Impact of Green Building Design and Construction on Worker Safety and Health

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Abstract: Sustainable, or "green," rating systems, such as the United States Green Building Council's *Leadership in Energy and Environmental Design* (LEED), are leading to changes in the way owners, designers, and contractors approach the design, construction, and operation of buildings. The processes and features included in green design and construction may have positive and/or negative impacts on construction worker safety and health. This paper presents the findings of a research study of the impact of green building design and construction practices on construction worker safety and health. Occupational Safety and Health Administration (OSHA) recordable and lost time injury and illness data from green projects (as identified by LEED) and from nongreen projects was collected through a structured questionnaire survey. The data collected was analyzed to test for the presence of a difference in OSHA recordable incident rates (RIRs) and lost time case rates (LTCRs) between green and nongreen projects. It was found that there was suggestive, but inconclusive evidence of a statistically significant difference in the RIRs of the green and nongreen building projects included in the study. No statistically significant difference was found between the LTCRs for the green and nongreen projects included in the study. The study findings provide valuable information to the construction industry for the purposes of project safety planning and the assessment of safety and health on projects.

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Introduction

Past research has focused on the impact of green design and construction on the health and productivity of the final occupants (end-users) of a facility. Literature indicates that green building concepts, applied to the design, construction, and operation of buildings, can enhance both the economic well-being and environmental health of a building's final occupants [United States Green Building Council (USGBC) (2006)]. However, questions exist regarding whether the inclusion of concepts in the building development process has positive and/or negative impact on construction worker safety and health. For instance, what is the difference in injury rates between green projects and nongreen projects? Does the injury rate differ depending on the number of green features incorporated into the building and the level of sustainability achieved?

The building industry's current perspective of sustainability is centered primarily on the principles of resource efficiency and the health and productivity of the building's occupants. The writers argue, however, that if a building is to be labeled as "sustainable," sustainability should be considered across its entire lifecycle, including the construction phase, and the green design and construction practices should also consider the safety and health of the construction workers. Based on this belief, the building industry's sustainability philosophy and principles should incorporate construction worker safety and health. The research described in this paper was conducted to investigate the relationship between current sustainability practices and construction site safety in order to provide evidence of the need to change the industry's view of sustainability to include consideration of construction worker safety and health.

The primary objective of this study was to examine the relationship between green building design and construction practices and construction worker safety and health. Accordingly, two research questions were posed:

- Is there a difference in safety and health performance, based on Occupational Safety and Health Administration (OSHA) recordable and lost time injury and illness rates, between green projects and nongreen building projects?
- Does the injury rate differ with respect to the extent of green features and processes included, i.e., the level of certification and/or number of certification points received?

LEED Rating System

The United States Green Building Council (USGBC) was formed in 1993 as a coalition of leaders from every sector of the building industry working to promote buildings that are environmentally responsible, profitable, and healthy places to live and work (USGBC 2006). USGBC's core purpose is to transform the way buildings and communities are designed, built, and operated, enabling an environmentally and socially responsible, healthy, and prosperous environment that improves the quality of life (USGBC

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2006). USGBC released the *Leadership in Energy and Environmental Design* (LEED) rating system as a voluntary, consensus-based national standard for developing high-performance, sustainable buildings. The official version for new commercial construction and major renovations, LEED-NC 2.0, was released in March of 2000. Currently there are nine different versions of the LEED rating system: new commercial construction and major renovations; multiple buildings and on-campus building projects; existing building operations and maintenance; commercial interiors projects; core and shell development projects; homes; neighborhood development; schools; and retail. The most commonly used version is LEED-NC for new construction. LEED-NC is organized based on a point system consisting of a total of 69 possible points in six categories: sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, and innovation and design process. Buildings which satisfy or exceed the green requirements posed by the LEED rating systems are formally certified by USGBC. There are four levels of formal certification based on the number of points a project receives: Certified, Silver, Gold, and Platinum. LEED has been accepted as a national standard for rating green building design and construction in the United States, Canada, and many other countries.

Literature Review

A literature search of journal databases and the World Wide Web did not uncover documentation about the impacts of green design and construction on the safety and health of construction workers. This absence of documentation may be attributed to the fact that the most commonly used green building rating system, LEED, is relatively new, introduced by USGBC in 2000, and studies of its impact on construction safety have yet to be completed and published.

A review of the LEED-NC rating system was conducted to identify any formal incorporation of construction worker safety and health (Gambatese et al. 2006). Of the 67 green design and construction elements contained within LEED-NC, 19 of the elements (28.4%) and 19 of the 69 points available (27.5%) impact the constructor's scope of work. The rating system contains one element, Indoor Air Quality (IAQ) Management during Construction that explicitly addresses construction worker safety and health. The intent of this element is to protect the construction workers and building occupants from potential air quality problems during the construction or renovation process. On successful implementation of an IAQ management plan, the project will receive one LEED-NC credit. Considering that the total number of possible LEED-NC credits for a project is 69, one credit is almost negligible and underscores the minimal consideration that the rating system gives to construction worker safety and health (Gambatese et al. 2006). It should be noted, however, that other elements within the rating system which are aimed to improve the safety and health of the end-user, such as the use of low-emitting materials, may benefit the safety and health of construction workers as well.

The writers conducted a pilot study to serve as a preliminary investigation of the relationship between green buildings and construction worker safety and health (Gambatese et al. 2006). The purpose of the study was to assess whether there is an impact, either positively or negatively, of green building design and construction on the safety and health of the construction workers. In addition, the study aimed to uncover green design and construction practices that affect worker safety and health. A LEED-NC "Gold" registered building construction project was used as the focus of the pilot study. The project consisted of the construction of a new university engineering building. Data used for the pilot study was collected through focus group interviews of project personnel and from a review of project documentation. It was found that some features of the building, such as the construction materials recycling program, negatively impacted the *safety* hazards to which the construction workers were exposed, while others, such as the use of low volatile organic compound materials, helped to eliminate construction site *health* hazards. Project personnel felt that green building projects were "a little safer" than conventional building projects. One of the OSHA recordable injuries experienced on the project (foot punctured by nail) occurred while a laborer was separating material for recycling, a green feature of the project. It should be noted, however, that this type of injury may also occur during general housekeeping on any project and not just on a LEED project (Gambatese et al. 2006).

The United Kingdom's *Building Research Establishment Environmental Assessment Methodology* (BREEAM) is another commonly used sustainable building rating system. BREEAM assesses the performance of buildings in the following areas: management, energy use, health and well-being, pollution, transport, land use, ecology, materials, and water (BREEAM 2006). *Green Star* is administrated by the Green Building Council of Australia (GBCAUS). Green Star certification identifies projects that have demonstrated a commitment to sustainability by designing, constructing, or owning a building to a determined standard. Green Star certification is given to projects that have demonstrated they meet all requirements detailed in the relevant Green Star Technical Manuals for each of the rating tools (Green Building Council of Australia 2006). Review of the three major sustainable rating systems reveals an absence of construction worker safety and health consideration. This indicates that the building industry's current perspective of sustainability is based on the principles of resource efficiency and the health and productivity of the building's occupants.

The primary purpose of USGBC LEED certification is to make buildings "greener" by promoting a whole-building approach to sustainability by recognizing performance in five key areas of human and environmental health: sustainable site development, water savings, energy efficiency, materials selection, and indoor environmental quality (USGBC 2006). By doing so, USGBC aims to reduce the environmental impacts of a building's lifecycle and protect the health of the building's occupants. However, there is a difference between the terms "green" and "sustainable." These two terms have been used interchangeably in the construction industry, yet they are different. Green is a term used to address primarily the design and construction practices that impact the environment. Sustainability is a broader concept which, in addition to the environmental aspect, addresses the continuity of economic and social aspects of human society. For a green building to be sustainable, consideration must be given to more than just protecting the environment. For example, Gilding et al. (2002) argued that the term "sustainability" is too narrowly focused on the environment, ignoring other important aspects such as worker safety. They contended that no entity that presides over avoidable workplace deaths, injuries, or illnesses can ever claim to be sustainable. In the United States, the construction industry has historically employed about five percent of the workforce, yet has accounted for a disproportionate number, approximately 20% annually, of occupationally related fatal and nonfatal injuries and illnesses (United States Bureau of Labor Statistics 2007). The

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causes of injuries and illnesses in construction have long been recognized and their persistence continues to frustrate construction safety and health practitioners and researchers (Hill 2003). Research has identified best practices which improve the safety and health performance of construction workers (for example: Construction Industry Institute, University of Texas at Austin 2003; Jaselskis et al. 1996). However, the construction industry consistently experiences higher fatality and injury/illness rates when compared with other industries (National Safety Council 2007). Sustained control and elimination of safety and health hazards is required to improve safety performance in the construction industry. The writers believe that this can be advanced by introducing the concept of sustainability in construction worker safety and health.

Research Methods

Subsequent to the pilot study described above, a detailed study was performed to identify the impacts of green building design and construction on the safety and health of construction workers. The premise of the research was that a difference in safety and health performance exists between green and nongreen construction projects. The research design used for the research study consisted of: (1) the collection and analysis of safety and health performance data for both green and nongreen projects and (2) informal interviews of construction safety representatives regarding the safety performance of green and nongreen buildings.

The first research task consisted of the development, distribution, and analysis of a short questionnaire. The questionnaire consisted of three sections requesting information on project demographics, safety performance, and LEED rating. The first section was aimed at gathering demographic information such as the project type (new construction, major remodel, or mixed), facility type (education, healthcare, condominiums, office, mixed use, laboratory etc), project cost, size, type of ownership, location, etc. The second section solicited information related to the safety performance of the project: total project work hours (self-performed or subs included), number of OSHA recordable, and lost time injuries and illnesses, and number of near misses, if recorded. The last section focused on LEED information: whether the project was certified or registered, the type of certification, level of certification, number of LEED points, and whether the project LEED documentation was available for review by the writers. Fig. 1 shows the survey form.

The questionnaires were sent to fifteen construction contracting firms with offices located in the Pacific Northwest and nationally. Firms selected for the study were primarily those with which the writers have personal contact and which expressed an interest in helping out with the research (convenience sample). More than one firm was included in the study in order to help eliminate possible bias that one single firm might have with respect to safety and its green or nongreen projects. The group of firms consisted of medium- and large-sized companies which construct buildings, including green buildings.

The respondents at each firm were asked to compile the survey information for as many projects as possible, limited to building projects constructed in the past five years. The firms' safety directors/managers were contacted to obtain the safety performance information. The firms' LEED professionals or project specific managers were contacted to obtain information regarding the LEED rating of each project designed to be sustainable. LEED information on each project was also obtained from other sources such as the USGBC website which contains a list of all of the registered and certified projects. The website information includes the project name, owner, level of certification, number of points, and the final LEED scorecard. Data from a total of 86 building projects was received.

Company Name:		Project #1	Project #2	Project N
Project Demographic Data				
1	Project type (e.g., school, hospital, etc.)			
2	Project size (square feet)			
3	Total cost of project			
4	Percent project complete (e.g., 100%, 75%, etc.)			
5	Location (city, state)			
6	Year project completed/in-progress			
Project Safety Data				
7A	Total number of worker hours worked on the project (if project is in-progress, total hours worked to date)			
7B	If subcontractor work hours not tracked by your firm, please mention and report the self-performed work hours			
8A	Total number of OSHA recordable injuries (if project in-progress, injuries to date)			
8B	If injuries of subcontractor employees not tracked by your firm, please report the number of recordable injuries of your employees			
9A	Total number of lost time, transfer, or restriction injuries (if project is in-progress, injuries to date)			
9B	If injuries of subcontractor employees not tracked by your firm, please report the number of lost time injuries of your employees			
10	Number of near misses (if tracked)			
Project LEED Data				
11	Is the project LEED certified/registered? (Y/N)			
12A	What type LEED certification is being sought? (NC, EB, CS, etc.)			
12B	If LEED certification or registered, what is the level of certification? (Certified, Silver, Gold, or Platinum)			
13	Number of LEED points obtained for the project			
14	Is LEED documentation available? (Y/N)			

Fig. 1. Questionnaire survey form

The survey questionnaire was followed by personal interviews of safety professionals to seek their opinions of the affects of green building design and construction on construction worker safety and health. The respondents consisted of the safety managers/directors from eight of the 15 construction firms which provided project data for the research. Unstructured, open-ended interviews were conducted to provide an opportunity for the experts to put forth their thoughts on this issue and respond to the question whether LEED projects (green design and construction) have any impact on construction worker safety and health.

Results

Nine of the 15 firms (60%) contacted responded to the questionnaire survey. Of the firms that responded, seven provided data from their projects, one firm was not interested in providing the information due to confidentiality purposes, and the other was just in the process of constructing a LEED certified building and therefore was not able to contribute data. Several follow-up e-mails to the respondents were unsuccessful in increasing the response rate. The information requested was, in some cases, difficult to obtain. Collecting the information commonly required the efforts of more than one department within a firm such as the safety, finance, and sustainable building divisions. In some cases, firms either did not maintain historic records of their work, or only tracked safety records for self-performed work. The survey

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Table 1. Distribution of Projects Based on Responding Firms ($n=86$)

Firm id	Number of projects	Study sample projects (%)	Number of green projects	Number of nongreen projects
A	46	53.5	17	29
B	6	7.0	4	2
C	10	11.6	6	4
D	2	2.3	1	1
E	4	4.7	2	2
F	8	9.3	3	5
G	10	11.6	5	5
Total	86	100.0	38	48

response rate of 46.6% (7 out of 15) is reasonable considering the sensitivity of the data being collected.

The seven responding construction firms provided data on 86 building projects. All of the projects were constructed (some in-progress) in the period from 2000 to 2006. The study sample included projects built in the United States (83) and Canada (3). Of the 86 sample projects, the majority of the projects (82.6%) are located in Oregon and Washington. The responding firms' annual volume of work ranges from \$220 million to \$1 billion. All of the firms have an experience modification rating (EMR) less than 1.0. The breakdown of the construction firms based on the number of projects contributed to the study sample and the corresponding number of green and nongreen projects is presented in Table 1.

The majority of the green and nongreen projects in the study sample were new construction projects (67.4%) followed by mixed new and remodel projects (18.6%). The 86 sample projects consisted of many facility types: housing, hotels, mixed use, condominium, library, hospital, or medical building, office buildings, K-12 education, higher education university buildings, and convention center. For the purposes of the study, the projects were grouped under five categories based on their similarity in design, construction, and operation: education (higher and K-12 education) (31.4%), commercial offices (all private and government office buildings) (18.6%), public gathering (19.8%), healthcare and lab (16.3%), and residential high-rise (condominiums and hotels) (14.0%).

The cost of the 86 sample projects ranged from \$4 million to \$271 million (mean=\$47.86 M; median=\$30.0 M), and the size ranged from 12,000 sf to 1,150,000 sf (mean=194,140 sf; median=139,000 sf). Unit cost was calculated for the sample projects by dividing the project cost by the project square footage to normalize the projects based on size. The unit cost of the projects included in the study ranged from \$22 to \$1,429 per sf (mean=\$288/sf; median=\$253/sf). Fifty of the sample projects (58.1%) were valued in the range of \$100 to \$300 per sf. Comparing the green and nongreen projects, the green projects were more expensive (in terms of unit cost) than the nongreen projects. The 38 green projects had a mean unit cost of \$296/sf, while the mean unit cost for the 48 nongreen projects was \$281/sf. This difference in unit cost could be attributed to the additional up-front costs that green projects often require for materials, energy modeling, LEED documentation and registration, and so forth.

In order to assess whether the vertical height of buildings is a contributing factor due to increase injuries from falls to lower levels, the survey asked for the number of stories in each building. The number of stories was not provided on three projects. Based on the remaining 83 projects, the height of the buildings in the study ranged from 1 to 57 stories (mean=7.3 stories; median=4 stories). There was a wide variation in the heights of the 83 buildings, with 57.8% of the buildings equal to or shorter than four stories. Seven buildings were taller than 15 stories. Among the green projects, 50% of the buildings were equal to or taller than five stories. In contrast, only 32.2% of the nongreen projects were equal to or taller than five stories.

Project Safety Performance

The second section of the questionnaire survey solicited information on the safety performance of the projects. For the purposes of the study, safety performance was measured using the OSHA recordable incident rate (RIR) and lost time case incident rate (LTCR) on the projects. OSHA recordable incidents are defined as those incidents that resulted from an exposure or event in the workplace and that required some type of medical treatment or first-aid. The RIR is calculated as the number of recordable incidents per 100 workers per year (200,000 worker-hours). Lost time case incidents are defined as those incidents that resulted from an exposure or event in the workplace and that required the employee to be away from work or limited to restricted work activity. The LTCR is calculated in a manner similar to the RIR except that it uses the number of cases that contained lost work days.

The study questionnaire requested information about the number of OSHA recordable and lost time case injuries sustained on each project and the total number of work hours that were worked on each project. All of the 86 sample projects provided the requested injury and work hour information. However, not all of the projects tracked subcontractor injuries and illnesses and their work hours. Of the 86 projects, only 74 projects (86%) provided information on total project employee incidents and work hours. The remaining 12 projects (14%) provided information only on the incidents and work hours involving self-performed work of the responding contracting firm. For all of the 86 projects, the RIRs ranged from 0 to 52 (mean=5.85; median=4.98), with 17 projects (19.8%) reporting zero injuries. The LTCRs ranged from 0 to 52 (mean=2.48; median=0.7), with 36 projects (41.8%) reporting zero injuries.

Project LEED Information

The third section of the questionnaire solicited information about the green aspects of the projects. Of the 38 green projects present in the study sample, 34 projects (89.5%) were certified under the LEED-NC category, two (5.3%) under the LEED-CS (Core and Shell) category, one (2.6%) under LEED-EB (Existing Building) category, and one (2.6%) did not have this information available. The study sample predominately consists of LEED-NC projects, which may be due to the fact that LEED-NC was the earliest certification category introduced by USGBC. Currently, there are very few projects that have been certified/registered under the other types of certification categories (USGBC 2006). Hence, the study sample can be considered representative of the current population of green projects. Other certification categories are slowly being introduced into the building market or are still in the pilot phase.

As mentioned previously, the LEED rating system consists of four levels of certification: Certified, Silver, Gold, and Platinum. The study sample consisted of five Certified projects (13.2%), 20

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Table 2. Green and Nongreen Project Safety Performance

Safety measure	Project type	Number of projects	Mean	Standard deviation	Median	Mann-Whitney (2-tail *p*-value)
RIR	Green	38	6.12	5.36	6.86	0.186
	Nongreen	48	5.63	7.65	4.63	
LTCR	Green	38	2.45	4.24	0.70	0.721
	Nongreen	48	2.50	7.75	0.78	

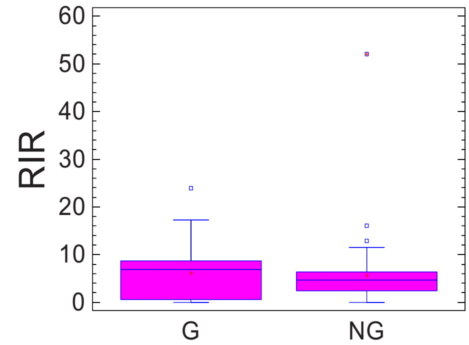

Fig. 2. Box plots of RIRs of green (G) and nongreen (NG) projects

Silver projects (52.6%), 12 Gold projects (31.6%), no Platinum projects, and one (2.6%) for which the respondent did not know whether it was certified or not. Not all of the projects in the study sample are certified. 26 projects (68.4%) are certified, 11 (30%) are registered, and one (2.6%) had an unknown status. Data on the number of LEED credits received by the projects was also documented. This information was only provided on 25 projects (both certified and registered). Five of the LEED certified projects did not have the information on the credits available. The LEED credits received by the 25 projects ranged from 29 to 44 credits (mean=36; median=35).

It should be noted that the term "certified" is used in two contexts by LEED. First, "certified" is used to describe completion of the entire process of getting a building recognized as green by meeting the requirements set forth by the LEED rating system. In order to get certified, a project must be registered with USGBC and the LEED guidelines followed. The project will be labeled as a "registered" project during this process. "Certified" is also used to describe a project that has implemented the minimum number of green features required to be recognized as a green building. Increasing the amount of green features will lead to higher levels of certification such as Silver, Gold, or Platinum.

Analysis and Discussion

Statistical analysis software, Statgraphics Plus 5.1, was used for the analysis in this study. For tests of statistical significance that are described in this paper, two-sided *t*-tests were conducted. A test of the data for normality (Kolmogorov-Smirnov test) revealed that the distributions of both the RIR and LTCR data were nonnormal ($p=0.000$). In addition there were several outliers present in the data which would make a *t*-test invalid. Hence, it was decided to use the nonparametric Mann-Whitney and Kruskal-Wallis tests. The Mann-Whitney *U*-test examines the null hypothesis that the medians of two samples are the same (Statgraphics, Statgraphics Plus 5.1 2001). Mann-Whitney compares the medians of the two samples by combining the two samples and sorting the data from smallest to largest, and then comparing the average ranks of the two samples in the combined data. For items in which there were more than two samples to compare, the Kruskal-Wallis test was used. The Kruskal-Wallis test examines the null hypothesis that the medians of several samples are the same (Statgraphics, Statgraphics Plus 5.1 2001). Given that the primary objective of the analysis was to identify the presence or absence of any significant difference in median RIR and LTCR rates of green and nongreen projects, two different hypotheses were framed: (1) there is a difference between the median RIR of green and nongreen projects; and (2) there is a difference between the median LTCR of green and nongreen projects.

Given the inconsistencies in some of the data received, it was necessary to address the presence of projects which were either incomplete (in-progress) or for which information was provided only for self-performed work. Of the 86 projects, complete information needed for the analysis was only received on 63 projects. The researchers felt that the other 23 projects might skew the results if included in the analysis. The safety performance of these 23 projects was therefore compared to the other projects in the sample to determine if there was any significant difference. The median RIRs and LTCRs of the "complete" and of the "self-performed and incomplete" projects were evaluated using the Mann-Whitney test. No statistically significant difference was found between the medians of these two groups at the 95% confidence level for both the RIR and LTCR ($p=0.999$ and 0.157 respectively). Based on this result, the researchers decided to retain all of the self-performed and incomplete projects in the study sample. Table 2 presents a summary of the RIRs and LTCRs for the 38 green and 48 nongreen projects.

Fig. 2 shows box plots comparing the RIR of green and nongreen projects. The green projects have a higher median RIR (6.86) than the nongreen projects (4.63). In addition, the range of RIRs for the green projects is greater than for the nongreen projects. A Mann-Whitney test revealed suggestive evidence that the green projects experienced a higher median RIR than the nongreen projects ($p=0.186$). Analyses similar to that performed for the RIR were performed for the LTCR metric. It was found that the green and nongreen projects had little difference in median LTCRs as shown in Fig. 3. However, it was clearly evident as seen in Fig. 3, that there were several green projects that have LTCRs greater than the nongreen projects. The statistical test revealed that there was no statistically significant difference in the median LTCRs between the green and nongreen projects ($p=0.721$).

The above analyses were based on the assumption that any differences in safety performance in the 86 sample projects were

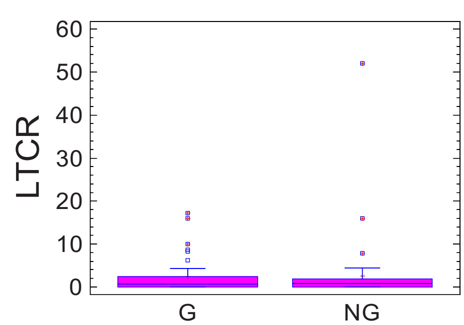

Fig. 3. Box plots of LTCRs of green (G) and nongreen (NG) projects

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due to the project being "green" or "nongreen." However, there are several confounding variables that might affect the safety performance of a project. A confounding variable is related both to group membership and to the outcome. Its presence makes it difficult to establish the outcome as being a direct consequence of group membership (Ramsey and Schafer 2002). In this study, the group membership is green or nongreen, and some of the measurable confounding variables include: project type, facility type, project complexity as defined by the unit cost, project height, project location, and type of funding. The presence or absence of a difference in sample medians may not just be attributed to a project being green or nongreen. Further tests taking into consideration these confounding factors were undertaken as described below.

The univariate analysis did not reveal any statistically significant difference between green and nongreen projects (only inconclusive evidence for median RIR), and as a result it is unlikely that a multivariate analysis would show any trends in the sample. This is especially true since the study sample size is small. However, the researchers decided to test the individual variable's affect on safety performance by assuming that all other variables have been controlled and do not have any affect on safety.

Contractor Type

Construction firms can vary in many different ways, including with respect to safety culture and performance. Even though the EMRs of all of the contractors who participated in the study were less than 1.0, the difference in their safety performance could be a factor contributing to the difference in safety performance between green and nongreen projects in the study sample. A Kruskal-Wallis test was performed to test for the presence of any difference in median RIR and LTCR among the seven contractors. One contractor only contributed two projects to the sample and has one of the projects with an incident rate of 52. Therefore, this contractor was removed from the analysis. The analysis revealed a statistically significant difference between the six remaining contractors based on the median RIRs ($p=0.015$). In addition, there is suggestive but inconclusive evidence of a difference between the median LTCRs ($p=0.104$). This result prompted the question of whether the suggestive difference in RIR between the green and nongreen projects from the previous analysis could be attributed to the contactor type. Therefore a comparison of the median RIR and LTCR for green and nongreen projects constructed by the same contractor was conducted. The available data made such a comparison possible for Contractor A, Contractor C, and Contractor G.

Contractor A provided 54% of the sample projects that included 17 green and 29 nongreen projects. A Mann-Whitney test was performed, revealing that there was significant difference in the median RIR ($p=0.010$) between the green and nongreen projects, and no difference in median LTCR ($p=0.923$). Considering the p-value for RIR, the green projects built by Contractor A were less safe than the nongreen projects. Since, Contactor A contributed more than 50% of the projects to the study sample, the "suggestive" difference between the median RIR of green and nongreen projects among the entire sample could have been confounded.

For Contractors C and G, there was no evidence of a difference between the median RIRs and LTCRs. However, it should be noted that this conclusion is limited in its generalization, since Contractors C and G contributed only a small number of projects to the study sample.

Table 3. Project Unit Cost and Safety Performance

Unit cost ($/sf)	Number of projects	Mean	Standard deviation	Median	Kruskal-Wallis (2-tail p-value)
		RIR			
0–100	5	3.19	3.40	3.87	
100–200	32	5.18	3.64	5.05	
200–300	18	6.77	11.54	4.54	0.549
300–400	15	6.89	5.54	7.25	
>400	16	5.99	6.24	5.59	
		LTCR			
0–100	5	1.04	1.69	0.00	
100–200	32	2.71	3.75	1.33	
200–300	18	3.35	12.16	0.21	0.270
300–400	15	2.13	4.43	0.00	
>400	16	1.82	3.88	0.85	

Project Ownership

The study sample contained projects funded by both private and public entities. Analyses of these two sets of projects revealed that there was not a statistically significant difference for the median LTCR ($p=0.412$) between the private and public projects in the study sample. There was suggestive evidence of a difference in the median RIR, and as a result of the presence of a reasonable number of data points, a detailed analysis of green and nongreen projects within these ownership types was performed.

Of the 44 privately funded projects, there was an approximately equal distribution of green (21) and nongreen (23) projects. The private green projects had a higher median RIR (7.06) than the nongreen (4.96) projects. The difference in median RIR was found to be statistically significant with a two-sided p-value of 0.051. For the LTCR, there was inconclusive evidence of a difference in the median of the two samples within the private projects. Of the 42 publicly funded projects, 17 were green projects and 25 nongreen projects. Statistical tests did not reveal any statistically significant difference in median RIR ($p=0.289$) and LTCR ($p=0.136$) among the green and nongreen public projects.

Project Unit Cost

Tests for the presence of a difference in median RIR and LTCR while accounting for an increase in unit cost of the projects were also conducted. A simple linear regression analysis would have been an ideal test for evaluating the presence of this relationship. However, the normality assumption required for the simple linear regression analysis was not met by the sample distribution. Hence, nonparametric tests were conducted. The sample projects were grouped into five categories as shown in Table 3. A statistical analysis was performed to test the presence of a difference between the medians of the five groups. It was found that there was not a statistically significant difference between the medians of the five groups at the 95% confidence level. Since the sample did not reveal any difference, any test within the green and non-

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green project sample was not warranted. In addition, the study did not have enough projects within each category to arrive at any meaningful conclusion.

Project Height

When working on tall buildings, construction workers face threats to their safety that may exist to a greater extent than on shorter buildings. The green projects in the study sample were taller on average than the nongreen projects. The 38 green projects had a mean height of 7.5 stories and a standard deviation of 5.9, while the 43 nongreen projects (3 projects did not provide this information) had a mean of 5.1 stories and a standard deviation of 5.5. A test of whether the RIR and LTCR increased with an increase in height was conducted. A simple linear regression was not performed due to the absence of normality in the data. Hence, the researchers organized the projects into four groups based on the number of stories: 1–4, 5–10, 11–15, and >15 stories, and tested for a difference in the median RIR and LTCR with the help of the Kruskal-Wallis test. It was found that there is not a statistically significant difference between the median RIR and LTCR of the four groups at the 5% significance level. Since the entire sample did not reveal any difference, a test for the impact of project height within the green and nongreen samples was not warranted. In addition, the study sample did not contain enough projects within each group to arrive at a meaningful conclusion.

Project Type

The sample projects were organized into three types of projects: new construction, major remodels, and mixed new and remodel. These three types of projects differ from each other in scope and complexity. In the case of renovation projects, workers work within and adjacent to the existing structure which can create complex work environments and pose a greater hazard than construction of a new structure. However, a Kruskal-Wallis test revealed that there was no statistically significant difference between the median RIRs ($p=0.288$) and LTCRs ($p=0.137$) of the three project types at the 95% confidence level.

Facility Type

The sample projects were also grouped into five major facility types: education, office, public gathering, medical, and residential facilities. Each type of facility may affect safety performance differently. For example, healthcare construction projects are commonly considered more complex to build than residential buildings because they involve installation of heating, ventilation, and air-conditioning systems, major laboratory equipment, piping, and so forth. A multiple sample comparison was performed to identify any difference between these five groups. It was found that there was no significant difference between the median RIRs and LTCRs of the five facility types. Since the sample did not reveal any difference, a test within the green and nongreen samples was not warranted, and the study sample did not contain enough projects to arrive at any meaningful conclusion.

LEED Certification and Safety Performance

The 38 green projects in the study sample were predominantly (90%) LEED-NC certified projects which did not allow for comparing safety performance among different types of LEED certification. However, sufficient data was available to compare

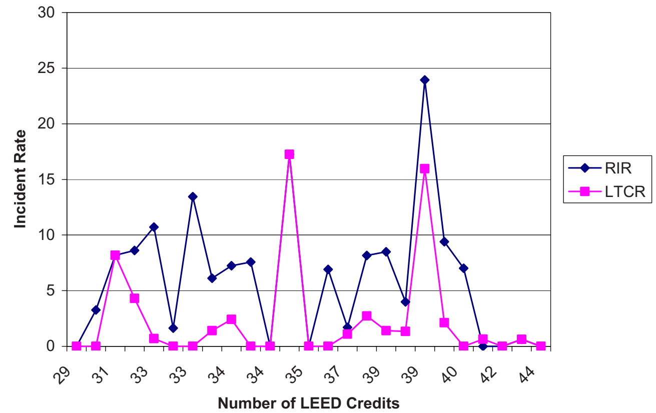

Fig. 4. Comparison of LEED credits and safety performance

projects based on the level of certification. The sample consisted of projects with three levels of certification: Certified, Silver, and Gold. In order to answer the question of whether the safety performance varied with a different level of certification, the median RIR and LTCR of these three certification levels were compared. The Kruskal-Wallis test revealed that there was not a statistically significant difference in the median RIR of the three levels of certification ($p=0.258$).

In order to compare the number of LEED credits to safety performance, simple linear regression would have been an ideal test. However, the nonnormal data would make this test invalid. Hence, a simple line graph (see Fig. 4) was drawn to observe any trend associated with the number of credits and safety performance. As can be seen in the figure, the graph does not reveal any trend in a relationship between the number of LEED credits and safety performance.

Interview Data Analysis

Simple informal interviews were conducted with safety representatives from eight of the responding construction firms. The safety representatives were asked whether there was any negative or positive impact of green design and construction on worker safety and health and, if so, what were the impacts. Six of the respondents said that they did not see any difference in safety performance between green and nongreen projects. One safety professional noted that green projects tend to improve the "health" of construction workers due to the provision of using less harmful construction materials as part of LEED. One respondent noted that the extra efforts due to material handling "could" be a cause of concern for employee safety.

Study Limitations

As with many studies of construction project performance, the selected research methods and data used in the studies inhibit the generalization of the findings beyond the study sample. Major limitations present in this study are described below:

- One limitation impacting the study is the data collection process. The projects contained in the study sample were not collected randomly. Since the data was not randomly sampled, statistical inferences could not be made to the study population which, in this case, consists of all of the green and nongreen projects built in United States and Canada. The sample selection was a two-stage selection process. First, a set of builders

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was selected to study and, second, a set of building projects were selected by these builders. The selection of the builders was based on the researchers' knowledge of whether they build green projects and was not random. Selection of the projects within each firm was at the discretion of the builders. The researchers did not have any influence on this process. In summary, builder and project selection were not random and, therefore, inferences can be made only to the data set. Generalization to the population is speculative.
- A second limitation is associated with the study inferences. The OSHA recordable and lost time injury and illness rate data used for the study is observational data and cannot be used to make cause and effect statements.
- Another limitation is the small sample size. A major reason for this small sample size was the reluctance of contractors to provide safety and LEED information from their projects. Safety data was considered by some contractors to be part of the client-contractor confidentiality agreements. Similarly, the LEED documentation which outlines the specific green design aspects of the projects was considered to be a trade secret and some contractors declined to provide this information. A larger sample size would have provided greater confidence in the results.
- Last, a significant number of the sample projects (54%) were built by one contractor. Interpreting the results may be skewed by the dominance of the contractor's projects and generalization to an expanded population limited. Further study of a diversified pool of projects based on contractor type is needed.

Conclusions and Recommendations

The major objective of this study was to investigate the impacts of green building design and construction on construction worker safety and health. A comprehensive statistical analysis of 86 projects (38 green and 48 nongreen) tested the presence of a difference in safety performance between green and nongreen projects. Based on the above analyses of the study sample:
- There is suggestive but inconclusive evidence of a statistically significant difference between the median RIR of green and nongreen projects in the study sample. Green projects had a higher median RIR than nongreen projects.
- There is not a statistically significant difference between the median LTCRs for the green and nongreen projects included in the current study.
- There was a statistically significant difference between the safety performances of the contractors who participated in the study. Contractor A's green and nongreen projects have significant differences in median RIRs and suggestive difference in median LTCRs. Contractor A had better safety performance on nongreen projects than on green projects.
- No significant difference in safety performance in the study sample projects was found based on project type, facility type, ownership, height, and unit cost.
- There was not a significant difference in median RIR and LCTR with respect to different levels of LEED certification. No negative or positive impact on safety performance was found when the amount of green design and construction features varied.

Based on this research study, there appears to be little or no difference between green and nongreen projects in terms of construction worker safety and health. With both green and nongreen buildings having the same safety performance, a question arises as to whether LEED buildings should be labeled as sustainable buildings. Because no difference in safety performance is experienced, LEED projects are perhaps sustainable environmentally but not sustainable in terms of worker safety and health. The writers believe that, similar to end-user safety and health, construction workers safety and health must be considered if a project is to be labeled as sustainable. An understanding of whether current green design and construction practices impact construction worker safety and health will provide the construction industry with the knowledge required to move forward and develop green design and construction practices, and green building rating systems, that benefit construction worker safety and health. Current status indicates that designing for the environment is given a higher priority than designing for construction worker safety and health (DfCSH). The DfCSH concept was originally introduced by Hinze and Wiegand (1992), refined by Gambatese et al. (1997), and is currently part of a new initiative named Prevention through Design spearheaded by the National Institute for Occupational Safety and Health (National Institute for Occupational Safety and Health, Atlanta 2008). Given the recent national momentum, this research hopes to promote additional research which seeks to include construction worker safety and health in a more holistic view of sustainable construction efforts. Future research might include evaluating specific LEED criteria and their relationship to construction safety and health.

The project LEED information that was available for the study included the type and level of LEED certification, number of LEED points, and general descriptions of the green features on the project. Therefore, it was not possible to make connections between each injury incident and specific green design and construction features. Relating injury incidents to specific green design and construction features could be accomplished in a much larger study that involves a significant data gathering and project documentation review effort on multiple projects. Future research is encouraged to establish such relationships.

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