Sustainable Buildings
Applying Prevention Through Design

By Mohammed Albattah, Marielle Roucheray and Matthew Hallowell

Construction accounts for more fatal injuries than any other industry (BLS, 2011). Improving construction worker safety and health is a critical societal concern, involving owners, designers, contractors and subcontractors. Unfortunately, recent research suggests that the work processes required to construct emerging sustainable building components involve increased exposure to high risk work (Fortunato, Hallowell, Behm, et al., 2012; Dewlaney, Hallowell & Fortunato, 2012). As the trend of building green continues, SH&E professionals must identify the specific hazards associated with sustainable design elements and develop design interventions that reduce worker exposure.

Sustainable building is an accelerating trend in the architecture, engineering and construction (AEC) industry. The most recognized green building initiative is the U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED). LEED is a certification system that evaluates the potential environmental performance of a building over its life cycle (USGBC, 2011).

The LEED certification program was first implemented in 1998 and has since grown to encompass more than 25,000 commercial projects and 1.6 billion sq. ft of developed space (USGBC). LEED for New Construction is the latest and most commonly used version of the certification. It has almost 55 credits with 110 possible points. Because LEED is a design-related issue, the most effective means to integrate occupational safety with this certification system is via prevention through design (PTD).

IN BRIEF
- Although the number of high-performance sustainable buildings has grown rapidly in the U.S., recent studies show that these projects may increase worker exposures to hazardous construction environments.
- This article describes the development of a web-based prevention through design tool that utilizes data from recent research and the results of pilot testing the tool with active professionals working on Leadership in Energy and Environmental Design projects.

PTD is especially effective in mitigating safety risk early in the development of a project (Behm, 2005). Also known as design for construction safety, PTD is the deliberate consideration of construction worker safety and health in the design of the permanent features of a project (Gambatese, Behm & Hinze, 2005). PTD relies on the underlying concept that a portion of safety risks can be removed during design by altering a building's features so that they are safer to construct and maintain (Safer Design, 2011). Natural synergies exist between sustainable building design and PTD when one considers that a building is not truly sustainable if workers are injured or killed during its development or maintenance.

This article describes 1) recent research that identifies specific exposures to hazards connected to sustainable building components, the magnitudes of their impacts and the methods of risk mitigation; 2) a web-based tool that organizes this information into a single decision support system; and 3) the results of pilot testing this tool on active projects with experienced professionals.

Background

The adoption of the LEED rating system has increased greatly in recent years. This trend is due to the perceived benefits attributed to green buildings, both in terms of positive environmental impact and reduction of utility costs (Eicholtz, Kok & Quigley, 2008; Fuerst & McAllister, 2008; Miller, Spivey & Florance, 2008). The construction industry's current perspective of sustainable building is mainly focused on the principles of resource efficiency and the health of the final occupants. However, it has been argued that sustainability encompasses the effects throughout a building's entire life cycle. This must include the health and well-being of construction workers (Rajendran, Gambatese & Behm, 2009).

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Recently, several studies have evaluated the effects of pursuing LEED certification on worker safety and health. For example, Rajendran, et al. (2009), conducted a study on 86 projects to test for a difference in safety performance between green and nongreen projects. These researchers found suggestive statistical evidence that LEED-certified projects incur higher OSHA recordable injury rates than conventional construction projects.

Following this study, Fortunato, et al. (2012), conducted six detailed case studies to identify how the common design elements and construction practices implemented to achieve LEED certification affect construction worker safety and health. The case studies revealed that of the 55 applicable credits, 12 increase safety risks when compared to conventional projects mainly because workers are exposed to unfamiliar situations and additional work at height and near electrical systems, unstable soils and heavy equipment.

Dewlaney, et al. (2012), extended this work by quantifying the increase or decrease in base-level safety risk for the credits Fortunato, et al. (2012), highlighted. Through 37 interviews with experienced designers and contractors, these researchers concluded that the most significant negative effects to construction safety are the green roof credit, also known as the heat island effect credit (19% increase in eye strain when installing reflective roof membranes); on-site renewable energy (24% increase in falls to lower level during roof work); and construction waste management (36% increase in lacerations, strains and sprains). As noted, a viable technique to mitigate these risks is to apply PTD in concert with sustainable design.

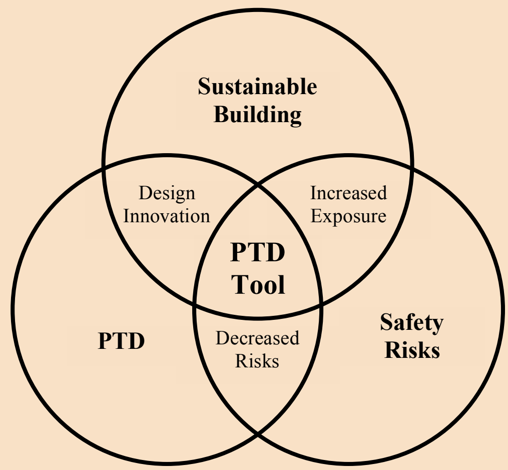
Several studies have investigated the viability of PTD. For example, Smallwood (2004) surveyed 71 general contractors in South Africa and found that design was identified as having a negative influence on worker safety in 50% of reported injuries. Similarly, Gibb, Haslam, Hide, et al. (2004), found that changes in facility design could reduce the likelihood of the accident occurrence in 47 of 100 accidents studied. Finally, Behm (2005) reviewed 226 injuries and 224 fatalities, and determined that design was linked to approximately 22% of injuries and 42% of fatalities.

Despite these perceived benefits, PTD implementation encounters several barriers. For example, the OSH Act of 1970 gives employers the responsibility for construction safety and health, which essentially absolves designers from legal responsibility for construction worker safety. In addition, the lack of construction safety and PTD education and resources for designers makes implementation infeasible even if designers have the best intentions (Toole, 2005). Other barriers include designers' fear of liability, lack of safety education for designers, and lack of communication between designers and contractors on typical projects (Gambatese, et al., 2005; Toole, 2005).

Several tools have been developed to facilitate designer adoption of PTD best practices. In a prominent example, Gambatese, Hinze and Hass (1997) created the Design for Safety and Health Toolbox that provides designers with hundreds of specific design suggestions for improving construction safety and health. Toole (2005) built on this by defining a PTD integration model that includes reviewing the design elements, creating design documents, assisting the owner in procuring construction, reviewing submissions and inspecting work in progress. Together, these publications provide designers with basic guidance for navigating the PTD process. Although these decision support systems and guidance documents are helpful, they do not specifically address the hazards that are unique to LEED projects.

Figure 1

Position of This Study Within Existing Literature



To address this knowledge gap, Dewlaney and Hallowell (2012) identified design and management techniques that mitigate risks associated with the means and methods used to achieve LEED certification. Through interviews with experienced design engineers and construction professionals, this study found specific strategies to mitigate each hazard identified by Fortunato, et al. (2012).

Theoretical & Practical Contributions

To provide a flexible and accessible platform for knowledge access and transfer, the authors incorporated the information provided by Fortunato, et al. (2012), Dewlaney, et al. (2012), and Dewlaney and Hallowell (2012) into a decision support tool in a PDF file and dynamic HTML web page. As shown in Figure 1, this tool addresses the intersection of LEED, PTD and construction safety.

This article presents the results of original research that aimed to develop and field test a research-based decision support system that helps designers and construction managers identify and control hazards linked to green building features.

These contributions advance both knowledge and professional practice. First, this is an original

PTD relies on the underlying concept that a portion of safety risks can be removed during design by altering a building's features so that they are safer to construct and maintain.

The most recent scorecard from LEED for New Construction serves as the interface for the software tool.

Figure 2

Opening Screen of the Sustainable PTD Tool

Y N			
	Sustainable Sites	**Possible Points:**	**26**
	Prereq 1	Construction Activity Pollution Prevention	
	Credit 1	Site Selection	1
	Credit 2	Development Density and Community Connectivity	5
	Credit 3	Brownfield Redevelopment	1
	Credit 4.1	Alternative Transportation - Public Transportation Access	6
	Credit 4.2	Alternative Transportation - Bicycle Storage and Changing Rooms	1
	Credit 4.3	Alternative Transportation - Low-Emitting and Fuel-Efficient Vehicles	3
	Credit 4.4	Alternative Transportation - Parking Capacity	2
	Credit 5.1	Site Development - Protect or Restore Habitat	1
	Credit 5.2	Site Development - Maximize Open Space	1
	Credit 6.1	Stormwater Design - Quantity Control	1
	Credit 6.2	Stormwater Design - Quality Control	1
	Credit 7.1	Heat Island Effect - Non-roof	1
	Credit 7.2	Heat Island Effect - Roof	1
	Credit 8	Light Pollution Reduction	1
	Water efficiency	**Possible Points:**	**10**
	Prereq 1	Water Use Reduction - 20% Reduction	
	Credit 1	Water Efficient Landscaping	2 to 4
	Credit 2	Innovative Wastewater Technologies	2
	Credit 3	Water Use Reduction	2 to 4
	Energy and Atmosphere	**Possible Points:**	**35**
	Prereq 1	Fundamental Commissioning of Building Energy Systems	
	Prereq 2	Minimum Energy Performance	
	Prereq 3	Fundamental Refrigerant Management	
	Credit 1	Optimize Energy Performance	1 to 19
	Credit 2	On-Site Renewable Energy	1 to 7
	Credit 3	Enhanced Commissioning	2
	Credit 4	Enhanced Refrigerant Management	2
	Credit 5	Measurement and Verification	3
	Credit 6	Green Power	2
	Materials and Resources	**Possible Points:**	**14**
	Prereq 1	Storage and Collection of Recyclables	
	Credit 1.1	Building Reuse - Maintain Existing Walls, Floors, and Roof	
	Credit 1.2	Building Reuse - Maintain 50% of Interior Non-Structural Elements	
	Credit 1	Construction Waste Management	
	Credit 2	Materials Reuse	
	Materials and Resources, Continued		
	Credit 4	Recycled Content	1 to 2
	Credit 5	Regional Materials	1 to 2
	Credit 6	Rapidly Renewable Materials	1
	Credit 7	Certified Wood	1
	Indoor Environmental Quality	**Possible Points:**	**15**
	Prereq 1	Minimum Indoor Air Quality Performance	
	Prereq 2	Environmental Tobacco Smoke (ETS) Control	
	Credit 1	Outdoor Air Delivery Monitoring	1
	Credit 3.1	Construction IAQ Management Plan - During Construction	1
	Credit 3.2	Construction IAQ Management Plan - Before Occupancy	1
	Credit 4.1	Low-Emitting Materials - Adhesives and Sealants	1
	Credit 4.2	Low-Emitting Materials - Paints and Coatings	1
	Credit 4.3	Low-Emitting Materials - Flooring Systems	1
	Credit 4.4	Low-Emitting Materials - Composite Wood and Agrifiber Products	1
	Credit 5	Indoor Chemical and Pollutant Source Control	1
	Credit 6.1	Controllability of Systems - Lighting	1
	Credit 6.2	Controllability of Systems—Thermal Comfort	1
	Credit 7.1	Thermal Comfort—Design	1
	Credit 7.2	Thermal Comfort—Verification	1
	Credit 8.1	Daylight and Views - Daylight	1
	Credit 8.2	Daylight and Views - Views	1
	Innovation and Design Process	**Possible Points:**	**6**
	Credit 1.1	Innovation in Design: Specific Title	1
	Credit 1.2	Innovation in Design: Specific Title	1
	Credit 1.3	Innovation in Design: Specific Title	1
	Credit 1.4	Innovation in Design: Specific Title	1
	Credit 1.5	Innovation in Design: Specific Title	1
	Credit 2	LEED Accredited Professional	1
	Regional Priority Credits	**Possible Points:**	**4**
	Credit 1.1	Regional Priority: Specific Credit	1
	Credit 1.2	Regional Priority: Specific Credit	1
	Credit 1.3	Regional Priority: Specific Credit	1
	Credit 1.4	Regional Priority: Specific Credit	1
	Total	**Possible Points:**	**110**

attempt to test the efficacy of a research-based tool for PTD in green buildings. Thus, researchers may use the results presented as a foundation for future attempts to test the viability of PTD tools in different software platforms and integrate PTD with green building design and construction. Second, the decision support system created and presented can be used to advance practice because the output (specific design and safety management suggestions) can be immediately integrated.

Decision Support System Development

LEED for New Construction's scorecard (v. 3.0, 2009), USGBC's most recent checklist, is the interface of the tool (Figure 2). This opening screen has two options for each credit ("yes" or "no" to indicate whether the credit will be pursued on the project). Fortunately, this is a procedure that the user would perform as a standard part of the project. Thus, the input to the decision support system creates no additional work for the user. Figure 3 summarizes the tool's operation.

Once the user selects the credits that will be pursued, s/he can elect to review the risk report or the mitigation report. The tool will include feedback only for the selected credits. The risk report provides the expected increase or decrease in risk for each selected credit by the following categories based on past research: falls to lower level, falls to same level, overexertion, exposure to harmful substances and other.

Figure 4 shows the sample output for three common LEED credits. Additionally, the mitigation report provides PTD and construction management best practices for each selected credit. Figure 5 (p. 80) presents a sample mitigation report. For those interested in the complete list of risks, quantity of risks, mitigation strategies and research methods to achieve them, refer to Fortunato, et al. (2012), Dewlaney, et al. (2012), and Dewlaney and Hallowell (2012), respectively.

Pilot Testing & Results

The tool was piloted then refined based on feedback from eight designers and eight contractors. On average, the 16 participants had 18 years' experience and had completed at least two LEED projects. The purpose of testing the tool was to ensure that it adequately meets the needs of the AEC industry.

Therefore, the authors asked participants to use the tool on an active LEED project and provide their feedback within the context of their project. Once they pilot tested the tool, they were asked to complete a questionnaire that included questions about the tool's accuracy, usability and overall value using a modified Likert scale.

Table 1 (p. 80) summarizes the aggregate responses received. This table includes all evaluation criteria, the average and median overall rating, average and median rating of contractor participants, and the average and median rating for designer participants. The overall rating of the tool was 7.7 on a 10-point scale.

Based on these responses, the usability of the tool is very high. In fact, evaluation criteria such as the user interface, graphical displays, ease of use and efficiency received average ratings above 8.4 on the 10-point scale.

However, other criteria have lower average ratings. For example, two criteria, 1) that safety personnel will accept the tool as standard practice and 2) that the tool will be used in the companies if it became available, both received ratings below 6.3. The implication is that even if a tool exists that the industry finds valuable and easy to use, some aversion to its integration is likely. Another interesting finding is that designers and contractors had similar ratings.

Participants were also asked to comment on the tool's format and areas for improvement. All participants agreed that the combination of PDF and HTML versions improves the tool's accessibility. Interviewees liked the way the tool was organized, especially the output reports.

However, nine of the 16 participants had suggestions for improvement. All recommended having a simple tutorial with specific written instructions to help users read and understand the output. Seven participants believed that the risk report would be more useful if it had more detail, such as contextual information for the hazards associated with each credit. Another interesting recommendation, made by three respondents, was that the tool would be enhanced if cost information for the suggested mitigation strategies were included. These are all recommendations for future research and development.

One surprising trend in the open-ended feedback was outright resistance of several designers to the PTD concept. Two believed that since the contractors are responsible for worker safety, the tool is not useful to designers. In addition, one other participant commented that it is not fair or reasonable to expect designers to take a role in construction safety.

Such comments are related to the designers' fear of liability described in past research (Gambatese, et al., 2005). Perhaps the most progressive comment from the design community was that the tool facilitates "forward, intentional and proactive thinking that can result from having a discussion with the design team and contractor early on regarding safety matters." Such resistance should be considered in future research and policy making.

Figure 3

Decision Support Workflow

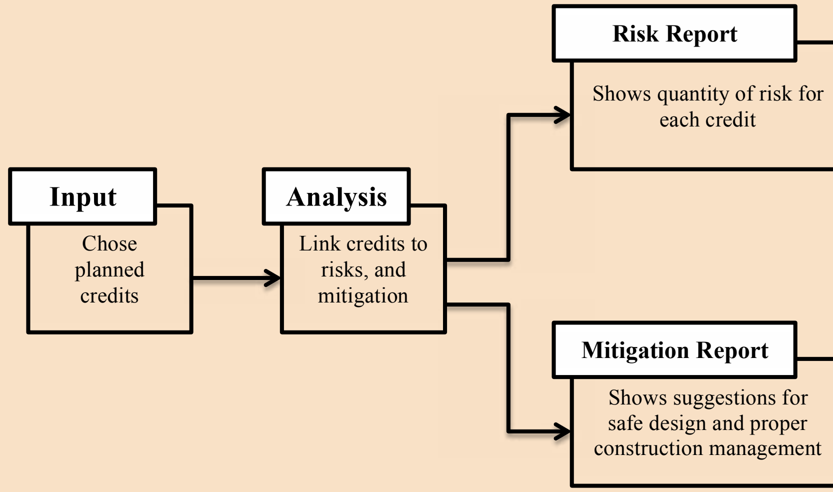


Figure 4

Risk Report Output From Decision Support System

LEED Credit	Falls to lower	Falls to same	Overexertion	Exposure - harmful substances	Other	Total
Heat Island Effect - Roof	4%	5%	13%	-	19%	41%
On-site Renewable Energy	24%	9%	3%	-	2%	37%
Low-Emitting Materials - Adhesives/Sealants	-	-	-	-1%	12%	11%

Figure 3 summarizes the tool's operation, while Figure 4 shows the sample output from three common LEED credits.

Conclusions & Recommendations

While an increase in injury rates may not be associated with LEED, some LEED credits present increased safety risks. The tool described here provides specific, research-based guidance for PTD and construction safety management for each credit. Pilot testing indicates that the tool is considered useful and will improve practice. This work builds on Gambatese, et al.'s (1997), Design for Safety Toolbox. As Behm (2005) shows, the most effective safety measures are those implemented early in the project. The tool itself is currently available for free at **www.buildgreenandsafe.org**, a website that promotes construction and maintenance safety as an integral component of sustainable building.

The generalizability of these findings is limited because all study participants were from Colorado. Additionally, the PTD suggestions only apply to the means and methods of construction used to achieve LEED credits. Therefore, when new methods or technologies appear, the tool output might no longer be suitable. Another limitation is that the designers provided mixed feedback that ranged from praise for a tool to rejection of the PTD concept.

Despite these limitations, the authors firmly believe there are strong practical implications of the use of the tool. The authors recommend future research to investigate the life-cycle safety effects of sustainable high-performance buildings, so that effects to suppliers, maintenance and operation workers may also be considered. **PS**

Figure 5

Mitigation Output From Decision Support System

CEM CONSTRUCTION ENGINEERING and MANAGEMENT

LEED Credit	Increased hazards	Design for safety mitigation strategies	Construction management plan mitigation strategies
Stormwater Quality Control	Increased exposure to on-site excavation and trenching specifically with the use of on-site detention ponds used to achieve credit, which may increase the number of falls	Design detention ponds with vertical cuts simliar to a "zero-entry pool" (i.e.gradually sloping entry in manner of natural beach). Ensure proper sloping in design for safety of workers.	Pre-construction planning: avoid concurrent activities near excavation (sequencing and site-layout planning). Schedule excavation to limit exposure. Use combination of flagging, barricades and signage. Ensure accuracy of as- built documents and adequate utility surveying (potholing).
Heat Island Effect- Roof	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.	Specify tan or light grey membranes (still achieve high SRI but lower glare and brightness). Adjust top's reflectivity. Include dull peel-off cover that could be prefabricated onto the TPO to lessen brightness and provide traction-recyclable material that would be removed and disposed upon completion of roof work. Texturize surface or include more rubber walkpads on high traffic areas.	Mandatory break rules. Ensure tinted eyewear. Provide warning signs at entrance to roof. Purchase higher number of smaller rolls from supplier to reduce weight and therefore minimize overexertion. Also, contractor may provide temporary walkpads if not in design.

Table 1

Pilot Test Survey Results

	Average			Median		
Evaluation criteria	**All**	**GC**	**AE**	**All**	**GC**	**AE**
The displays are easy to understand	8.0	8.1	7.9	8	8	8
The tool is easy to use	8.9	8.6	9.1	9	9	9
The amount of work required to use the tool is acceptable	8.4	8	8.8	8	8	8.5
User interface of the tool is appropriate	8.5	8.6	8.4	8.5	8.5	8.5
Graphical capabilities of the tool are appropriate	8.9	9.2	8.6	9	9.5	8.5
The tool will be accepted by safety personnel as standard practice	6.1	6.4	5.8	6.5	6.5	6.5
If the tool becomes available for the company, it will be used in most of the sustainable projects in the company	6.3	6.8	5.8	6.5	7	6
The safety risk mitigation techniques provided by the tool are useful for improving the current safety management activities	7.1	7.4	6.8	7	7.5	6.5
The safety risk quantification results provided by the tool are useful for improving the current safety management activities	6.8	7.1	6.5	7	7	7
Using the tool is not time consuming	8.4	8.2	8.6	9	8	9
This tool is valuable for improving safety	7.1	7.3	6.9	7	7	7
I recommend continued development of this tool for operational use	8.6	8.6	8.5	9	8.5	9
Total average	7.7	7.9	7.5	7.9	7.9	7.8

Note. *All = all respondents; GC = general contractors; AE = architects and engineers.*

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