits were found to involve design elements or construction methods that increased safety risk: Brownfield Redevelopment and Daylighting. The brownfield redevelopment credit involves workers excavating, handling, and disposing of hazardous and contaminated materials. Often times, the safety risk associated with these contaminates is not fully understood prior to construction. Additionally, the daylighting credit often will involve the use of atriums and skylights that can result in serious fall hazards in addition to overhead construction tasks.

Table 2: Perceived percent increase in safety risk

LEED Credit	Fall to lower			Fall to same			Overexertion			Exposure			Other		
	F	S	E	F	S	E	F	S	E	F	S	E	F	S	E
Brownfield Redevelopment															
Stormwater Quality Control			6.5			0.2									
Heat Island Effect- Roof			4.4			4.6			12.5				0.2		18.8
Innovative Wastewater Technologies										8.8	4.6	0.2			4.4
Optimize Energy Performance			8.8	0.4		8.1									3.8
On-Site Renewable Energy	10.2	2.9	9.2	4.2	1.9	2.4							1.0	1.0	
Enhanced Commissioning															11.1
Construction Waste Management													3.8	3.8	26.2
Outdoor Air Delivery Monitoring				0.6	0.4	0.5							1.2		1.1
Construction IAQ Management Plan			4.6			9.9									2.0
Low-Emitting Materials-Adhesives/Sealants															12.4
Indoor Chemical and Pollutant Source Control						6.7									5.8
Controllability of Systems- Lighting	0.2		1.3	0.2		7.7									
Daylight and Views	2.3	1.3	12.0	2.3	2.3	6.7									

F = Frequency (incidents per unit of time)
E = Exposure (time)
S = Severity (impact per injury

LEED credits impact the frequency and severity of and exposure to hazards in different ways. The three most significant impacts to the frequency of injuries are on site renewable energy (10.2% increase in frequency of falls to a lower level); innovative wastewater technologies (8.8% increase in frequency of exposures to harmful substances); and on-site renewable energy (4.2% increase in falls to the same level). The three greatest increases in exposure to known hazards are a 26.2% increase in lacerations, strains, and sprains in the 'other' category for construction waste management, an 18.8% increase in the 'other' category and a 12.5% increase in exposure to overexertion hazards for innovative wastewater technologies. Another significant risk involves on-site renewable energy credit that results in a 9.2% increase in exposure to falls to lower due to the increased amount of time workers must spend working at heights to install the photovoltaic panels. As one can see from Table 2, most increases in risk involve increases in exposure to known hazards and increases in frequency of injuries due to new work environments. Only a few sustainable designs and construction methods make incidents more severe. For example, innovative wastewater technologies result in a 4.6% increase in severity for injuries with an exposure to harmful substances, construction waste management has a 3.8% increase in severity for cuts/abrasions/sprains, and the daylighting and views credit involves a 2.3% and 1.3% increase in severity for falls to same and falls to lower level, respectively.

Though most interviewees provided positive risk ratings indicating green buildings were more dangerous to build, some believed that outdoor air delivery monitoring systems and the low-emitting adhesives and sealants *reduce* the amount of risk on site. For example, there was a -0.6% decrease in both frequency and severity of exposure resulting from the use of low-emitting adhesives and sealants and a construction indoor air quality management plan.

Standard deviations were calculated for each credit and risk category for the aggregated data as well as separately between the designers and general contractors. The combined data is reflective of the understanding that there is a perceived percent increase in hazard though it varies from person to person based on experience, projects worked on, and risk personality type (i.e. risk averse or risk taker). Overall, the standard deviation between general contractors only revealed that the majority of general contractors have similar perceptions of hazards on a jobsite while on the other hand, the standard deviations associated with the designer's data reflected somewhat of a lack of overall similar perceived increase in hazard.

7.0 Analysis

The research team aimed to achieve the following objectives during the data analysis: (1) identify the overall impact of each credit on the salient safety and health risk categories by combining frequency, severity, and exposure ratings using Equation 1; (2) measure the overall impact of each credit; (3) identify the most impacted risk categories; and (4) test for a statistically significant difference between the designer and contractor ratings.

In order to achieve the first three objectives the data were combined for each category by multiplying the frequency, severity, and exposure values. As indicated in the literature review, the product of these three values corresponds to the overall safety risk. The values shown in Table 3 represent the product of these values for each credit and each salient injury classification. As one can see, the most significant impacts are a 36% increase in lacerations, strains and sprains (other category) for construction waste management because of the need for material recycling; a 24% increase in falls to lower level during roof work because of the installation of on-site renewable energy (e.g., PV panels); a 19% increase in eye strain when installing TPO membranes to reduce the heat island effect; a 14% increase in exposure to harmful substances when installing innovative wastewater technologies, a 13% increase in overexertion injuries when lifting heavier materials when installing roof membranes; and a 10% increase in slips and trips (fall to the same level) when new workers are on site to plan for indoor environmental air quality. Fortunately, the analysis also shows that there is a 1% decrease in exposure to harmful substances resulting from the specification of low-emitting materials and an indoor air quality management plan.

Table 3 – Increase in risk associated with LEED credits

LEED Credit	Falls to Lower	Fall to same	Overexertion	Exposure-harmful substances	Other	Total
Brownfield Redevelopment	0%	0%	0%	4%	8%	12
Stormwater Quality Control	6	0	0	0	0	7
Heat Island Effect- Roof	4	5	13	0	19	41
Innovative Wastewater Technologies	0	0	3	14	4	22
Optimize Energy Performance	9	9	0	1	4	22
On-Site Renewable Energy	24	9	3	0	2	37
Enhanced Commissioning	0	0	0	0	11	11
Construction Waste Management	0	0	0	0	36	36
Outdoor Air Delivery Monitoring	1	2	0	0	2	5
Construction IAQ Management Plan	5	10	1	-1	2	16
Low-Emitting Materials- Adhesives/Sealants	0	0	0	-1	12	11
Indoor Chemical and Pollutant Source Control	0	7	1	0	6	14
Controllability of Systems- Lighting	2	8	0	0	1	10
Daylight and Views	16	12	4	0	0	32
Total	67	60	24	16	107	

When the increases in risk are summed across all risk categories, the most impactful credits are those associated with reducing the heat island effect (41), installing on-site renewable energy (37), and material recycling for construction waste management (36). The values reported in Table 3 for the total impact of each credit are a unit less measure of the relative impact of each credit, which have no practical mathematical application during risk analysis. When the increases in risk are summed across all credits, one can see that the risk categories that are most impacted are Other (107), Falls to lower levels (67) and falls to the same level (60). Again, these values are reported above and in Table 3 to measure the relative impacts to each risk category only and these summed values cannot be integrated into mathematical risk analysis.

To determine if there is a statistically significant difference between the designer and contractor (i.e., subcontractor and general contractor) mean ratings, the samples were tested using a Wilcoxon Rank Sum Test. Wilcoxon Rank Sum was selected because the samples were found to have and approximately equal variance from an F-test with a p-value of 0.78 and because the samples were not normally distributed because of several outlying responses. The Wilcoxon Rank Sum test revealed that designers rated frequency, severity, and exposure values an average of 4% higher than the contractors (p-value = 0.03). To further investigate this phenomenon, the differences between contractor and designer ratings were tested for each possible case. The results of these statistical analyses are provided in Table 4 for all tests that returned a p-value of 0.20 or less.

Table 4: Statistically significant differences between designer and contractor ratings

Credit	Risk classification	Difference between average designer and contractor ratings	Statistical significance (p-value)
Indoor Chemical/Pollutant	Other	21.00%	<0.01
Innovative WW Technologies	Other	-10.50%	0.19
Low-E Materials-adhesives/sealants	Other	14.70%	0.12
Heat Island Effect-Roof	Overexertion	10.40%	0.13
Indoor Chemical/Pollutant	Falls to same level	6.30%	0.06
Daylight and Views	Falls to lower level	17.70%	0.06
On-Site Renewable Energy	Falls to same level	-10.70%	0.17

The most significant of the differences reported were ratings that were, on average, 21% higher for designers than contractors when rating the other category for indoor chemical and pollutant source control (p-value <0.01) and an 18% higher rating for designers for falls to lower level with daylighting (p-value = 0.06). Interestingly, despite the statistically higher ratings for the designers on the whole, there were two cases where contractors had statistically higher ratings than the designers (see Table 4). This is the first known observation of risk perceptions that are statistically higher for designers than contractors, which warrants future research to determine the cause and potential implications. Because the designer and contractor ratings had an approximately equal variance, the research team was not concerned with inaccuracies in the relative magnitudes of the risk impacts reported.

8.0 Limitations

The primary limitation of this research was that the data was received solely through interviews with project participants and, therefore, the ratings are perceived ratings based on expert opinions. Additionally, the majority of the participants were located in Colorado at the time of the interview, which limits the external validity of the results. However, most of the participants have performed work outside of the state on both LEED and traditional projects. Lastly, it should be noted that the data collected are comparative ratings and not absolute ratings of safety risk. Consequently, the research team recognizes the need for a study that quantifies base-level risk for building construction tasks so that the data presented here can be applied to obtain absolute risk values for high performance sustainable buildings.

9.0 Conclusions and Recommendations

The results indicate that, of the fourteen LEED credits identified by Fortnato (2010), Rajendran et al. (2009), those with the greatest impact include minimizing the heat island effect, inclusion of on-site renewable energy, construction waste management, innovative wastewater technologies, and optimizing energy performance. It should be noted that the highest level of LEED certification, LEED Platinum, can be achieved without implementing any of these five credits and the lowest level of LEED certified, simply called 'certified,' can be achieved without implementing any of the fourteen credits highlighted in this study. Thus, in addition to developing design interventions and effective constriction management methods to reduce safety risk on these projects, owners and designers should consider seeking credit for other sustainable building elements that do not increase safety risk and avoid high risk credits.

When the data were analyzed it became apparent that there was a trend in increase of strains, sprains, and lacerations; fall hazards; and slips and trips. With the exception of falls to lower levels, these risk categories tend to involve lower severity injuries, which are not as sensational as medical case injuries, disabling injuries, and fatalities. This may explain why the increased risks have not been discussed in literature until 2009.

This study also explored the difference in risk perception between designers and general contractors. When all ratings for all categories were analyzed, it became apparent that designers rated risks 4% higher on average than contractors (p-value = 0.03).

The writers recommend that future researchers identify and catalog promising risk mitigation strategies for the fourteen LEED credits highlighted. Such strategies may include Design for Safety (DfS) techniques and construction safety management methods that are specifically designed to mitigate the hazards identified in this study and current literature. Additionally, researchers may consider quantifying the base-level risk for common building elements so that this and other comparative analyses can be translated into absolute risk values that may be more effectively integrated with design, scheduling, and financial planning. Finally, researchers may wish to conduct a lifecycle safety risk analysis on high performance sustainable buildings that also includes the safety risks of the supply chain and maintenance work.

CHAPTER THREE: MANUSCRIPT TWO: RISK MITIGATION

1.0 Abstract

Recent studies have found that LEED buildings have a higher injury rate than traditional non-LEED buildings and that there are twelve LEED credits that increase risks for construction workers. The objective of this study was to identify and describe risk mitigation strategies that reduce the safety risk associated with the design and construction of high performance sustainable projects by conducting extensive interviews with experienced designers and constructors for high performance sustainable projects. To achieve this goal, a total of twenty-six interviews were conducted with designers and general contractors. Interviewees averaged at least eighteen years of experience in the industry and had completed four LEED projects and over one hundred traditional projects at the time of the interview. The results indicate that there are feasible prevention through design and construction safety management strategies that can be used to mitigate safety risk for each of the twelve LEED credits. Most commonly, designers and contractors identified prefabrication, effective site layout, and alternative products as method to prevent injuries that specifically relate the hazards of each sustainable element. Practitioners may use the findings from this study to enhance safety for construction workers, an aspect of sustainability that is not currently addressed in the LEED program. Researchers may also use the techniques described as a starting point for lifecycle safety analyses for sustainable buildings.

2.0 Introduction

The occupational fatalities in the construction sector are disproportionate relative to the number of employees in the industry. In 2004, the construction industry consisted of 7% of the workforce but accounted for 23% of all work-related injuries in the United States (Bureau of Labor Statistics 2004; NIOSH 2004). The Bureau of Labor Statistics (2010) stated workers in construction incur more fatal injuries than any industry in the private sector and that about half of all fatal falls occur in construction. Reports from the Occupational Safety and Health Administration (OSHA 2007) have shown that: construction accounts for 21% of all fatal work injuries; construction workers experienced 135,350 injuries and illnesses; there are over 1,100 fatalities in the industry; and the overall recordable injury rate is 190 per 10,000 employees.

Though the construction industry's injury rate has improved following the inception of the Occupational Safety and Health Act of 1970, improvement has decelerated over the past ten years (BLS 2010). There are significant concerns that high performance sustainable building construction involves higher risk work environments that are not being properly managed or controlled. In fact, a recent study found that Leadership in Energy and Environmental Design (LEED) certified buildings have a recordable injury rate that is 8.7% higher than traditional, non-LEED projects (Rajendran et al. 2009). In a follow-up study, Fortunato (2010) compared LEED and traditional building strategies and found that workers on LEED projects tend to have more work at height, in trenches and excavations, and near energized electrical systems. Additionally, workers enter unfamiliar, high-risk work environments when installing vegetated roofs, photovoltaic (PV) panels, atria, skylights, or enter dumpsters to retrieve recyclable materials.

Managing and controlling these hazardous work environments will become even more important as the construction of high performance sustainable buildings continues to grow.

Increased adoption of the LEED Green Building Rating System for new construction is an emerging trend in the construction industry. Since its inception in 1998, LEED has grown to encompass more than 14,000 projects in all US States covering 3.6 billion square feet of developed space (USGBC 2009). In the next decade, the USGBC expects that approximately 10% of commercial construction starts will be LEED certified and that the value of green building construction projects is expected to increase to $60 billion (USGBC 2008). Though this rapid growth is exciting, the architecture, engineering and construction (AEC) industry must identify and implement design interventions and construction management strategies that mitigate LEED safety risks.

Managing construction hazards has long been viewed as an essential component of effective project management. Preventing injuries can be achieved by hundreds, if not thousands, of different strategies (Rajendran 2006). However, several researchers have identified the 'essential' elements of an effective safety program such as worker orientation and training, project-specific safety plans, substance abuse programs, recordkeeping, employee involvement in safety management and planning, and others (Hinze 2006; Jasleskis et al. 1996; Hallowell and Gambatese 2009; Findles et al. 2004; Liska et. all 2004; Rajendran 2009). Among these strategies prevention through design (PtD) is regarded by many to be one of the most effective (e.g., Gambatese et al. 1997; O'Toole 2002; Hallowell 2008). In order to facilitate adoption of this technique, Gambatese et al. (1997) developed a tool for designers that provides design suggestions that improve the ability of workers to construct the design elements safely. Unfortunately, this tool was created before green building became common and, therefore, does not include design suggestions for sustainable design features.

The objective of this study was to identify and describe risk mitigation strategies that reduce the safety risk associated with the design and construction of high performance sustainable projects by conducting extensive interviews with experienced designers and constructors (use in abstract). Because LEED is the most common and most standard method of certifying sustainable projects, the LEED credit system was used to develop the research framework. Also, special attention is paid to methods of risk mitigation that can be incorporated into design because (1) many of the risks identified by previous researchers were directly connected to specific design features and (2) PtD has been shown as a very effective injury prevention strategy because it occurs early in the project development process.

3.0 Literature Review

In order to develop context for the study and effectively structure the research framework, literature related to the sustainable building design and construction, the relationship between these projects and safety, and effective methods of injury prevention was reviewed.

3.1 High Performance Sustainable Buildings

The United States Green Building Council (USGBC) was formed to promote the construction of buildings that are environmentally responsible, profitable and healthy (USGCB 2006). The USGBC developed a green building rating system called Leadership in Energy and Environmental Design (LEED), which was first introduced for new construction in 1998. This system is a voluntary consensus-based national standard used to develop high performance sustainable buildings. LEED rating systems are developed through an open consensus-based process LEED by LEED committees in which each volunteer committee is composed of a diverse group of practitioners and experts from the building and construction industry. The most commonly used of the nine different versions is the LEED-NC for new construction. This is a point based system with 69 total possible points in six different categories: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Material and Resources, Indoor Environmental Quality, and Innovation in Design (USGBC 2010). Buildings can be formally certified by USGBC if they satisfy the green requirements based on the LEED rating system as one of the following levels of certification: Certified, Silver, Gold, and Platinum. For the purpose of this paper, LEED will be used as the metric to measure and evaluate different green building initiatives as this is the most widely accepted green building accreditation program in the US.

Green building's popularity has grown rapidly due to perceived benefits from decreased impact on the environment and monetary savings through decreased utility costs (Eicholtz et al. 2008; Fuerst et al. 2008; Miller et al. 2008). Though there are apparent benefits to the LEED program, general contractors have explained that LEED projects tend to be more involved and can take extra time to complete (Schaufelberger et al. 2009). Past research on green design has typically focused on the health of the final occupants and not the health and safety of the workers who build the facility. As Rajendran et al. (2009) argued, to be truly "sustainable" a building's impact to the health and wellbeing of the public should be considered not only for the final occupants but also for the individuals that construct, operate, maintain, and destruct the facility. Despite apparent benefits from building high performance sustainable buildings, these types of projects have also had enough safety-related accidents to raise concern.

3.2 LEED and Safety

Several recent studies have been performed to investigate the relationship between the LEED certification and construction worker safety and health. These studies were prompted by Rajendran et al. (2009) who found moderate statistical evidence that the recordable injury rates were higher for LEED certified projects. Gambatese and Behm (2009) examined the relationship between sustainable buildings and injury rates and found that there was suggestive evidence of a statistically significant difference between the OSHA recordable incidence rates (RIRs) of green versus non-green buildings. Another study by Silins (2009) examined LEED and attempted to identify areas were occupational safety and health was specifically impacted and found that safety by design is both more protective of the workers and more cost effective than safety by default. In an effort to integrate safety with the LEED system, Rajendran and Gambatese (2009) developed a sustainable construction safety and health rating system to rate projects based on the level of safety prevention implemented on the project.

In a recent study, Fortunato (2010) identified specific hazards that resulted from individual LEED credits. Out of the fifty-five applicable credits (some were removed because they did not involve specific design features or construction methods) it was shown that sixteen credits had an impact on construction worker safety and health when compared to traditional design and construction. Twelve of these credits involved additional hazards that increase safety risks, five decrease hazardous exposures, and two credits involved design elements or construction methods that had mixed impacts. Subsequently, Dewlaney (2011) quantified the increase or decrease in safety risks for the credits highlighted by Fortunato (2010). These results are included in Table 1, which shows that the three credits with the greatest safety impacts are the heat island effect-roof, on-site renewable energy, and construction waste management. The present study builds directly on this previous work.

3.3 Safety Management Strategies

Of all the parties involved in construction, contractors typically take the lead role in addressing worker safety and health (Rajendran 2009). Though this is primarily due to the mandate of OSHA regulations, several studies have identified elements that are effective for safety programs. The Meridian Research Group conducted a study that reported various elements of an effective safety program, including: a written, comprehensive safety and health program; safety and health responsibility and accountability clearly established and implemented; employee involvement in design and operation of the safety and health program; and frequent worksite inspection (Findley et al. 2004). Hinze et al. (2001) developed the following nine best management practices to make zero accidents realistic for contractors: demonstrated management commitment; staffing for safety; safety planning; safety training and education; worker participation and involvement; recognition and awards; subcontractor management; injury reporting and investigations; and drug testing. Finally, Liska et al. (2004) found that pre-pre-task planning; safety orientation/training; safety incentives; alcohol and substance abuse programs; and accident or near miss investigation are the most effective safety strategies. It should be noted that these studies are only a small sample of safety studies that have attempted to identify the most effective injury prevention techniques. Since the writers aim to identify PtD and safety management strategies for sustainable building elements, the discussion of general safety management methods will remain brief.

3.4 Prevention through Design

The technique of designing a facility in a way that is safe and healthy for construction workers to build goes by many names including designing for safety, safety constructability, and prevention through design. The strategy typically involves identifying and mitigating hazards during the design phase by changing the design of the permanent structure so it is safer to build (Behm 2005). Eliminating the hazard is far more effective than simply reducing the hazard or providing personal protective equipment to works (Gambatese et al. 2005; Manuele 1997). O'Toole (2002b) explained that designers are in the best position to implement safety design recommendations prior to construction. There are many existing examples of how designers can improve construction site safety through the design process. One example would be to design higher parapet walls. Since designers tend to specify parapet walls that are relatively short in height, fall protection is still required by OSHA. If designers were to design parapet walls to a height of 42" falls may be prevented. In an early publication, Gambatese et al. (1997) identified over a hundred such examples that can be reliably employed to remove hazardous work conditions and organized them into a user-friendly software system called the Design for Safety Toolbox. Unfortunately, this tool was created before the hazards associated with LEED were identified.

Behm et al. (2006) demonstrated that PtD is a viable strategy that can have a significant influence on construction safety. Through interviews of architects and engineers, this study found that a large percentage of design professionals are in fact interested in implementing the PtD practice in their design. The results from this initial study on the topic are indicative that this is a viable intervention for construction. Additionally, the European Foundation for the Improvement of Living and Working Conditions (1991) found that 60% of all fatal accidents on construction sites were related to decisions made prior to the construction phase. However, due to several significant barriers such as fear of liability, lack of safety knowledge, and typical safety roles and responsibilities assigned by the Occupational Safety and Health Act of 1970, the PtD strategy has not diffused through the industry (O'Toole 2002). In fact, when designers were recently asked to rate the importance of six aspects of their design work, it was found that construction worker safety ranked the lowest behind quality, end user safety, cost, schedule and aesthetics (Gambatese et al. 2005). Fortunately, the increased use of integrated project delivery (e.g., design-build) and owner representatives' recent interest in PtD is likely to increase the adoption of the strategy. The writers believe that the use of the technique will also increase during the design of high performance sustainable buildings as new knowledge of the hazards and viable design interventions improves.

4.0 Point of Departure

After reviewing current literature, it was clear that there is a need to establish safety risk mitigation techniques for high performance and sustainable construction. Though researchers have identified the safety issues with the design techniques and construction methods implemented to achieve LEED certification, no research has been performed to identify potential mitigation strategies. The present study aims to fill this gap in knowledge.

5.0 Research Methods

In order to identify construction management and prevention through design techniques that can be used to mitigate identified construction risks for high performance sustainable buildings, interviews were conducted with highly experienced design and construction professionals. Interviews were selected as the data collection method because (1) the research was highly exploratory because specific construction methods and design interventions have yet to be identified for sustainable building elements; (2) the interviewer could provide context by describing the hazards identified in previous research and ask follow-up questions and obtain rich responses; and (3) the data could be gathered in a relatively short timeframe with the resources available. Though the majority of the interviewees worked and resided in Colorado, all of the interviewees had completed projects outside of the state.

It was of the utmost importance that the interviewees were highly experienced and had been involved as key members of the design or construction of several LEED certified projects. In total, 11 contractors, 13 designers, and 2 subcontractors were interviewed. The individuals selected for participation were highly qualified. On average, each interviewee had completed 103 traditional projects and 4 LEED certified projects and had 18 years of experience in the architecture, engineering, and construction (AEC) industry. It was also important to ensure that the interviewees were not employed in a position where their input may be biased by their role. For example, during previous research, the writers have noticed that LEED professionals and safety professionals often have views that are biased toward their primary function, which can lead to invalid and unreliable results. Thus, for this study, interviewees who were employed as superintendents, project managers, or lead designers were targeted. Furthermore, the findings from this study should be applicable to a large base of LEED construction projects as the data collected was based on participants with extensive background on mostly large-scale projects.

A mix of in-person and phone interviews was conducted. Each interview was opened with a brief description of the research objectives and the hazards associated with the 14 LEED credits under investigation. As previously indicated, the LEED rating system was used as a framework for the questionnaire because it is the most standard and commonly-used sustainable building certification system. The scope of this study was limited to the 14 credits that Fortunato (2010) and Rajendran et al. (2006) found that increase safety risk when compared to traditional building design and construction. Once the context for the study had been established interviewees were asked to identify construction management strategies and design interventions that could be implemented to mitigate the safety risk associated with specific hazards caused by the means and methods achieved to earn specific LEED credits. Interviewees were encouraged to identify both design and construction interventions rather than focus solely on the techniques that could be employed in their function. That is, contractors were asked to identify potential design interventions and vice versa. This strategy was employed to encourage innovative ideas and an integrated approach to safety. When interviewees were asked to identify construction interventions, they were instructed to focus on the specific strategies that can be used to mitigate the specific hazards previously indentified (e.g., prefabrication of a specific component) rather than describe commonly-used strategies that apply to construction in general (e.g., job hazard analyses, written safety plans, and employing a safety manager). Because each credit was addressed individually, the results can be applied to not only projects attempting to achieve LEED certification but to any project that incorporates the sustainable elements or practices encompassed in the 14 LEED credits. This is important because many local governments have sustainable building programs that are unique to their geographic region.

Interviews were conducted in a structured fashion where the interviewer introduced a credit and its associated safety hazards then solicited safety management strategies. Interviews were conducted until no new prevention through design or construction safety management strategies were identified. This replication was observed after 26 interviews. This strategy ensured that the results were complete, the process could be easily replicated by future researchers, and the results were both internally and externally valid.

7.0 Results

This results section describes the aggregate results obtained from the 26 interviews. The strategies identified are discussed credit-by-credit. It is expected that these strategies can be easily incorporated on site; however, some strategies may not be cost-effective for all projects. The hazards discussed for each credit are those identified by Fortunato (2010) and Rajendran et al. (2009) and were confirmed and elaborated upon by the interviewees. For further reading on how designers and contractors can achieve LEED certification, refer to USGBC (2009).

Brownfield Redevelopment

Though this credit was not highlighted by previous researchers, many of the interviewees in this study discussed health and safety hazards resulting with the construction activities required to develop brownfield sites. Interviewees noted that handling and disposing of contamination is a very hazardous activity because of exposure to harmful substances. Additionally, workers may be more likely to be exposed to fall, collapse, and transportation hazards because of the extensive earthwork operations typically involved in removing subsurface contaminants. Interviewees noted that using impermeable plastic liners in the beds of heavy equipment and completely washing all equipment after construction could help prevent the spread of contamination throughout the worksite and would reduce exposure. Additionally, contractors may consider adding training and safety planning for construction tasks that involve chemicals and providing breathing apparatus and other personal protective equipment.

Stormwater Quality Control

Most commonly, detention ponds are used to achieve this credit, which have been found to increase the risk of falls due to increased excavation and trenching. Typically, these ponds will be constructed in the first phase of the project when several trades are working concurrently. The risk of falls due to detention pond excavation can be mitigated by designing the detention ponds without vertical cuts similar to a zero-entry pool (i.e., edge or entry that gradually slopes from the deck into the water in the manner of a natural beach), and by ensuring a proper slope to avoid steep embankments. During pre-construction planning, construction managers should avoid concurrent activities near the excavation during sequencing and site-layout planning. For example, scheduling the excavation when there are fewer concurrent tasks can help to limit hazardous exposure. During construction, hazards should be identified, highlighted, and explained using a combination of flagging, barricades, and signage. Additionally, during construction, it is essential to ensure the accuracy of the as-built documents and drawings and to provide an adequate utility survey through potholing. Having an adequate utility survey can help to mitigate any issues that could arise during the construction of a stormwater system by having a very thorough geotechnical report.

Heat Island Effect-Roof

The hazards associated with this credit are a result of using thermoplastic polyolefin (TPO) single-ply roofing membranes or other white roofing options rather than traditional black ethylene propylene diene monomer (EPDM) rubber roofing. TPO membrane material is slightly heavier and slipperier than EPDM that can increase overexertion injuries and falls. Additionally, TPO has been described as, “blindingly bright” and causes eye strain and an increase in slips, trips and falls. These risks can be mitigated by specifying tan or light grey membranes. Though these alternate colors decrease the reflectivity of the materials, the SRI index required for certification can still be achieved. Second, during the fabrication process, TPO membranes could be designed to include a dull peel-off cover that could be prefabricated onto the TPO material to lessen the brightness and provide traction. Such a cover could be made of recyclable material and removed upon completion of roof work. Third, interviewees suggested that surface could be texturized to aid in traction and rubber walkpads could also be placed on the higher traffic areas for traction. To reduce the potential for the eye strain, contractors can mandate tinted eyewear and provide signs at the entrance to the roof warning about brightness. Lastly, contractors can purchase a higher number of smaller rolls from the supplier to reduce the weight and, consequently, overexertion injuries. This strategy, however, may increase the cost of the roofing materials.

Innovative Wastewater Technologies

This credit can be achieved through a variety of different design techniques including a dual waste water system, purple piping, and a roof cistern. Researchers found that there is an increase in the risk of working at heights and exposure to hazardous chemicals when constructing a dual waste water system compared to a traditional single waste water system because there is an increase in piping material handling and installation time. Furthermore, workers may be exposed to chemicals used in the on-site filtration process. To mitigate these risks, the construction management plan can employ extensive quality control measures beyond the typical due diligence to monitor the additional work being installed and utilize prefabricated piping that can be pre-assembled to eliminate excessive connections. By keeping the system protected and not filtered into any other systems on the project or using self-contained assemblies that include the necessary chemicals, workers can decrease their time spent working with hazardous chemicals. Additionally, crews should avoid work on ladders or scaffolds that can be completed at ground-level or in a controlled environment. In order to minimize exposure to chemicals, workers should wear non-polyester gloves and respiratory protection. The specifications drafted by the architect or owner may also include a requirement for the contractor's installer to have met certain training requirements with the related chemicals.

Optimize Energy Performance

Energy performance may be optimized by using more energy efficient window system and mechanical systems, high efficiency heat wheels and exchangers, LED light fixtures, mechanical window shades, advanced automation systems, and changes in the building envelope such as double caulking. For this credit, there is typically an increase in time required to install wire and controls, which increases the time spent on ladders. Interviewees suggested that designers could specify prefabricated panels of the exterior skin system, framing, structure, and vapor barrier. This strategy would involve off-site fabrication and the use of a crane to place the panels during construction. Before implementing this design technique, however, it would be prudent to perform a comparative lifecycle risk analysis to ensure that using a crane would not actually increase safety risk. For the case of double caulking to improve energy performance, workers tend to spend more time on scaffolding and ladders. To reduce the amount of time spent at height, contractors may double joint and caulk from the interior of the building prior to installing finish materials.

On-site Renewable Energy

Inclusion of on-site renewable energy most commonly involves installing photovoltaic (PV) panels or the infrastructure for the future installation of PV panels. When installing these panels, workers face an increased exposure to falls because PV panels are often installed on the roof and an increased frequency of overexertion injuries because the panels are heavy and unwieldy materials. If possible, designers should consider locating the PV panels on the ground to protect both construction and maintenance workers from exposure to work at height. If the panels must be placed on the roof, they should be located as far from the edges, skylights, and vegetation as possible. Additionally, panels that are pre-assembled (i.e., "plug-and-place") may be specified as long as they are not cost prohibitive and are of a size and weight that can be easily placed with available workers and equipment. The use of higher parapet walls and designed tie-off points could also be considered to help reduce the risk of falls. Finally, as sustainability market continues to flourish, photovoltaic panels have taken new forms such as being incorporated into the roof membrane, roof shingles, wall panels, and windows. These new products should be considered during the design if there are apparent safety benefits to the construction or maintenance crews.

Enhanced Commissioning

This credit can be achieved by beginning the commissioning process early in the design phase and executing additional activities after systems performance verification has been completed. These processes tend to involve personnel on site who are not familiar with construction means and methods or safety protocol. The presence of these individuals on site is distracting and has been shown to increase the safety risk to commissioning agents and construction workers resulting in more frequent falls, strains, abrasions, and workers being struck by equipment or materials,. To mitigate these risks all commissioning agents should receive a site-specific orientation and obtain appropriate personal protective equipment. Interviewees also suggested that these agents pass an OSHA 10-hour course before being permitted on site. Finally, designers should optimize the access to mechanical, electrical and plumbing (MEP) equipment during design.

Construction Waste Management

A LEED credit is awarded when contractors divert waste and demolition debris from disposal in landfills and incineration facilities rather than simply comingling all waste into one dumpster. However, on many sites Fortunato (2010) observed "dumpster diving" where workers climb into dumpsters to retrieve and sort recyclable materials when materials have been erroneously placed in the incorrect receptacle. These activities result in a severe increase in the frequency of lacerations, strains, and sprains. Interviewees offered several innovative solutions that would prevent this hazardous activity. First, contractors could use multiple, smaller trash receptacles throughout the site. Smaller dumpsters (5-10 yards or clamshells) can be distributed around the site and then when full, they can be hoisted to the main dumpster area. Clamshells are dumpsters where the complete cover assembly is mounted on a subframe and hinged from the rear of the container so that when emptied, the whole assembly spreads open like a clam shell allowing the refuse to dump freely. Second, interviewees recommended having well-labeled dumpsters that includes bilingual text and images to encourage proper sorting. One interviewee also suggested initiating an industry-wide receptacle color-coding system. Third, manufacturers of recycling bins could install a "window" on the side of each dumpster made out of a clear polycarbonate material so that workers could actually *see* the type of material in each bin. Fourth, multiple interviewees suggested having a specific worker who oversees waste management and monitors the recycling efforts. Finally, throughout many areas of the United States, smaller, local waste management companies are developing programs where they will receive comingled materials from construction sites and sort the recyclable materials at an off-site facility. Interviewees suggested that such a strategy may actually save the construction firm money because the cost savings associated with fewer injuries and time spent recycling on site would outweigh the estimated $100 per standard 30 yard dumpster for off-site recycling.

Outdoor Air Delivery Monitoring System

The construction activities required to install a permanent monitoring system for outdoor air delivery was found to have a minimal impact on worker safety. Nevertheless, workers face a slight increase in exposure to fall hazards because of the increases in wiring and mounting of the system. Interviewees suggested that incorporating the monitoring equipment into the prefabrication process would eliminate these observed risks.

Construction Indoor Air Quality Management Plan

The indoor air quality management plan involves maintaining covers over open ducts during construction, not running diesel equipment indoors, proper ventilation, dust mitigation, housekeeping, and protection of on-site stored materials and installed absorptive materials from moisture damage. Risks associated with these activities include increased exposure to fall hazards because of an increased time spent on ladders maintaining covers on the ductwork and overexertion. Interviewees noted that it is becoming more common for subcontractors to prefabricate "caps" onto the ends of the ducts; however, this practice does not necessarily reduce the increased time spent on ladders because workers must still ascend and descend ladders to remove caps and work with cellophane that is easily punctured and awkward to install. Interviewees suggested changing the material used for the caps such as using a magnetic "universal" cap. Such an investment would be a one-time cost as the caps could be used on subsequent projects. Unfortunately, such caps are not commercially available at this time. Finally, several interviewees suggested off-site fabrication of longer sections of ductwork to decrease the time spent at height.

Low-emitting Materials - Adhesives and Sealants

To achieve this credit, all adhesives and sealants must comply with South Coast Air Quality Management District (SCAQMD) Rule #1168 (e.g., the VOC limit of wood flooring adhesives is 100 g/L less water) (USGBC 2009). Though it is known that using low-emitting adhesives and sealants is a health benefit to workers and occupants, these products have been found to be of lower quality and require significant rework. This rework typically involves work at height, overhead work, and exposure to dusts from grinding and sanding. Interviewees suggest that designers and contractors research the available products and verify that they will withstand expected temperatures and are compatible with other construction materials. The use of mock-ups can often mitigate future problems with these products and enable the contactor or designer to select a different product before installation. Designers may also wish to specify natural flooring systems on a sweeper system (i.e., a floating floor with wood planks resting on resilient spacers or rubber pads) to eliminate the use of adhesives altogether.

Indoor Chemical and Pollutant Source Control

Minimizing building occupant exposure to potentially hazardous particulates and chemical pollutants can be achieved by designing and constructing carpet tiles that are at least 10 feet long in entranceways and exhaust systems that are separated from spaces that could include harmful chemicals (e.g. coffee rooms or janitor's closets). Safety risks for these building elements include increased exposure to fall hazards because of overhead work and work at height when installing additional piping and ductwork. To mitigate these risks, interviewees noted that designers can implement PtD strategies including designing a floor plan with access to fresh air thereby minimizing the total amount of overhead ductwork needed. Designers may also choose to design the HVAC systems to be housed under the floor making them easier to install and maintain. During construction, a permit system should be established if workers must work on top of or within ducts.

Controllability of Systems-Lighting

To meet the requirements for the LEED lighting controls credit, 90% or more of the multi-occupant spaces must have occupancy sensors or timing controls. The hazards associated with these elements include more complex wiring that increases workers' exposure to electrical shock and work at height. As with many other sustainable elements, the interviewees believed that elements of the lighting controls could be prefabricated or simplified to avoid on-site electrical work where energized systems are common. Interviewees also suggested that designers locate the sensors at a reachable height from the floor, instead of the ceiling, so that electricians may construct or maintain them without working at height.

Daylight & Views: Daylight 75% of Spaces

Daylighting requires that 75% of more of all regularly occupied spaces achieve daylight illuminance levels of a minimum of 25 footcandles and a maximum of 500 footcandles in a clear sky condition on September 21 at both 9a.m. and 3p.m. Daylighting has been shown to be one of the most hazardous aspects of the LEED system because the credit is achieved by installing skylights, large windows, and atriums, all of which involve work at height or near exposed openings. Interviewees suggested that designers include a courtyard or minimize the depth of the building to enhance daylight rather than atriums and skylights. Additionally, increasing the height if ceilings allows light to penetrate deeper into the building, orienting the building to appropriate cardinal directions, opening floor plans, and specifying solar tubes, automated shade systems, and daylight concentrators all help to achieve the requisite daylighting without subjecting construction workers to extremely high risk tasks. Finally, if skylights or atriums must be included, they should be designed with tempered glass to prevent severe lacerations that may be caused by shattered glass. Finally, contractors may wish to purchase commercially available equipment that is designed to aid in the handling of heavy glass.

8.0 Limitations

The primary limitation of this research was that the data was received solely through interviews with project participants and, therefore, the results are not based on empirical data. Additionally, the majority of the participants were located in Colorado at the time of the interview, perhaps degrading the external validity of the results. However, because most of the interviewees have performed work throughout the US, the writers believe that the results can be extended to the US AEC industry. The results are also limited to the common design elements and means and methods of construction used to achieve 14 specific LEED credits. As new technologies are introduced to the industry, their safety impacts and methods of managing new risks or exposures must be independently evaluated. Lastly, this inquiry did not evaluate the cost of the design and construction interventions or their viability. Rather, the focus was on identifying potential injury prevention strategies that may be considered by practitioners and evaluated by future researchers. Therefore, some strategies may not be cost-effective or realistic for some projects.

9.0 Conclusions and Recommendations

The objective of this study was to identify and describe risk mitigation strategies that reduce the safety risk associated with the design and construction of high performance sustainable projects without compromising the building's performance. This study specifically focused on methods that mitigate safety risk rather than strategies that simply transfer risk from one project participant to another. Rajendran et al. (2009), Fortunato (2010), and Dewlaney (2011) found that fourteen credits increase the safety risk for the following injury types: falls to lower level, falls to the same level, overexertion, and 'other' injuries such as scrapes, lacerations, eye strain, and muscle sprains. The interviews conducted with contractors and designers revealed that each of the 14 credits have at least one construction method or PtD strategy that can be used to mitigate the identified risks. This is the first known attempt to identify such strategies, which are likely to have a positive impact on worker safety and health on high performance sustainable building construction projects.

A common trend in the design suggestions was that the designer has the option to specify alternative design features or construction materials. There multiple methods to achieve the points associated with the LEED credits and many of these alternatives do not have a perceived increase in risk. Therefore, simply by analyzing each of the options available to achieve the points, systems and materials can be chosen that reduce safety risk. Furthermore, designers have the opportunity to use different spatial layouts during the design process that could eliminate many of the hazards. For example, the hazards associated with the indoor chemical and pollutant source control credit could be eliminated by ensuring that each room has windows for air flow. It was found that PtD, if strongly applied, can mitigate many risks associated with many LEED credits. Therefore, it becomes the responsibility of the designers to not only take into consideration the health and safety benefits of high performance sustainable buildings to the end user but also to preserve the safety of construction workers.

It was crucial for the achievement of the research objectives that interviewees identify construction safety management strategies that extend beyond a standard safety plan that include elements such as job hazard analyses (JHAs) or job-specific safety orientation. Prefabrication is a strategy that was suggested by the expert interviewees for six of the credits. By completing work in an off-site controlled environment, risks associated with construction at height, overhead, with energized electrical systems, and in confined spaces can be reduced. It should be noted that the suggestion to prefabricate some elements was not made in an effort to transfer the risk from the contractor to vendors and subcontractors but, rather, to move high risk tasks from dynamic and complex construction sites into a controlled environment where they can be more effectively managed and controlled. Similarly, interviewees also commonly suggested that work be performed on the ground surface whenever possible thereby reducing the time that workers are exposed to work at height and near exposed edges. Using a selective approach to choosing a subcontractor who may already design mitigation techniques or that uses prefabrication whenever possible, many of the risks discussed in this study could be avoided.

Properly sequencing a project can allow for different trades to work in areas at different times, thus eliminating hazards of trades working above or below other work and simply having too many workers in an area. Proper sequencing can also allow for workers to be less exposed to any trades that are using dangerous equipment or working with hazardous materials. If a project could be sequenced during the planning stages in a way such that over-stacking of trades would not occur, this could greatly reduce the risk of many construction tasks.

The results of this study compare to Gambatese et al. (1997) in that designers are in fact influential on the safety of construction workers. Gambatese et al. (1997) claimed that their current lack of involvement is attributed to minimal education and experience in this area and the present study aims to bridge that gap. By combining the specific LEED-based mitigation techniques for high performance sustainable construction with findings from a study by the Construction Industry Institute (CII) on best practices to implement in project design to minimize or eliminate hazards, a comprehensive safety plan can be employed from the design process through final completion of construction. Similarly, building on previous elements of effective safety programs found by Jaselskis et al. (1999) Findley et al. (2004) Liska et al. (2004) and Rajendran (2009), with the strategies identified in this study will help contractors manage safety risk for the rapidly growing green building market. Combining all injury prevention techniques and integrating them into the design and construction phases will make high performance sustainable buildings more sustainable. As argued by Rajendran et al. (2009) buildings are not truly sustainable unless effort has been made to ensure that construction workers are safe and healthy when constructing the facility.

The writers suggest that future researchers conduct a lifecycle safety assessment that tracks and quantifies safety impacts for high performance sustainable projects and includes material and product suppliers, subcontractors, contractors, occupants, and maintenance workers. Such an analysis should compare the lifecycle safety impacts of various design and construction alternatives to determine the best possible option. Researchers may also wish to evaluate the cost-effectiveness of the strategies identified and described in this paper.

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APPENDIX

1.0 Example of general contractor risk quantification interview data sheet

LEED Credit	Fall to lower			Fall to same			Overexertion			Exposure to hazardous substances			Other		
Sustainable Sites	**F**	**S**	**E**	**F**	**S**	**E**	**F**	**S**	**E**	**F**	**S**	**E**	**F**	**S**	**E**
Credit 6.2: Stormwater Quality Control	0%	0%	40%												
Credit 7.2: Heat Island Effect- Roof							0%	0%	15%				0%	0%	70%
Water Efficiency															
Credit 2: Innovative Wastewater Technologies										30%	30%	0%	0%	0%	2%
Energy & Atmosphere															
Credit 1: Optimize Energy Performance	0%	0%	5%										0%	0%	5%
Credit 2: On-Site Renewable Energy				35%	0%	0%									
Credit 3: Enhanced Commissioning													0%	0%	10%
Materials and Resources															
Credit 2: Construction Waste Management													0%	0%	45%
Indoor Environmental Quality															
Credit 1: Outdoor Air Delivery Monitoring													10%	0%	0%
Credit 3.1: Construction IAQ Management Plan- During Construction				0%	0%	5%							0%	0%	3%
Credit 4.1: Low-Emitting Materials- Adhesives and Sealants													0%	0%	20%
Credit 5: Indoor Chemical and Pollutant Source Control				0%	0%	5%							0%	0%	5%
Credit 6.1: Controllability of Systems- Lighting				0%	0%	2%									
Credit 8.1 Daylight and Views	0%	0%	5%												

1.1 Example of designer risk quantification interview data sheet

LEED Credit	Fall to lower			Fall to same			Overexertion			Exposure to hazardous substances			Other		
Sustainable Sites	**F**	**S**	**E**	**F**	**S**	**E**	**F**	**S**	**E**	**F**	**S**	**E**	**F**	**S**	**E**
Credit 6.2: Stormwater Quality Control	0%	0%	20%												
Credit 7.2: Heat Island Effect- Roof							0%	0%	20%				0%	0%	40%
Water Efficiency															
Credit 2: Innovative Wastewater Technologies										5%	0%	0%	0%	0%	5%
Energy & Atmosphere															
Credit 1: Optimize Energy Performance													0%	0%	10%
Credit 2: On-Site Renewable Energy	50%	0%	0%				30%	0%	0%				25%	25%	0%
Credit 3: Enhanced Commissioning													0%	0%	20%
Materials and Resources															
Credit 2: Construction Waste Management													0%	0%	40%
Indoor Environmental Quality															
Credit 1: Outdoor Air Delivery Monitoring													0%	0%	10%
Credit 3.1: Construction IAQ Management Plan- During Construction				0%	0%	30%							0%	0%	10%
Credit 4.1: Low-Emitting Materials- Adhesives and Sealants													0%	0%	100%
Credit 5: Indoor Chemical and Pollutant Source Control				0%	0%	30%							0%	0%	30%
Credit 6.1: Controllability of Systems- Lighting				0%	0%	5%									
Credit 8.1 Daylight and Views	0%	0%	40%				0%	0%	40%						
Credit 3: Brownfield Redevelopment															

2.0 Example of general contractor risk mitigation interview data sheet

LEED Credit	LEED Design Elements	Traditional Design Elements	Hazards Associated with LEED Design	Mitigation for Hazards
Sustainable Sites				
Credit 6.2: Stormwater Quality Control	On site detention water running through site, pervious pavers, water runoff plans, water quality vault, 100 year storm detention, erosion and sedimentation control plans, seeding/watering disturbed soil to control dust.	Lower capacity water detention systems	Additional work creates additional exposure time: hazard of trucks, machinery, and people falling into holes. Extra caution required.	New methods. Has installed a few and they are worst case scenarios while building and do not work after completion.
Credit 7.2: Heat Island Effect- Roof	TPO, White roof, PVC, clay tile	Lower quality black EPDM roof	TPO roof is slightly more labor intensive, materials are heavier. This increases the severity of an overexertion injury. Blindingly bright.	Adjust top's reflectivity. Mandatory break rules- OSHA.
Water Efficiency				
Credit 2: Innovative Wastewater Technologies	Dual waste water system: water comes from showers then to separate system from toilet	Single traditional waste water system	Increased piping and time. Chemicals in the filtration systems have chlorination processes that workers are exposed to as well as the food coloring.	Rework of installing backwards. Use quality control to pipe correctly (like mixing up hot and cold water).
Energy & Atmosphere				
Credit 1: Optimize Energy Performance	Optimize the window system as well as mechanical system with a more complex control system, high efficiency, occupancy sensors, heat wheels/exchangers, LED light fixtures, mecho shades, building automation system	Less efficient units could have been installed	Slightly more exposure time to wire the extra controls	Typical safety program.
Credit 2: On-Site Renewable Energy	Infrastructure for power leads to provide the future option of installing photovoltaic panels	This infrastructure would not have been included.	More exposure time on the roof and potential for heavier material for the insulation in a fall hazard situation as well as larger ERV units for the crane to pick that would need to be considered. Electricians on the roof.	Stringent roofing rules for OSHA that should be continued during PV work rather than removed.

Credit 3: Enhanced Commissioning	Commissioning agent, more non-worker exposure	No commissioning	New personnel on construction site.	Wear proper PPE including shoes. Have someone walk with person.
Materials and Resources				
Credit 2: Construction Waste Management	Waste diverted from landfills by having construction workers sort waste by material type into different dumpsters.	Waste would just be thrown in dumpsters	Dumpsters diving to sort more materials can result in twisting ankles, scrapes.	Having separate means of handling different types of waste. Three or four smaller carts at each trash location to sort from the beginning. Education.
Indoor Environmental Quality				
Credit 1: Outdoor Air Delivery Monitoring	Installation of an outdoor air monitoring system.	Alarm system would not have been installed for the CO2.	Does not see increase in hazards.	
Credit 3.1: Construction IAQ Management Plan- During Construction	A construction indoor air quality management plan, covering of open ducts, not running diesel equipment inside, infrared gun to detect moisture in walls, proper ventilation of building, dust mitigation, housekeeping.	Traditional means/measures would have been utilized-not covering ducts, running diesel equipment, less housekeeping/dust mitigation	Workers exposed to increased time up and down ladders to cover ducts as well as additional materials required and extra time spent cleaning. Smaller people sent through ductwork to re-clean.	Fabricate longer sections of ductwork (10-15 feet rather than 5). Due diligence is very important here.
Credit 4.1: Low-Emitting Materials-Adhesives and Sealants	Low VOC adhesives and sealants.	Traditional glue and adhesives would be used rather than water soluble. Traditional methods can overcome poor floor prep whereas low VOC adhesives cannot.	Future rework and additional prep work.	LEED needs to change VOC levels or manufacturer needs to fix products.
Credit 5: Indoor Chemical and Pollutant Source Control	Entranceways with walk off carpet tiles exhaust systems in all areas that could have harmful chemicals including janitor's closet, mechanical rooms, computer rooms and all laboratories.	Traditional mechanical system with minimal exhaust systems.	Increased ductwork that involves increased exposure at heights as well as other trades working around existing hanging ducts.	No hazard

Credit 6.1: Controllability of Systems- Lighting	Occupancy sensors and additional lighting controls were added to the rooms. Tie in with automated building system.	Fewer sensors or no sensors would have been installed in the facility.	Extra wire and device mounted.	Typical safety program.
Credit 8.1 Daylight and Views	Atriums/skylights.	Less or no atriums and skylights.	Additional exposure to working at heights. Glazers working at heights. Heavy materials.	

2.1 Example of designer risk mitigation interview data sheet

LEED Credit	LEED Design Elements	Traditional Design Elements	Hazards Associated with LEED Design	Mitigation for Hazards
Sustainable Sites				
Credit 6.2: Stormwater Quality Control	On site detention water running through site, pervious pavers, water runoff plans, water quality vault, 100 year storm detention, erosion and sedimentation control plans, seeding/watering disturbed soil to control dust.	Lower capacity water detention systems	Does not see increase in hazards.	No way to reduce exposure. General safety with trench wall systems.
Credit 7.2: Heat Island Effect- Roof	TPO, White roof, PVC, clay tile	Lower quality black EPDM roof	TPO roof is slightly more labor intensive, materials are heavier. This increases the severity of a overexertion injury. Blindingly bright. Fall potential and eye fatigue.	Research alternative light roof materials that are more easily installed (white EPDM). Eye protection for glare as well.
Water Efficiency				
Credit 2: Innovative Wastewater Technologies	Dual waste water system: water comes from showers then to separate system from toilet	Single traditional waste water system	Increased piping and time. Chemicals in the filtration systems have chlorination processes that workers are exposed to as well as the food coloring.	Maybe dry urinals. From design standpoint, just use an alternative system. Mitigate frequency/severity with additional labor training/education on chemicals and proper on-site storage.
Energy & Atmosphere				

Credit 1: Optimize Energy Performance	Optimize the window system as well as mechanical system with a more complex control system, high efficiency, occupancy sensors, heat wheels/exchangers, LED light fixtures, mecho shades, building automation system. Changes in building envelope.	Less efficient units could have been installed	Slightly more exposure time to wire the extra controls. Falls when working on building envelope. Falls when installing mecho shades, wiring, etc. Spray on building insulation as a hazard for installer.	Already have safety program for scaffold work or ladder work. From design standpoint, reduce use of a mecho shade and design windows/sun shades based on solar orientation and heigh of sun at different seasons to shade the windows with a passive system versus active system.
Credit 2: On-Site Renewable Energy	Infrastructure for power leads to provide the future option of installing photovoltaic panels	This infrastructure would not have been included.	More exposure time on the roof and potential for heavier material. Steel erectors and electricians on the roof.	Tie-offs and parapet walls should be installed. From design standpoint, use an integrated PV shingle system (roofing system is also PV system). All accomplished by same trade.
Credit 3: Enhanced Commissioning	Commissioning agent, more non-worker exposure	No commissioning	New personnel on construction site regularly so no major risk.	Wear proper PPE including shoes.
Materials and Resources				
Credit 2: Construction Waste Management	Waste diverted from landfills by having construction workers sort waste by material type into different dumpsters.	Waste would just be thrown in dumpsters	Dumpster diving to sort more materials can result in twisting ankles, scrapes, sprains, abrasions, etc.	From design standpoint, no mitigation measures--all materials required on most any job. GC standpoint, single stream recycling--use a major waste management company to do sorting.
Indoor Environmental Quality				
Credit 1: Outdoor Air Delivery Monitoring	Installation of an outdoor air monitoring system.	Alarm system would not have been installed for the CO2.	Fall hazards associated with minor increase in wiring.	No alternative in terms of design. Utilize general contractor's standard safety program.

Credit 3.1: Construction IAQ Management Plan-During Construction	A construction indoor air quality management plan, covering of open ducts, not running diesel equipment inside, infrared gun to detect moisture in walls, proper ventilation of building, dust mitigation, housekeeping.	Traditional means/measures would have been utilized-not covering ducts, running diesel equipment, less housekeeping/dust mitigation	Workers exposed to increased time up and down ladders to cover ducts as well as additional materials required. Sees reduction in injury by keeping jobsite clean and reduction in hazard for construction workers from not running diesel equipment.	Ductwork delivered to jobsite with cellophane cap on ends. Reduce dust by other trades with different sequencing or sequence so that complete sections of system are installed without having to do intermediate end-capping.
Credit 4.1: Low-Emitting Materials-Adhesives and Sealants	Low VOC adhesives and sealants.	Traditional glue and adhesives would be used rather than water soluble. Traditional methods can overcome poor floor prep whereas low VOC adhesives cannot.	Future rework and additional prep work.	Non-adhesive based flooring systems. Use exposed concrete in lieu of tile, carpet, etc. Wood flooring on a sweeper system (floating floor-wood floor planks are sitting on resilient spacers or rubber pads) so not physically glued to substrate.
Credit 5: Indoor Chemical and Pollutant Source Control	Entranceways with walk off carpet tiles exhaust systems in all areas that could have harmful chemicals including janitor’s closet, mechanical rooms, computer rooms and all laboratories.	Traditional mechanical system with minimal exhaust systems.	Increased ductwork that involves increased exposure at heights as well as other trades working around existing hanging ducts. Other trades using ducts as elevated work surface.	Panning: rather than running ducts as normal, adhere sheet metal directly to the joists and sheathing to make space between sheathing and joist into a duct to mitigate other trades using ducts as elevated work surface. Use a filtered system instead of an exhaust to decrease ductwork.

Credit 6.1: Controllability of Systems- Lighting	Occupancy sensors and additional lighting controls were added to the rooms. Tie in with automated building system.	Fewer sensors or no sensors would have been installed in the facility.	No hazard with occupancy sensors or timers. Fall through or fall to lower/same with atriums and skylights as well as falling material.	Design building around courtyards so spaces are fronting glazing on outside of building or courtyard. Decreasing depth of building. Mirror system to direct light. Increase floor play lights (higher ceilings in general could allow light to penetrate deeper into building instead of using an atrium. Use walls that are not full height to separate spaces.
Credit 8.1 Daylight and Views	Atriums/skylights.	Less or no atriums and skylights.	Additional exposure to working at heights. Glazers working at heights. Heavy materials.	