www.cpwr.com • www.elcosh.org

CPWR
THE CENTER FOR CONSTRUCTION
RESEARCH AND TRAINING

Occupational Safety and Health in Green Buildings: LEED PtD Pilot Credit Analysis

Michael Behm
Annie Pearce

East Carolina University

August 2017
CPWR Small Study Final Report

8484 Georgia Avenue
Suite 1000
Silver Spring, MD 20910

PHONE: 301.578.8500
FAX: 301.578.8572

Occupational Safety and Health in Green Buildings: LEED PtD Pilot Credit Analysis

CPWR Small Study 15-3-PS

Michael Behm, PhD, CSP
Professor, Occupational Safety
East Carolina University
231 Slay Hall
Greenville, NC 27858

Annie Pearce, PhD, LEED AP, CPD
Associate Professor and Graduate Chair
Sustainable Facilities & Infrastructure Lab
Myers-Lawson School of Construction
330A Bishop-Favrao Hall, Virginia Tech
Blacksburg, VA 24061-0156

August 24, 2017

Contents

Key Findings 3

Executive Summary 3

Integrative Approaches to Green Projects 3

Study Motivation and Objectives 4

Overview of the Study and this Report 5

Green Rating Systems as a Means to Effect Change 7

History and Proliferation of Rating Systems 9

Evolution of Rating Systems 10

The LEED Rating System 11

Certification strategies used by project teams 16

Evidence of market transformation 17

History and Current State of PtD Practice in the US 19

Incorporation of PtD concepts in rating systems 20

Occupational Safety and Health on Green Projects 23

OSH in the LEED 4.0 Rating System 25

The PtD Pilot Credit as a Solution 25

Adoption of the PtD Pilot Credit to Date 26

Research Design and Methods 27

Objectives and Research Questions 27

Approach to Outcome 1: Case Studies of LEED PtD Pilot Credit Implementation 28

Approach to Outcome 2: LEED Credit Structural Review 30

Approach to Outcome 3: Studies of Potential Credit Adopters 30

Approach to Outcome 4: Comparison of Design Phase vs. Construction Phase Risk Assessments 31

Outcome 1: Case Studies of LEED PtD Pilot Credit Implementation 32

Outcome 2: LEED Credit Structural Review 33

Approach used to develop and launch the PtD Pilot Credit 34

Decision to modify existing credits vs. develop new credit 35

Process attributes of the LEED PtD pilot credit 37

Framing PtD as a credit vs. a prerequisite 40

Outcome 3: Studies of Potential Credit Adopters 41

Study of USGBC PtD webinar participants 41

Study of ANSI PtD Standard Development Committee 42

Exploring the Designer's Perspective 43

Outcome 4: Design-phase vs. Construction-phase Risk Assessment Comparison 48

Conclusions and Recommendations 51
Overarching issues about motivating designers to champion PtD 51
Possibilities for restructuring how PtD is incorporated into LEED 52
Understanding the effects of PtD implementation process on safety and health outcomes 53

References 54

Key Findings

- Support for Prevention through Design and the PtD Pilot Credit in the United States is coming primarily from the construction safety community rather than the design community.
- Opportunities remain limited for construction stakeholders to influence design at the earliest stages, when PtD is most effective.
- Motivation to implement the PtD Pilot Credit in the US was limited primarily by the lack of lead designer and architect enthusiasm for PtD and recognition of it as a viable concept.
- Practice and research opportunities (grants and funding) should be considered that target architects and designers to take the lead in PtD and own the processes involved.
- For PtD to be more broadly adopted as part of sustainable construction, the concept should be included as part of the Integrative Process credit rather than a standalone credit.
- Higher order controls are more likely to be identified during the design phase compared to the construction phase.

Executive Summary

Green building represents a significant evolution of the construction industry in the United States and worldwide. High performance green buildings are becoming more prevalent in the US and beyond, with both market forces and public policy driving the development of green projects at an ever-increasing rate (Ahn & Pearce 2007; Pearce et al. 2017; McGraw-Hill, 2013). McGraw-Hill Construction (2013) reports that the green building market is becoming standard design and construction practice in the United States, growing from 2% in 2005 to 44% in 2012.

Green facilities can be defined as *facilities that have net environmental benefits over their life-cycles compared to conventional construction, including benefits for occupants of their indoor environments as well as the natural environment* (Pearce & Kleiner 2014). These facilities offer a number of advertised and potential benefits to their owners and/or occupants, and environment, including a healthier indoor environment, increased resource efficiency and reduced operating costs, and overall lower impact on the natural environment (discussed in Pearce et al. 2017).

Integrative Approaches to Green Projects

For projects pursuing the leading edge of green design and construction, both the delivery process and resulting outcome are significantly transformed compared to conventional construction practice. Previous studies have shown conclusive differences in the design and project delivery processes used in projects containing green innovations (Ahn et al. 2011; Langar 2013). The behavior of stakeholders also has been found to be different on green vs. conventional projects, with studies characterizing and modeling stakeholder behavioral differences including the decision processes used by key stakeholders to make critical project decisions (Ahn & Pearce 2007; Keysar & Pearce 2007; Langar 2013). The application of systems analysis to buildings within their socio-enviro-technical context has been key in understanding emergent properties of these complex systems that cannot be effectively studied in isolation (Pearce & Ahn 2013; Pearce et al. 2010).

One notable feature for the delivery of green projects is the use of integrative processes that bring together project stakeholders from all lifecycle phases to systematically consider all building systems that comprise the project as well as the systems comprising the context of which it is a part (Malin et al. 2012). Integrative Process is now a part of the latest version of the LEED rating system (version 4.0), where interdisciplinary project teams are required to analyze opportunities for water savings, energy savings, and other building performance optimization early in design while flexibility still exists to make significant design choices with low or no cost impact (USGBC 2013; Malin et al. 2012).

Along with increasing formal and informal adoption of rating systems for guidance, a more integrative design and delivery process for green projects represents a significant opportunity to improve safety and health for building stakeholders over the project's life cycle. NIOSH recognized the potential to ensure that worker safety and health is infused into green jobs and the broader green economies by holding a 2009 workshop, *Making Green Jobs Safe,* emphasizing Prevention through Design (PtD) (Schulte et al. 2010). NIOSH's Safe Green Jobs website (2013) states that, "for the product of work to be truly sustainable, the work itself must also be sustainable".

Recognizing the potential for using an integrative process to improve the health and safety of both building occupants and workers, in 2015 the US Green Building Council launched a new pilot credit on Prevention through Design (PtD) as a potential innovation credit for projects pursuing certification under the Leadership in Energy and Environmental Design (LEED) green building rating system. If successful in the competitive environment of projects seeking LEED certification, the pilot credit could be integrated into new releases of the rating system. The LEED pilot credit process allows testing of new credit ideas in the context of real projects, allowing them to be refined and vetted before including them in USGBC's Innovation Credit Library or incorporating them into new releases of the rating system.

Study Motivation and Objectives

The original motivation for this study was to explore the LEED PtD pilot credit as an intervention for improving occupational safety and health on green construction projects. The primary aim was to develop a series of exploratory case studies of construction projects in which the credit was pursued, to address the following objectives:

1. To determine whether implementing the pilot credit reveals life cycle safety and health risks that would have not otherwise been identified until later in the construction, operations, or maintenance process.
2. To identify barriers that inhibit implementing the strategies used under this credit.

3. To evaluate whether implementing the pilot credit is viewed by key stakeholders as cost-effective, both individually and in comparison with other implemented credits.
4. To determine opportunities to improve the credit in future revisions.
5. To evaluate the potential for diffusing the pilot credit to other contexts beyond the United States.

Specifically, we hoped to impact occupational safety and health (OSH) on green projects by improving our understanding of the unique hazards associated with green projects and evaluating the use of green building rating system credits as an intervention to address them. Although the uptake of the LEED PtD pilot credit has been to date very small, both compared to other pilot credits and to our original expectations, our study was able to document through case studies the process by which the credit was actually employed in real projects, along with perceptions of project stakeholders about its effectiveness. Development of case studies and follow-on efforts resulted in identification of barriers and improvement opportunities that can be used to improve the PtD credit as it is considered for permanent incorporation into the LEED rating system and diffused to other contexts.

Overview of the Study and this Report

This report contains the findings of a small grant from the CPWR to study the early implementation of the LEED PtD pilot credit in practice. The original approach proposed for the study involved a series of case studies developed using participatory action research methods in which the research team actively participated in supporting pilot credit implementation for the case study project teams. Initial letters of support suggested that it would be possible to obtain cooperation and be invited to participate in multiple projects throughout the United States, and adoption of the PtD pilot credit was expected to be extensive, both in the U.S. and abroad.

As the project proceeded, the research team experienced significant difficulty in obtaining permission to participate in U.S. projects as planned, and in fact, the uptake of the PtD pilot credit was far lower in the U.S. than anticipated. Two project case studies were eventually developed, but both were European projects where uptake was more extensive. The team hypothesized that this higher level of interest was because projects in Europe are already required by law to undertake review of health and safety risks during the design phase. This hypothesis was supported by stakeholder interviews on both projects. While the LEED PtD pilot credit requires teams to exceed local requirements to achieve the credit, the EU project teams were well-poised to do this since they already had processes in place during project design to identify risks and explore both design and construction phase actions to mitigate them.

Given that the team’s extensive attempts to develop case studies in the U.S. were unsuccessful, the aim of the project then shifted in the second part of the project to develop an understanding of *why* uptake of the credit in the U.S. was much lower than expected, and to further explore practices and processes employed internationally to implement PtD in capital projects. The goal was to identify specific recommendations for adapting the PtD pilot credit and the implementation processes it requires in order to improve diffusion of the credit and achieve its benefits for the industry.

To set the stage for this part of the research, the report begins in Part 1 with an overview of rating systems for green projects and how they have been designed to effect change in the Architecture/Engineering/Construction industry. It continues with an overview of the history and current state of practice of Prevention through Design in the United States, along with an overview of theoretical and practical understanding of its implementation. Then, the report describes the process used to develop the LEED PtD pilot credit and the history of its implementation and diffusion among projects to date, both in the U.S. and abroad. This information provides necessary context for the task of understanding why PtD implementation in the U.S. has been different than anticipated.

Part 2 of the report contains the research approach and findings developed throughout the study, including the original case studies, a structural review of the LEED credit, efforts to engage potential credit adopters in U.S. projects including a survey of USGBC webinar participants and members of an ANSI working group developing a standard for PtD implementation. A detailed analysis of the risk registers for one of the European case studies was also conducted to test hypotheses about the types of recommendations emerging from design-phase reviews vs. construction-phase reviews. The report concludes with a discussion of the conclusions developed based on outcomes of all the parts of the study, along with a set of recommendations both for PtD enthusiasts in the U.S. who wish to more broadly diffuse the concept to practice, and the USGBC who is presently considering whether to keep, modify, or retire the PtD pilot credit.

Part 1: The Context and Evolution of PtD in Green Projects

To understand the diffusion of the LEED PtD pilot credit both in the US and globally, it is critical to frame the credit within the context in which it has been deployed. Part 1 of the report provides an overview of this context, including the design and history of green rating systems as a mechanism to promote sustainability in the construction industry, a history and overview of the current state of practice of PtD in the United States, and the incorporation of PtD concepts as part of green building rating systems, both for LEED and other rating systems. This part of the report concludes with a summary of the current state of adoption of the LEED PtD pilot credit as of June 2017, thus establishing a point of departure for the findings of this study.

Green Rating Systems as a Means to Effect Change

The construction industry is historically recognized as being slow to change. Our understanding of changing to new practices in construction is evolving because the assumptions underlying conventional diffusion of innovation theory, including nature and relationship of actors involved, nature of the innovations themselves, and the context and environment of diffusion activities, do not fit well with the realities of the construction industry (Tatum 1984, 1986). For instance:

- Unlike manufactured products, facilities themselves vary considerably, meaning that benefits and challenges associated with implementing an innovation depend on the specific characteristics of the facility in which it is used or the project on which it is implemented (Toole 1994; Toole 1998).
- There is a long time frame and wide range of conditions associated with the production process of built facilities, meaning that even if one could generalize across similar end products, the uniqueness of the process that generates each end product would add additional uncertainty (Tatum 1987; Toole 1994; Toole 1998).
- Facilities consist of many interacting parts and/or dynamic subsystems, meaning that the influence of any particular component is extremely complex when propagated across the system as a whole, realizing maximum benefits from innovation requires extensive coordination across multiple systems, and the consequences of a poor adoption decision are severe - replacement of a component is non-trivial due to the many interactions with other components (Toole 1998; Slaughter 1998; Kelly 1986).
- The task of constructing built facilities requires high levels of tacit knowledge and skills among implementers, meaning that it is difficult to communicate potential implications of innovations (Toole 1998).
- The task of constructing built facilities requires interaction with a large number of diverse entities, meaning that adoption decisions influence and are influenced by many different organizations and their individual characteristics (CERF 1996; CERF 2000). Moreover, the configuration of entities engaged for any one job is unlikely to ever be repeated, making systems-oriented management difficult (Ventre 1980; Kelly 1986).

The last of these characteristics, number of diverse entities involved, has been studied by a wide variety of researchers, including NAHBRF 1972; Oster & Quigley 1977; Ehrenkrantz Group/Gershom Meckler Assn. 1979; Toole & Tonyan 1992; Toole 1998; Slaughter 1993a; Dibner & Lemer 1992. This research (summarized by Toole 1998) suggests that the following entities have a degree of influence over innovation adoption decisions by builders, at least in the residential construction industry: architects and designers; banks and financiers; product manufacturers, retailers, and suppliers; developers; facility owners and occupants; local building departments and planning boards; realtors; contractors and subcontractors; and local and national trade associations.

Despite these challenges, the AEC industry has evolved considerably with respect to sustainability since the mid-1990s when the first US green rating system was being developed. Over time, this evolution has been driven in part by regulatory guidelines and mandates resulting from increasing evidence of the negative environmental impacts of the built environment on the natural environment (e.g., Table 1). However, it has also been driven by other factors, most notably an increased focus on building performance as a contractual obligation provided by the AEC industry to facility owners, including directly measurable performance such as energy and water savings, plus indirect performance measures such as achievement of third party certification under recognized green building rating systems.

Table 1: Documented Impacts of the Built Environment on the Natural Environment

- Greenhouse gas emissions and global climate change
- Harvesting of renewable resources at a rate greater than regeneration
- Habitat loss, reduction in biodiversity, and species extinction
- Aquifer depletion, surface water depletion, and desertification
- Air and water pollution, including acidification
- Soil contamination and topsoil depletion
- Ozone depletion

History and Proliferation of Rating Systems

Starting in the 1990's, green building rating systems began to emerge in the construction markets of the UK and other leading countries (Figure 1). The main purpose of these systems was to create a common understanding of what a "green" project is, provide guidelines for achieving it, and create a common 'yardstick' to evaluate it across different projects. From a market standpoint, certification under a green building rating system provided market cues that a building might be expected to have higher levels of energy and water performance, and lower levels of resource depletion, unwanted impact on natural ecosystems, and toxicity for building occupants. Even to this day, many rating systems do not require ongoing performance information for the building in operation in order to award a certification. As such, the certification serves as a proxy for the expectation that the building will perform well.

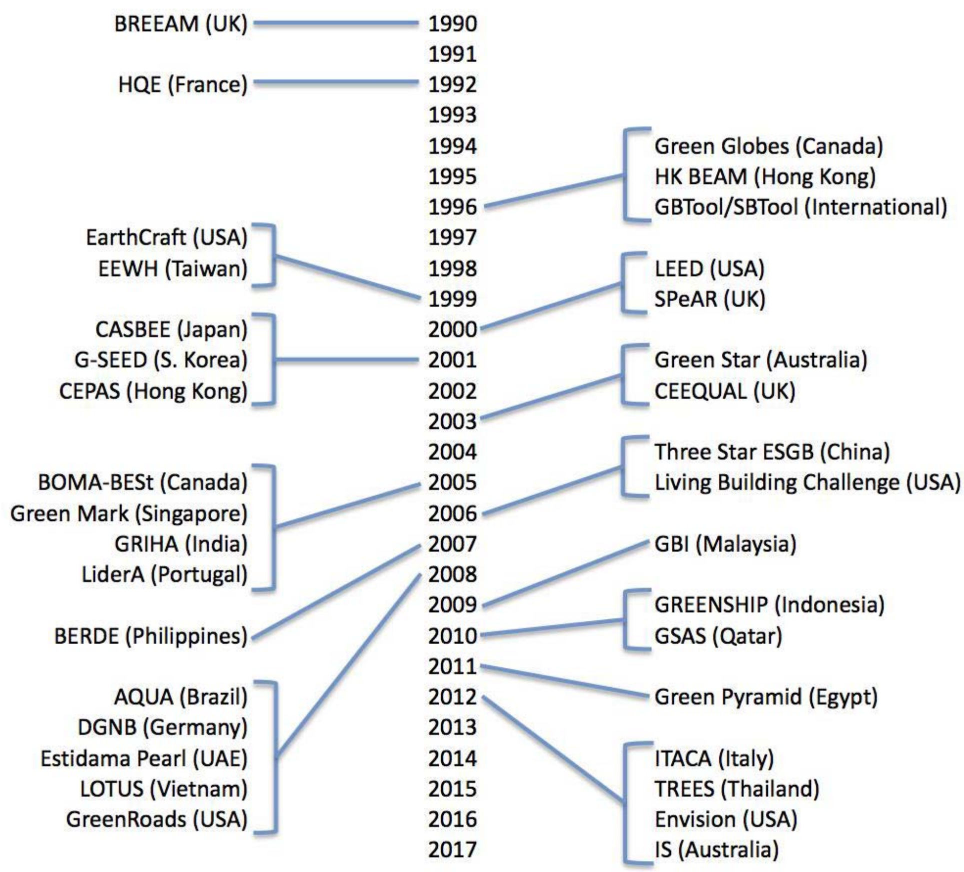

Figure 1: Timeline of Green Building Rating System Development (Pearce et al. 2017)

The first recognized green building rating system, the Building Research Establishment Environmental Assessment Method (BREEAM) was developed in 1990. Nearly 15 years later, an inventory conducted by the Building Research Establishment identified over six hundred distinct assessment tools worldwide (BRE 2004). The inventory included both broad-spectrum tools designed to evaluate multiple dimensions of sustainability including environmental, social, and/or economic impacts, as well as issue-specific tools focusing on a single indicator such as energy or greenhouse gas production. Among the broad spectrum tools, the most well known worldwide are BREEAM, the US Green Building Council's Leadership in Energy and Environmental Design (LEED) rating system, Sustainable Building Tool (SBTool), and the Comprehensive Assessment System for Built Environment Efficiency (CASBEE), developed in Japan. Most contemporary broad spectrum tools in widespread use today are derived at least in part from these tools (e.g., Xiaoping et al. 2009).

Today, depending on who you ask, there are between 5 and 35 or more distinct broad-spectrum rating systems in widespread use worldwide (Pearce & Kleiner 2014). Many of these have been locally adapted at the country level from one of the main ancestors (SBTool, BREEAM, LEED, CASBEE) to address specific issues relevant to the environmental and social context of projects in each country (e.g., Alvami & Rezgui 2012; Darus et al. 2009; Mao et al. 2009; Reed et al. 2009).

Evolution of Rating Systems

Over time, rating systems have evolved from checklists of best practices to more comprehensive, multi-attribute, multi-stakeholder processes that explore the whole lifecycle of built facilities (Berardi 2011a). Along the way, multiple studies have identified criticisms of existing tools, including:

- Unscientific criteria selection (Kuhn et al. 2012; Rumsey and McLellan 2005; Schendler and Udall 2005).
- Lack of overall lifecycle perspective in evaluation (Bower et al. 2006; Scheuer and Leoleian 2002)
- Lack of completeness (Ding 2008; Berardi 2011b)
- Lack of balance between environmental and economic/social aspects (Berardi 2011b; Sev 2009)
- Too many criteria/complexity of criteria (Mlecnik et al. 2010).

In response to these shortcomings, challenges faced by the users of rating systems in practice, and the growing body of knowledge about built environment sustainability over the past twenty years, several key trends are observable in the evolution of rating systems from earlier to later versions in current use today. One of these trends involves moving from unitless systems of measure to impact-based units that can be combined with mathematical validity but which require significantly more data and computational effort and expertise to calculate.

Among broad spectrum rating systems, many originated as straightforward multi-attribute tools where different types of indicators are scaled into generic units (points or credits) that can be simply summed in practice to provide a rough approximation of the relative performance of one building vs. another or of different design options for a particular building. In these tools, many different considerations are included (e.g., energy use, water use, pollution/waste production, ecosystem disturbance, indoor environment, etc.). Each issue is dealt with in its own set of credits or categories, and performance in those categories is rewarded with unitless points within the rating system. No attempt is made to reduce these disparate issues to a meaningful common unit of measure, and the final summation of points is often further reduced into a smaller number of categories representing different levels of certification possible under each system.

The relative weighting of points with respect to issues may be determined in various ways, but is often based on perceptions of relative importance by stakeholders of the rating system, sometimes using formal processes such as the Analytical Hierarchy Process (e.g., Banani et al. 2016). Many of these tools have BREEAM as a common ancestor (Xiaoping et al. 2009; Poston et al. 2010). A different approach modeled after lifecycle assessment methods formed the basis of other systems such as CASBEE and SBTool. Rather than using unitless points weighted by stakeholders, these tools define common units of impact and attempt to relate building attributes to the impacts.

In parallel to the evolution of impact-based metrics, rating systems have also become more performance-based as opposed to prescriptive (Pearce 2008). This allows the project team to determine for each project what combinations of strategies and technologies will best meet overall sustainability goals, rather than including arbitrary solutions such as bicycle facilities or pervious paving in situations where they may be neither appropriate nor useful in context of use. Along with this trend has been the emergence of new rating systems such as Living Building Challenge for buildings (LBC 2017) and Envision for infrastructure systems (ISI 2017), which are focused on regenerative or “better than net zero” development rather than “less bad” development.

Lastly, many of the more widely used rating systems have evolved the level of transparency and scientific support for their choice of indicators and weightings, invoking formal review and updating cycles involving stakeholders from across the industry. Where early versions of rating systems were often developed in isolation from practice by researchers, today organizations such as the American National Standards Institute (ANSI) are engaged by rating systems development organizations to provide consistent and valid approaches to updating those systems. Multiple interest groups have the opportunity to provide input during public review and comment cycles, and they may also participate more intensively in the revision, expansion, or overhaul of individual credits, categories of credits, or even the restructuring of the rating system approach overall, as was done in the most recent release of the LEED rating system, v4.0 (e.g., Attia 2014; Khese et al. 2016).

The LEED Rating System

Development of the LEED rating system began in the mid-1990s, based on the original Building Research Establishment Environmental Assessment Method from the UK. The original rating system was developed by the newly formed US Green Building Council (USGBC), a membership-based non-profit organization, using funding provided by federal grants and membership revenues. Then and now, the USGBC has representation from a wide variety of stakeholder groups, including public and private sector owners, designers, contractors, facilities managers, product manufacturers, and others.

Now in its fourth major version, LEED has evolved from a mix of prescriptive and performance-based credits to a much more quantitative, performance-oriented rating system (Table 2) that puts the burden on developing solutions on the project team rather than prescribing how they should behave.

Table 2: Versions of the LEED Rating System

Version	Launch	Approach
LEED v1.0	1998	Somewhat prescriptive; limited building types – application guides proposed as mechanism for customization.
LEED v 2.0, 2.1, and 2.2	2001ff	More performance-based; most credits converted; additional application guides developed; additional core rating systems developed for Homes, Neighborhood Development, Existing Buildings, Core & Shell, and Commercial Interiors
LEED 2009 (v 3.0)	2009	Regional credits and bookshelf approach introduced; pilot credit library formalized and expanded (USGBC 2008). New types of professional accreditation implemented; System types reorganized to BD+C (Building Design + Construction), EBOM (Existing Buildings Operation and Maintenance), Neighborhood, and Homes.
LEED v 4.0	2012	Significant changes to Materials and Resources credits; greater use of lifecycle assessment. Split of former sustainable sites category into Location and Transportation (LT) and Sustainable Sites (SS). Addition of Integrative Process (IP) credit category.

Over time, there has been increased reliance on third party standards, which overall reduces the burden on USGBC working committees for each credit category to maintain state of the art specifications for the large number of issues covered by the rating system. Over time, the number of credits that are strictly prescriptive has diminished, and even credits with prescriptive options also generally have performance-based paths that can be used instead if the project team wishes to customize the project's approach. There is an increased focus on processes used to develop green projects, most notably the new Integrative Process credit category in v 4.0, in which project teams are encouraged to work in cross-disciplinary sessions starting early in design to identify possible optimization paths for design of systems for water and energy.

There has also been a requirement added to provide energy and water performance data back to USGBC for all certified buildings, to improve the accountability of certified projects in performing up to their design standards.

LEED also rewards projects for finding new ways to make projects green that are not currently included in the rating system (ID Credit: Innovation in Design). Project teams can propose new credits based on best practices they have achieved, or they can pursue a credit from the LEED Pilot Credit Library. The Pilot Credit Library contains credits still under development that generally have been field-tested by at least one project. However, these credits are not yet a part of the official rating system standard. Projects can also receive innovation credits for greatly exceeding regular credit thresholds in areas including water efficiency, energy performance, materials use, and waste diversion. These are called exemplary performance credits and are counted within the ID credit category up to the maximum number of points available under the rating system (typically no more than four points).

The pilot credit process, formalized around the same time as LEED 2009, originated with the growing collection of novel ID credits submitted over time by projects seeking to excel in new areas. Each time a project team submitted a new credit, it would be reviewed by the certification team and evaluated with regard to both its novelty compared to existing credits and its contribution to the overall aims of improving project sustainability. Approved credits established precedent for subsequent projects and were placed into the LEED Pilot Credit Library for use by future projects pursuing innovation credits. Over time, similar innovation credits have been refined and combined together to form new versions that are considered for inclusion in the next major version or release of the rating system. Credits in the Pilot Credit Library may thus come from projects in which they have actually been achieved or from external organizations or working groups interested in expanding the LEED systems to cover new topics or issues relevant to sustainability.

The LEED rating system applies to a wide variety of project types. It is designed to be applicable in different climates and contexts throughout the U.S. and worldwide. Each of the LEED rating systems employs groupings of credits organized together by topic, and each credit may be worth one or more points depending on its relative importance. Some credits are designated prerequisites, all of which must be met in order for a project to qualify for certification.

In order to be considered for LEED certification, a project must meet the LEED Minimum Program Requirements or MPRs. This means that not all types of projects are eligible to be LEED certified, although project teams can always use the LEED guidelines to create a better project. MPRs are designed to ensure that LEED is only applied in ways that make sense. Some of the projects that cannot be certified under LEED include:

- Projects that are designed to be moved from one place to another, including boats and mobile homes

- Projects built on artificially created land, unless the land was previously developed for another project
- Buildings smaller than 1,000 square feet (93 square meters) of gross floor area to be certified under LEED BD+C

Moveable projects are not qualified because many LEED credits depend on the site chosen for the building. Projects on new artificially created land are not qualified because developing new land often displaces or disrupts ecosystems. Projects that are too small often do not have all the components LEED is designed to measure. Projects must also specify a reasonable site boundary to meet MPRs.

LEED for New Construction, now known as LEED for Building Design + Construction (LEED BD+C), was the first of all the LEED rating systems to be developed. Each of the subsequent systems was modeled after the same structure. The LEED rating system consists of a series of performance goals and requirements in nine primary categories:

- *Integrative Process (IP)* – This category addresses the process by which the project is planned, designed, and delivered.
- *Location and Transportation (LT)* – This category covers issues related to the location of the project site and the amenities around and near the project that affect transportation needs.
- *Sustainable Sites (SS)* – This category covers impacts to the project site during construction and the impacts the project will have on neighboring sites after completion.
- *Water Efficiency (WE)* – This category addresses water consumption and wastewater generation by the building during operation.
- *Energy and Atmosphere (EA)* – This category covers all aspects of the building's energy performance, energy source(s), and atmospheric impacts.
- *Materials and Resources (MR)* – This category pertains to the sources and types of materials used on the project, the amount of waste generated, and the degree to which the project makes use of existing buildings.
- *Indoor Environmental Quality (EQ)* – This category covers aspects of the building's indoor environment, ranging from ventilation to air quality to daylight and views.
- *Innovation in Design (ID)* – This category rewards the project for going beyond the minimum credit requirements and for using a LEED Accredited Professional.
- *Regional Priority (RP)* – This category rewards projects for addressing local environmental priorities (identified by ZIP code at www.usgbc.org).

Projects can receive credit for features of special regional importance with Regional Priority (RP) credits. They can also receive credit for going significantly beyond basic credit requirements with Innovation in Design (ID) credits. For example, a system that pays special attention to water efficiency in a desert environment might be given an extra RP credit in addition to a WE credit.

The LEED system was initially developed to apply to new commercial construction. As the system grew in popularity, it became apparent that different types of projects would require different criteria to be properly rated. The original rating system was then customized through the development of special credits for specific project types such as hospitals and schools. These types of projects have characteristics that require special interpretation of LEED credit requirements. However, they can still use the basic LEED BD+C structure. Separate versions of the rating system exist in the following major categories:

- LEED for Building Design and Construction (BD+C), which has special credits applicable only for core and shell, schools, retail, data centers, warehouses and distribution centers, hospitality, healthcare, homes and multifamily lowrise, and multifamily midrise projects
- LEED for Interior Design and Construction (ID+C), which addresses commercial interiors as well as special requirements of retail and hospitality projects
- LEED for Building Operations and Maintenance (O+M), which covers existing buildings and has special credits for retail, schools, hospitality, data centers, and warehouses and distribution centers
- LEED for Neighborhood Development (ND), which can be applied to developments in the planning phase or at the completion of the development.

Some parts of different rating systems complement each other. For instance, a LEED BD+C project can receive up to fifteen points for choosing a project site within a development certified under LEED ND. Likewise, a LEED ID+C project can receive credit for being located in a building certified under LEED BD+C.
There are 110 possible points under the LEED-NC rating system, and fourteen prerequisites. Projects must meet all fourteen prerequisites to pursue certification. Certification can be achieved at four different levels:

- Certified: 40 to 49 points
- Silver: 50 to 59 points
- Gold: 60 to 79 points
- Platinum: 80 points and above

Platinum is the most difficult level to reach. Currently, just over 6,000 certified projects have achieved this level of certification, out of more than 107,000 worldwide (https://www.usgbc.org/projects). This is only about 5.6 percent of all projects. All LEED rating systems award certification at the four listed levels.

The process of certifying a building under LEED has several steps. These steps are guided by the LEED Online documentation system. Certification occurs in parallel with an integrative process that involves participation of many stakeholders. The first step in the plan is to undertake discovery and set a direction for the project. Based on the type of project, the appropriate rating system is chosen. Then, Minimum Program Requirements are verified. The team will review project information and hold a goal-setting workshop including the owner, design team, and construction team. This should all occur before design begins. A formal LEED project scope will be defined, including a project boundary.

Formal certification begins by registering the project with GBCI to declare intent to pursue certification. This allows the project team to access GBCI databases as well as set up an online workspace to manage project documentation. Registering the project requires paying a flat fee to GBCI that is the same for all projects. After the project has been registered, the next step is to identify LEED credits that can be pursued. This is based on the project goals, and typically involves a meeting to review the LEED checklist for the rating type being pursued. The process of documentation to prove compliance with LEED credit requirements continues throughout construction. It may also extend into the first year of occupancy depending on the credits pursued.

The project team can submit documentation to GBCI for review at two points in time: at the end of the design process, and after construction is complete. The project team may also opt to submit everything at once when the project is complete. All documentation is compiled by the project team using LEED Online. Submittal of documentation for review involves paying a review fee based on project size and which rating system is being used. This prompts GBCI to conduct the review. If the team submits a design review, GBCI will evaluate points under the rating system that can be measured at the end of the design process. It will not evaluate credits that require documentation during the construction phase. Design phase review is useful for the project team to get an idea of how many points they are likely to obtain in the project. It provides a basis for deciding how many additional points will need to be earned during construction to meet the project goals.

At the conclusion of the project, final documentation is assembled online. A fee is paid, and the package is reviewed by GBCI. Upon review of the full project documentation, GBCI may elect to request additional clarification as part of a point audit. The Council makes a final determination as to which points should be awarded and determines a level of certification for the project. The project team has the right to appeal any credits declined in the review by paying an additional fee and providing additional documentation. The ruling of GBCI following appeals is final.

Certification strategies used by project teams

The motivation to pursue certification on a particular project often comes from the project developer or owner, and a growing body of evidence suggests that certification can provide not only improvement in a building's performance over time, but also its market value and appeal. As a feature of an actual property, third party green building certification is a market-based way to signal greater efficiency with regard to water, energy, and other operational costs (McGraw-Hill Construction 2010). Third party systems such as LEED not only promote the reduction of negative environmental impacts to society as a whole but also provide directly measurable positive economic benefits to building stakeholders, including building value, return on investment, occupancy rate, and rent ratio, which have been shown to increase after certification for both green retrofit and renovation projects and for new green buildings (ibid.).

No matter who originates the decision to use LEED or another rating system as part of a capital project, project teams engaged in the process employ a variety of strategies to the task of implementation with the aim of ensuring that the desired level of certification is achieved. While some owners encourage project teams to use LEED as a tool for design improvement (i.e., make the project “LEED-certifiable”), many actually mandate a minimum level of certification that must be achieved. Although the costs associated with actual certification are not insignificant and could be directed toward increasing the budget for hard costs on the project, actual certification provides a level of accountability that can even be a contractual requirement.

Accordingly, the risk of not meeting target certification levels can be a significant motivator for project teams, whereas significantly overshooting the points required to achieve a particular certification level may end up costing more in documentation or hard costs without achieving perceived return by taking the project to the next level. A significant number of LEED credits offer no direct economic benefit to the project owner and some even cost significantly more, such as credits associated with using rapidly renewable or recycled content materials where benefits are externalized to society as a whole (Langar 2009). From a purely economic standpoint, achieving credits that have a higher first cost and no lifecycle cost advantages can be counterproductive and reduce budget that could be used for other things, unless it provides some recognition-based cue to the market such as a higher certification level or increased observability of the building’s attributes.

Choosing which credits to pursue is thus a matter of strategy, with considerable debate among project teams regarding both the level of effort required to achieve a credit in a particular situation and the potential return of that credit toward the project’s performance in general. The phenomenon of point-mongering or point-chasing has been described by multiple authors, where credits may be pursued that actually result in worse performance of the project or incorporation of “green” features that may never be used (e.g., Bray and McCurran; Cole 2005). Langar (2009) also identifies what he calls “Buy-me” credits, which are credits that require no significant effort on the part of the project team but can be obtained simply by allocating additional budget, sometime even after the project is complete, e.g., contracts for off-site renewable energy. He contrasts these with credits requiring process changes, either on the part of the project team or even worse, the owner’s operations and maintenance team over the lifecycle of the project. Often “Buy me” credits are kept in reserve for a project in case other targeted credits are not achieved, to ensure that the desired or mandated certification level can be obtained. All this can lead to what has been called “LEED Brain” (Reed et al. 2011), where the focus is on gaming the rating system itself rather than really striving for the best performing building as an outcome.

Evidence of market transformation

Despite cases of misuse in the pursuit of points, overall LEED appears to have had a role in changing expectations and practice within the market. Conte and Monno (2012) acknowledge that despite their suboptimalities, existing rating systems have “shown their enormous usefulness” in increasing environmental awareness of building stakeholders, disseminating best practices, stimulating laws/policies and implementation/incentives, and improving market supply and demand (citing Reed et al. 2011). Ultimately, the existence of LEED and its enthusiastic adoption by both public and private sector owners has led to sustained, market-wide changes among a significant share of the AEC industry.

Regarding the design process itself, green rating systems have both formally and informally incentivized the use of integrative design processes involving later lifecycle phase stakeholders of the building into the process from the earliest phases of design. Whether it be due to the opportunity to earn a LEED credit under LEED v4.0, or a recognition that earlier interventions can achieve dramatic improvements in building performance over the lifecycle for little or no first cost impacts, project teams are taking advantage of early phase opportunities to improve the environmental and economic sustainability of design. It makes sense that this same approach could be used to improve social sustainability as well.

LEED and rating systems like it have motivated project teams led by designers to expand their thinking to include choices that influence the level of certification earned, post-occupancy energy and water performance, operability and maintainability, and even design for disassembly. By involving later stakeholders whose job will either be facilitated or hampered by design choices, potential design changes can be systematically considered using processes such as the Construction Hazard Assessment and Implication Review (CHAIR) process (Work Cover NSW 2001), the Continuous Value Enhancement Process (CVEP) (Pulaski and Horman 2005), or others. Lessons learned from these experiences, along with theoretical knowledge about factors influencing the diffusion of innovations, can shed light on potentially successful strategies for a similar approach to occupational safety and health, one which results in measurable benefits and improved outcomes both for building occupants and the workers whose job it is to create, operate, and manage the built environment.

History and Current State of PtD Practice in the US

Prevention through Design (PtD) as a concept originally emerged in Europe with a report by Lorent (1987) and subsequent European directives (EEC, 1992). It has been implemented and researched mostly in the UK and Australia. The UK has regulated safe design and management planning through the construction design and management (CDM) regulations since 1994. Responsibility for site safety under CDM lies not only with the employer, but with the owner (client) and designers. Similar legislation exists in Australia (Bluff, 2003), and more recently Singapore.

The first attempt to understand the impact of designers' decisions on construction safety and health was from Hinze and Wiegand (1992) who sought to understand the design for construction safety concept as part of a survey of design firms and firms that conduct constructability reviews. They concluded that designers could play a role in reducing the incidence of construction injuries and fatalities and that construction worker safety can be addressed during the design process. However, few design firms regard the safety of construction workers as being within their scope of responsibility. There is no evidence in the literature of the concept being implemented and evaluated in any subsequent research by Hinze. Developed by engineer Szymberski as part of his work designing new pulp and paper facilities, the time / safety influence curve (1997) is often used to graphically describe the ability to influence safety over the life cycle of a built environment project. However, as with Hinze, there is no archival record of evidence that Szymberski actually implemented a safe design process, and attempts by the authors to locate Szymberski for interview have been unsuccessful.

Seeking to move the ideas of PtD to practice, Gambatese (1996) developed over 400 design suggestions that could be used by design professionals to minimize or eliminate safety hazards in their designs. These design practices were incorporated into a computer design tool titled "Design for Construction Safety Toolbox" (Gambatese et al., 1997). However, there is no evidence in the archival literature of anyone systematically using these suggestions, and no mechanisms are presently in place to track actual use by practicing designers. Moving from general resources to more specific hazards, OSHA (2007) and its partners, through the Alliance Program Construction Roundtable, developed a series of Construction Workplace Design Solution documents on fall hazards. Behm also developed additional design suggestions based on a review of accident investigations (2005) and site visits to green roofs (2011). These are examples of design research and practice oriented products that continue to be retrospective rather than prospective to understand the design process and how ideas about life cycle safety and health can be integrated. We find only one study in the US that evaluated a PtD-like process. Weinstein et al. (2005) studied a large computer chip manufacturer's integrated lifecycle safety process during the design and construction of a fabrication facility. They found that safe design suggestions could be implemented if identified early in the programming and design phases. Additionally, the input of trade contractors was found to be crucial to the success of idea generation. It is important to note that this process was driven by the owner (Weinstein et al., 2005).

We conclude that the current state of PtD research in the US is retrospective rather than prospective. This limits the application of PtD in practice, which has shown to be largely anecdotal with very little evidence of the impact of a holistic approach to integrating safety and health into the design process. This is precisely the leverage point targeted by the USGBC PtD Pilot Credit as an attempt to improve occupational safety and health on green projects.

Incorporation of PtD concepts in rating systems

As evidenced by adoption of the Integrative Process (IP) credit that became part of the LEED rating system in v.4.0, LEED has been successful in motivating design teams to think about new ideas in different ways. Tables 3 - 5 show the adoption of the IP pilot credit as of July 31, 2017, compared to the PtD pilot credit. Not included are the projects that have pursued and been awarded the IP credit as part of LEED v.4.0, where it is an official credit, not a pilot credit.

In particular, integrative design has provided mechanisms for designers to think holistically about the impacts of design choices on both first and lifecycle costs of systems that consume water and energy. As such, use of integrative design processes has enabled teams to find new solutions to provide essential building services without adding additional first costs to capital projects by investing additional costs in one system that allow commensurate savings in related systems, such as improvements in the building envelope allowing a reduction in the costs of HVAC equipment (Pearce et al. 2017).

Given these paradigm shifts in design thinking that are acknowledged and motivated by LEED, it is reasonable to think that LEED could motivate new ways of thinking about occupational safety and health. This was exactly the thinking that led to the original development of the LEED PtD pilot credit, in hopes of entertaining health and safety considerations far earlier in the process than ordinarily considered. The need for safety and health considerations in green projects has become increasingly apparent as the population of projects grows, as described in the next sub-sections.

Table 3: Adoption of the PtD and IP Pilot Credits by Rating System

Projects REGISTERED for pilot credit			Projects AWARDED pilot credit		
Rating System	***PtD***	***IP***	***Rating System***	***PtD***	***IP***
New Construction	0	35	New Construction	0	8
Schools (NC)	0	2	Schools (NC)	0	0
Existing Buildings: O+M	0	3	Existing Buildings: O+M	0	0
Core and Shell	0	8	Core and Shell	0	3
Retail (NC)	0	3	Retail (NC)	0	0
Healthcare	0	1	Healthcare	0	0
LEED-NC v2009	23	70	LEED-NC v2009	2	9
LEED-CS v2009	50	37	LEED-CS v2009	2	10
LEED FOR SCHOOLS v2009	0	6	LEED FOR SCHOOLS v2009	0	0
LEED-CI v2009	0	10	LEED-CI v2009	0	4
LEED v4 BD C: DC	4	1	LEED v4 BD C: DC	0	0
LEED-CI Retail v2009	0	1	LEED-CI Retail v2009	0	0
LEED Italia NC 2009	0	2	LEED Italia NC 2009	0	0
LEED-EB:OM v2009	0	1	LEED-EB:OM v2009	0	1
LEED v4 BD C: HC	1	1	LEED v4 BD C: HC	0	0
LEED v4 O M: MF	0	3	LEED v4 O M: MF	0	0
LEED v4 BD C: CS	4	3	LEED v4 BD C: CS	0	0
LEED v4 BD C: NC	8	4	LEED v4 BD C: NC	0	0
LEED v4 O M: EB	0	2	LEED v4 O M: EB	0	0
Total	**90***	**193***	**Total**	**4**	**35***

*Not all projects listed by year in the USGBC database contain complete information about the version of the rating system used or the country of the project. Different queries produce different project totals based on available data. Data shown are as provided to the research team by USGBC.

Table 4: Adoption of the PtD and IP Pilot Credits by Country

REGISTRATIONS by Country			AWARDED by Country		
Country	***PtD***	***IP***	***Country***	***PtD***	***IP***
US	16	122	US	1†	18
AT	4	0	AT	1	0
BE	1	0			
BG	0	2	BG	0	1
BR	1	1			
CA	3	0			
CL	0	15	CL	0	8
CR	0	1			
DE	1	0			
DK	2	0			
ES	3	6	ES	1†	1
FI	4	14	FI	0	1
FR	0	1			
GB	0	2			
GR	2	6			
HK	0	4			
HT	0	1			
HU	0	1			
IE	50	0	IE	3	0
IL	0	1	IL	0	1
IT	0	4			
JP	2	1	JP	1†	0
KW	0	1			
MX	0	3			
MY	2	1			
PE	0	1			
PK	1	1			
QA	4	0			

REGISTRATIONS by Country			AWARDED by Country		
Country	*PtD*	*IP*	*Country*	*PtD*	*IP*
RO	0	1			
RU	0	1			
TR	0	2			
VI	0	1	VI	0	1
YS	0	1	YS	0	1
Total	**96***	**193***	**Total**	**7**	**32***

*Not all projects listed by year in the USGBC database contain complete information about the version of the rating system used or the country of the project. Different queries produce different project totals based on available data. Data shown are as provided to the research team by USGBC.

†Credit awarded in design phase; final certification incomplete and therefore not counted in other queries.

Table 5: Adoption of the PtD and IP Pilot Credits by Year

Projects REGISTERED by year			Projects AWARDED by year		
Year	*PtD*	*IP*	*Year*	*PtD*	*IP*
2012	0	35	2012	0	5
2013	0	31	2013	0	5
2014	0	51	2014	0	9
2015	16	51	2015	1	8
2016	24	14	2016	1	10
2017	60	14	2017	2	0
Total	**100***	**196***	**Total**	**4**	**37***

*Not all projects listed by year in the USGBC database contain complete information about the version of the rating system used or the country of the project. Different queries produce different project totals based on available data. Data shown are as provided to the research team by USGBC.

Occupational Safety and Health on Green Projects

Until recently, rating systems such as LEED have put little, if any, focus on the safety and health of construction workers or those workers who maintain buildings over their lifecycle (Pearce & Kleiner 2014). Increasing evidence suggests that green projects pose unique safety and health hazards compared to conventional projects. Rajendran et al. (2009) found suggestive evidence that green building projects experienced higher injury rates than comparable non-green building projects. For example, in case study research, Fortunato et al. (2012) found that:

- Workers on LEED projects are exposed to work at height, electrical current, unstable soils, and heavy equipment for a greater period of time than workers on traditional projects;
- Workers are exposed to new high-risk tasks such as constructing atria, installing green roofs, and installing photovoltaic (PV) panels; and
- Some credits have positive impact on construction worker safety and health when low volatile organic compound adhesives and sealants are specified.

Pearce and Kleiner (2014; 2015) studied both incident/fatality reports and thirty-one international green rating systems and found evidence to support the claims that green projects involve activities that both increase and decrease risk to worker health and safety. In particular, they found multiple trends that tend to increase worker risk on green projects, including:

- Increased material handling requirements throughout the life-cycle;
- Greater use of electrical sensors and controls to monitor building conditions and make operational adjustments;
- Greater use of on-site renewable energy and alternative fuel technologies;
- Use of district heating and cooling requiring greater temperature ranges in occupational contexts;
- Potential exposures to pathogens resulting from alternative water technologies such as on-site water treatment and stormwater management facilities; and
- Increased use of building envelope components such as walls and roofs as platforms for other functions.

In order to realize the full spectrum of benefits on green projects and ensure the health and safety of their stakeholders, there is a need to better understand both the unique hazards posed by this significant trend in the construction industry and the tactics and interventions that can be applied to mitigate or eliminate those hazards. While existing studies have contributed to the body of knowledge about unique occupational hazards associated with green projects (Rajendran et al. 2009; Fortunato et al. 2012; Pearce & Kleiner 2014; 2015), comparatively few studies have systematically explored the risks associated with specific green technologies or the practices that make most sense to eliminate or mitigate those risks. One such study was undertaken by Behm (2012), who evaluated green roof design in the US, developed design suggestions, and evaluated safe design guidelines of urban greenery in Singapore (Behm & Poh 2012). Significant opportunities exist to expand on this understanding through systematic investigation of project best practices.

An opportunity also exists to better understand interventions that may specifically apply to green projects with respect to OSH. In the domain of green building, researchers have explored various interventions to drive change and diffusion processes for green building innovations (McCoy et al. 2012; Ahn et al. 2011) and the effects of mechanisms to accelerate change in the Architecture, Engineering, and Construction industry (DuBose et al. 2007; Pearce et al. 2007; Pearce 2009). Likewise, in the OSH domain, multiple studies characterize the attributes of effective interventions to improve occupational safety and health (e.g., Kleiner 2006; Haro &

Kleiner 2008). However, a gap exists in the body of knowledge regarding interventions that would synergistically enhance workplace safety and health AND sustainability.

As Rajendran et al. (2009) argued, to be truly "sustainable," a building's impact to the health and well-being of the individuals who construct, operate, maintain, and decommission the facility must be considered. However, existing research suggests that in some cases the opposite is true because green projects pose *higher* safety risks than conventional projects (e.g., in Branche 2012). A need exists to determine mechanisms by which project teams can be incentivized to apply Prevention through Design concepts to reduce or eliminate OSH hazards on green construction projects. Founded on the hierarchy of controls, PtD promotes reducing lifecycle OSH risks within the project's design and planning phases, prior to the start of construction. This model for OSH management is a critical component to the development of new innovations which have yet to be implemented and field-tested. It also supports effective stewardship of employees, a practice coexistent with green/sustainability concepts.

OSH in the LEED 4.0 Rating System

Ideas from Prevention through Design fit well with the overall philosophy of LEED projects and processes, particularly the Integrative Process (IP) credit category that was added to v4.0 of the rating system. The IP credit requires incorporating multiple stakeholder perspectives from the earliest phases of design to consider systems-level implications of key design choices on energy and water performance of the final building. Using an integrative process, project teams can work to find optimal solutions that improve building performance while maintaining budget constraints, iterating quickly through concepts to determine how improvements in one system can lead to savings in other complementary systems. Construction stakeholders are involved in the process to provide input on constructability and cost issues for different ideas, and operations and maintenance personnel are included to provide input on how different ideas will influence operational considerations and lifecycle performance.

Version 4.0 of the LEED rating system included health and wellbeing considerations in multiple credits from the start, including EQ prerequisites and credits to promote indoor air quality for occupants and installers and reduce exposure of occupants and cleaning staff to toxins. However, minimal attention was paid to occupational safety threats resulting from the use of green products, systems, and design elements, including fall hazards, electrical hazards, and other risks to which workers on green projects were subjected. Pearce and Kleiner (2014) also found this to be the general case in nearly all major broad-spectrum green building rating systems available worldwide. Thus, the attempt to introduce PtD into LEED as a means of including safety as a discrete goal for integrative design teams was novel in terms of rating systems, although PtD as an evaluative process step is already required by law in certain jurisdictions, e.g., in the European Union.

The PtD Pilot Credit as a Solution

In recognition of both the opportunities posed by integrative process and in light of unique hazards of green projects, a new LEED Prevention through Design (PtD) pilot credit was released in April 2015 (see https://www.usgbc.org/articles/new-leed-pilot-credit-prevention-through-design). The intent of the credit was "To support high-performance cost-effective employee safety and health outcomes across the building life-cycle through early attention to safety and health hazards" (USGBC 2015).

To achieve the Prevention through Design (PtD) Pilot Credit, projects seeking LEED certification must undertake a formal review before the completion of schematic design to identify and address potential future hazards in both the construction phase and operations/maintenance phase for building workers (USGBC 2015). Documentation for the credit requires both a discovery process and documentation of measures taken for implementation. The discovery process involves safety and health reviews that are then used to inform key documents and plans used for project implementation, including owner's project requirements (OPRs), basis of design (BOD), design documents, construction documents, and operations and maintenance plans submitted to the owner.

Adoption of the PtD Pilot Credit to Date

PtD has long been accepted within the construction health and safety community (Behm, 2008). However, the new PtD pilot credit represents a fundamental shift in thinking amongst the leaders of the green building and design community. Globally, there is still a major gap in PtD research that measures and understands PtD in practice. The 2007 and 2015 revisions to the United Kingdom's Construction Design and Management (CDM) regulations highlight this research gap. Unfortunately, there are no published research studies that have evaluated these regulations in practice. Therefore, the USGBC PtD pilot credit offered the United States construction and design communities an opportunity to measure PtD processes in practice, with possible national and international impact as a result.

Given these high hopes for benefits to the industry resulting from the PtD credit, the expectation of both the research team and the OSH community was that the pilot credit would receive considerable interest and widespread testing during the pilot credit phase. However, as shown in Tables 3-5, the uptake of the PtD pilot credit was very low compared to the Integrative Process pilot credit, which is one example of a successful similar credit in the USGBC pilot credit library.

As originally conceived, the aim of this project was to evaluate the diffusion of the LEED PtD Pilot Credit within the capital projects industry and identify barriers and enablers that should be considered in converting the credit to become a permanent part of a future version of LEED. However, given the low uptake of the credit in its current form over the course of our study, there is a real risk that USGBC will not see the merit in carrying the credit forward. Therefore, Part 2 of this report focuses on the experiences of project teams that *did* attempt the credit and identifying issues that will need to be addressed in order for the concept to more broadly diffuse.

Part 2: Understanding the Diffusion of the LEED PtD Pilot Credit

The primary focus of this study was to understand patterns of adoption of the LEED PtD Pilot Credit and evaluate its efficacy in achieving health and safety benefits vs. costs on projects. As mentioned previously, the pilot credit did not achieve significant diffusion during the study period, and as a result, the focus of the study shifted to understanding why this might be the case. This part of the report describes the research design and methods used to investigate why and how the credit was and was not used. It then presents four specific outcomes of the study, including case studies of projects that implemented the pilot credit, a structural review of the credit itself, several related studies of potential credit adopters, and an analysis of design-phase vs. construction-phase risk assessment processes using the hierarchy of controls. Part 2 concludes with the main conclusions of the study, along with limitations and recommendations for future work.

Research Design and Methods

The original design of the study focused on using participant action research as the basis for collecting information about capital projects and design decision processes for teams pursuing the LEED PtD Pilot credit. Assuming that such projects would be numerous and eager to participate in the study in exchange for free professional education and facilitation services, we proposed to develop a series of detailed cases that examined actual PtD opportunities and decisions identified by the project teams for real projects and evaluated their impacts compared to conventional practice.

Unfortunately, adoption of the pilot credit was far more limited than expected. No US projects agreed to participate in the study, and only two projects agreed to participate, both international. Accordingly, focus shifted to understand why the adoption of the credit was less enthusiastic than anticipated. This section presents the guiding objectives and research questions of the study and the approaches used to develop the four main study outcomes.

Objectives and Research Questions

The original specific aims and objectives were:

1. To determine whether implementing the pilot credit reveals life cycle safety and health risks that would have not otherwise been identified until later in the construction, operations, or maintenance process.
2. To identify barriers to implementing the strategies used under this credit.
3. To evaluate whether implementing the pilot credit is viewed by key stakeholders as cost-effective, both individually and in comparison with other implemented credits.
4. To determine opportunities to improve the credit in future revisions.
5. To evaluate the potential for diffusing the pilot credit to other contexts beyond the United States.

Due to the limited case studies with which we were able to develop partnerships and the non-existence of US based projects engaging with the credit during our study, we ultimately altered the aims and objectives of the project over time, given the absence of sufficient data to answer the original research questions. The revised activities, developed in consultation with CPWR staff in January 2017, were:

1. Interview original letter writers or other construction-phase PtD enthusiasts about their experiences trying to promote the concept with designers.
2. Work with CPWR in their project with Dodge Data Analytics to incorporate questions regarding PtD into the protocol for their upcoming architectural panel that may yield greater insight into barriers from the designer perspective.
3. Compare the outcomes of a PtD-based risk assessment from our European case studies with construction-phase risk assessments to evaluate whether there are significant differences in the risks identified. We will use the Hierarchy of controls to classify interventions recommended by these two types of assessments to test the hypothesis that PtD results in a greater number of interventions higher up the hierarchy of controls than a construction-phase risk assessment.
4. Conduct follow-up interviews with willing respondents to our internet survey of PtD webinar participants to identify why they did not pursue the credit.

The data collected in the initial stages of the research, along with activities undertaken following the redirection of effort in January 2017, enabled us to develop research outcomes in four basic areas presented in the next sections of the report:

- Outcome 1: Case Studies of LEED PtD Pilot Credit Implementation
- Outcome 2: LEED Credit Structural Review
- Outcome 3: Studies of Potential Credit Adopters
- Outcome 4: Comparison of Design Phase vs. Construction Phase Risk Assessments

The following subsections describe the approach and research design associated with each of these outcomes.

Approach to Outcome 1: Case Studies of LEED PtD Pilot Credit Implementation

The original research design for this study involved developing detailed case studies of projects pursuing the LEED PtD pilot credit in practice, using action research methods that included training and education on PtD for project stakeholders, facilitation of PtD reviews for project teams, analysis of PtD process outcomes, and drawing conclusions about the efficacy of the credit in achieving PtD aims. The original proposal included three letters of support from the Myers-Lawson School of Construction Industry Board, who committed to help locate projects that would be appropriate case studies. Additional contacts in the construction industry also expressed interest in the project, leading the research team to conclude that identifying cases would be straightforward.

As it happened, none of the projects identified by the original letter writers were interested or able to pursue the PtD pilot credit, in two cases because the construction-phase stakeholders who originally expressed interest were unable to motivate the owners and design team to commit to the project, and in a third case because the project was already beyond the schematic design phase when PtD reviews would have had to be implemented. After these original cases failed to materialize, the research team took on a broader sampling approach to identify potential case studies, including:

- Sending email invitations to local USGBC chapter members in Colorado and Virginia.
- Sending email invitations to American Institute of Architects members in North Carolina.
- Presenting the project at the 2015 Engineering Sustainability Conference in Pittsburgh, PA and soliciting participants during the talk.
- Via an email from USGBC technical managers, indirectly inviting project LEED APs who had registered for the PtD pilot credit to contact the research team and volunteer as case studies.

As a result of these efforts, three project LEED APs contacted the research team to express an interest in being interviewed for case studies. Of these three, two were located outside the United States and one was located in the U.S. Further follow-up with the U.S. project yielded no returned telephone calls or emails, ultimately resulting in that case being dropped. The two European case studies were both successfully interviewed and provided data for the project. Interviews were conducted via conference call with both researchers interviewing one or more project participants. Notes were taken by the research team and developed into case summaries that were validated using member checking with the original interviewees. In one case, the project team also provided detailed risk registers for the project, which were developed in response to relevant regulations in that country and which were analyzed by the project team as part of Research Outcome 4. The ultimate result was two case studies of the process and approach used by project teams to undertake the LEED PtD pilot credit, both from a European context. Detailed design and cost information was not available for these projects, and the research team did not have the opportunity to employ participant action research methods in either case.

Since the research team did not have direct access to USGBC data sources nor direct contact with project teams other than those who actively volunteered for our calls, we were unable to establish quantitative metrics of representativeness for this study. Despite the lack of geographic diversity among the case studies, however, they do represent the actual distribution of LEED PtD credit registrants reasonably well. As of the time of this writing, only one US project has achieved the credit, with the remaining six projects either fully certified or awarded the credit in design review being international. Verbal confirmation from the USGBC also indicated that the majority of new registrations for the credit were arising in one country, most likely associated with one of the teams that was interviewed for this project.

Approach to Outcome 2: LEED Credit Structural Review

As a result of Outcome 1, the two case studies, several suggestions emerged from project teams regarding how the pilot credit might be improved in future to make it easier to implement. These suggestions led the research team to consider how the overall credit was structured compared to other existing and pilot credits and prerequisites within the rating system. In this structural review, the team documented the history of the pilot credit development using reports and information from the original working group that developed the credit. Both researchers participated as part of that group, in one case as co-chair of the committee and in the other case as a subject matter expert who reviewed the draft credit language developed by the committee. The latter investigator conducted the structural review of the credit to avoid potential conflicts of interest with respect to the original committee work.

In particular, the structural review identified three design decisions made by the working group in developing the credit, as follows:

1) Developing a new, stand-alone credit vs. modifying existing credits
2) Setting the credit up as an optional credit vs. as a required prerequisite
3) Specific process requirements that must be undertaken by project teams to achieve the credit, and how they compare to current practice.

Based on these three issues, the structural review identified potential implications of each option and how they might influence perceptions of project teams deciding whether or not to pursue the credit. The process for pursuing pilot credits in general was also reviewed in the overall context of a team's pursuit of LEED certification, supported by the literature and by the evaluator's experience as a LEED AP working with projects pursuing certification. The outcome of this process was a set of recommendations for how the credit could be adjusted in future to increase its uptake by project teams by reducing the burden associated with the credit, increasing the risk of failing to achieve the credit, and improving the benefits resulting from its implementation.

Approach to Outcome 3: Studies of Potential Credit Adopters

Over the course of the study, as it became increasingly apparent that the number of teams actually implementing the credit was extremely small, the research team developed several different studies to explore the perceptions of stakeholders believed to influence the adoption decision for the pilot credit. In particular, three sets of stakeholders were surveyed or interviewed to determine their perspectives on the credit and the role of PtD in general in capital projects. These included:

1) Participants who completed the USGBC's online webinar about PtD as part of continuing education for credential maintenance.
2) Members of a working group developing an ANSI standard for PtD.
3) Respondents to a nationwide survey of architects conducted by Dodge Data Analytics in conjunction with the CPWR who sponsored our study.

Survey instruments were developed for each of these stakeholders based on the original case study survey protocol and administered electronically as described in each subsection. The outcome of these studies provided a rough snapshot of the current state of PtD knowledge and implementation across the industry in the U.S. As with previous tasks, this outcome was limited in its robustness but very useful in suggestion specific research questions to be pursued in future investigations to understand PtD diffusion.

Approach to Outcome 4: Comparison of Design Phase vs. Construction Phase Risk Assessments

Design phase and construction phase risk assessments from a European-based commercial building adapted for use LEED project were analyzed to determine the types of solutions identified. The solutions were classified according to the hierarchy of controls - Elimination, Substitution, Engineering, Administrative, and Personal Protective Equipment. Operational definitions for the control categories came from Behm and Powell (2014). For analysis, we later collapsed those solutions into two categories - higher order and lower order controls.

The outcome of this part of the study was an analysis to determine which phase of risk assessment and PtD implementation (design or construction phase) resulted in proposed controls that were higher in the hierarchy of controls and therefore more congruent with the aims of PtD. This task also resulted in a classification approach for controls that improves upon existing taxonomies used in the literature.

Outcome 1: Case Studies of LEED PtD Pilot Credit Implementation

The first outcome of the study was a series of two case studies of international projects that were pursuing the LEED PtD credit and whose stakeholders agreed to be interviewed for this research. Table 6 shows the primary features of each project and summarizes the key findings. Identifying details have been removed as per the request of the USGBC, who facilitated access to these case studies.

Table 6: Implementation Case Studies

Factor	Case Study A	Case Study B
LEED goal (driver)	Silver (Owner policy)	Platinum (Owner goal)
Project type	Manufacturing plant	Commercial office and associated facilities (approximately 28,000 sf)
Scope	Major retrofit (major mechanical and electrical systems replacement and replacement of production equipment; limited scope for building upgrades, e.g., no roof replacement)	Adaptive reuse/refurbishment of 1960's office block, with three distinct blocks of offices connected by underground parking and plant areas
Project cost	~$50 million (USD)	Not provided
Delivery method	Design-build (phased over 5 years for upgrade of the whole complex, with construction occurring during annual production shutdowns of 6-8 weeks)	Design-bid-build (one year construction period)
PtD required by law?	Yes (Belgium/EU)	Yes (Ireland)
Factors facilitating credit adoption	Similar process already required by law, with designated responsibility assigned to trained safety professional and special submittals required during bidding to show how safety is addressed; owner standards already very aggressive for building performance, so project team has precedent to go beyond minimum requirements; LEED is default certification system for this owner.	Similar process required by law and developed further as client requirement; project participants are bought in to the idea of going beyond the minimum overall
Barriers to credit adoption	Credit language written from an American point of view and intent is sometimes difficult to interpret for foreigners.	Confusion regarding whether project will sufficiently exceed local process requirements to meet LEED credit caveats; format of documentation

		required by LEED seems arbitrary and does not match required regulatory format
Additional comments	This project had not yet received feedback on the credit documentation at the time of interview, so they were unsure whether the project would achieve the credit.	This project has since completed certification and successfully received the credit.

Both case studies were from projects undertaken in a context where safety reviews are required by law already, and therefore it made sense to both project teams to pursue the PtD pilot credit as a comparatively low risk option requiring little change to current practice for them. Both project teams were working for owners that encouraged going “beyond the minimum”, which afforded confidence that the projects would meet the LEED requirement of going beyond minimum local standards.

From the standpoint of barriers, both teams felt that the structure of the credit was developed from an American point of view without taking into account existing reporting structures already in use elsewhere in the world. Converting the reports required by law in the EU and Ireland into the format required by USGBC represented an extra (and to them, unnecessary) step, although not enough of a barrier to deter pursuit of the credit. As early adopters, both teams believed they met the requirements and were likely to achieve the credit, although neither team at the time of interview had yet received formal confirmation from the USGBC. Case Study B later received confirmation of success for the PtD pilot credit.

In terms of costs to achieve the credit vs. benefits, the value of safety is already well ingrained as part of the construction paradigm in these countries. Processes are required by law and already in place to identify hazards and recommend controls. While the controls implemented on each project are ultimately determined by the owner’s cost/benefit judgement, the marginal overhead costs of pursuing the credit for both cases are comparatively low. In both cases, LEED certification was *already* an established project goal, and hazard/risk assessment was *already* a process required by law. The marginal cost of implementation for this credit therefore only consisted of reformatting reports to produce LEED documentation and documenting the actual implementation of measures on the project.

Outcome 2: LEED Credit Structural Review

In response to comments from case study interviewees who had actually attempted the LEED PtD pilot credit, a structural review of the credit itself was conducted to identify specific attributes that may have been associated with its lackluster diffusion to date. This review included documenting the approach used to develop and launch the pilot credit, the decision to develop a new credit instead of modifying existing credits within LEED, process requirements of the resulting pilot credit that must be completed by project teams to achieve the credit, and the decision to set up the credit as an optional credit vs. a prerequisite. These decisions likely influenced industry response to the pilot credit, and the structural analysis resulted in additional research questions and hypotheses that could be explored in future research to better understand its diffusion.

Approach used to develop and launch the PtD Pilot Credit

The USGBC maintains an ever-evolving library of pilot credits available for adoption by projects as one of the four possible Innovation in Design (ID) credits available to every project (https://www.usgbc.org/pilotcredits). Begun in 2010, the pilot credit library is designed as a means of introducing new credits to the rating system that are not part of the existing credit structure. (USGBC, 2017 - https://www.usgbc.org/leed/tools/pilot-credits). The process allows the USGBC to explore new ideas for credits through their use on actual projects, before the credits are judged worthy to go through the complete drafting and balloting process required for inclusion in the full rating system. Projects may register to pursue as many pilot credits as desired, although the number actually received is limited to the number of ID credits not already used by other requirements.

Pilot credits are generated and developed in one of several ways, including:

1. Proposal of new credits by project teams for possible certification on a particular project;
2. Credits independently developed by third parties that have not yet been deployed in practice on a project during certification; and
3. Pilot credits that are variations on existing credits proposed by the rating system working groups, based on needs and opportunities observed during implementation.

Since project teams are able to achieve ID credits by proposing their own credit requirements for these points, official pilot credits are often established by the USGBC following the success of a “home-grown” credit in receiving recognition by reviewers during the certification process. These “home-grown” credits have the benefit of having been vetted through certification on actual projects prior to being released in the pilot credit library, and as such, they have already undergone at least one round of implementation and testing that can help identify potential barriers and pitfalls to success. Likewise, pilot credits developed using the third path are based on the experiences of projects implementing original credits in older or current versions of the rating systems, and thus have the benefit of project team experience to refine the credit’s structure and requirements to better address implementation challenges while achieving the credit’s intent.

After release of a pilot credit in the pilot credit library, the LEED Technical Development committees review experiences of project teams deciding to register for the credit and evaluates their experiences and the impact of the credit in increasing the performance of the resulting buildings. Pilot credits evolve over time and may be split into multiple points if distinct facets emerge, or combined with other pilot credits as appropriate. After a sufficient number of projects have pursued the credit to properly evaluate its impact, the pilot credit is closed to new registrations and a report is developed to evaluate the pilot credit’s impacts. If determined to be impactful, the evaluation can lead to the pilot credit's inclusion in the Innovation Catalog, where refined versions of pilot credits that have passed the initial evaluation are available for use as ID points without registering as a pilot testing project. Eventually, the pilot credit may be included in the next release of one or more of LEED's rating systems, when it then becomes subject to public review and comment, followed by balloting among USGBC members (see https://www.usgbc.org/articles/closing-out-pilot-credits).

The PtD pilot credit was developed using the second path, based on strong advocacy from the National Institute of Occupational Safety and Health's Office of Construction Safety and Health and the National Occupational Research Agenda (NORA) Construction Sector Council, a non-partisan advisory group of approximately 30 individuals representing different perspectives of the construction sector, including academia, contractors, the insurance industry, product manufacturers, regulators, and others.

While engagement of GCCC members was extensive and their process reached out to many different types of stakeholders, ultimately the perspectives represented in the working group were limited to those with a significant interest and expertise in the field of occupational safety and health. Representation of green building expertise, particularly with regard to the structure and implementation of rating systems, was very limited and occurred very late in the credit development process, after significant work had already been done to develop concepts for credits. As such, the development team fell prey to the very same issues faced by project teams in using an integrative design process - they did not consider which perspectives might be missing and engage those perspectives early on. By the time proposed credit language was sent out to subject matter experts for review, many credit design decisions had already been made, and members of the GCCC were invested in their approach. This factor is an instance of commitment bias (Rogers 2003), often experienced by innovation advocates as they seek to diffuse innovations. Advocates can clearly see the benefits of the innovation from their own perspective, but the lens with which they view the problem is fundamentally different from potential adopters, in this case project teams who are faced with a need not only to change their design outcomes, but also the basic processes by which they develop those outcomes.

Decision to modify existing credits vs. develop new credit

Starting in 2011, initial work of the Green Construction Coordinating Committee (GCCC) included review of the then-current LEED 3.0 rating system to evaluate ways in which occupational safety and health could be included (Behm & Kleiner 2011). A review of existing credits identified several credits for further consideration within v3.0 in which health and safety hazards were likely to be more significant than on conventional projects or more logically addressed by project teams (Table 7).

Table 7: LEED 3.0 credits selected for further investigation and review

LEED 3.0 Credit	Reason for Selection

SS Credit 7.2: Urban Heat Islands	Opportunity for safe design of vegetated roofs
EQ Credit 3.1 & 3.2 Construction IAQ Mgmt Plan	Synergies of IAQ with construction worker health
EQ Credit 4.1-4.4 Low emitting materials	Synergies of healthy substitute with construction worker health
EQ Credit 8.1 & 8.2 Daylight and Views	Opportunity for safe design of skylights and atria
MR Credit 2 Construction Waste Management	Opportunity to better manage recycling to minimize injury
MR Credit 1.1 & 1.2 Building Reuse	Opportunity to understand existing structure stability

Multiple opportunities were developed within these existing credits for modification to improve lifecycle safety and health, both of building occupants and for workers during both construction and operations. Following internal development of draft credit language by the GCCC, the draft was sent out for review by external subject matter experts, including LEED Accredited Professionals and green building experts familiar with the credit adoption and use process by projects seeking LEED certification. Several key improvements were recommended at this point, including:

- Reworking the credit language to more closely match existing LEED credit language and structure
- Providing consistent information for each credit affected, including guidelines for processes and requirements for documentation
- Requiring projects pursuing each credit not only to create a plan, but also provide evidence of implementing the plan on projects.
- Providing supporting information, including plan templates and development guidelines to educate project teams about the kinds of actions desired in implementing PtD.

After further consideration, in 2012 the GCCC determined that it would be more effective to focus attention on the development of a single new credit focusing on lifecycle safety that could be deployed as a pilot credit by the USGBC as part of their pilot credit library. A set of follow-up ideas was generated that included developing products to improve general awareness of PtD among LEED practitioners, including webinars, presentations, case studies, LEEDuser threads, and other means of communications. Enhancements to existing credits were noted as actions that could be better achieved through modifications or inserts to the existing LEED Reference Guide rather than modification of the credits. The development of stand-alone guidance for safety in green construction projects was also proposed, through the development of either credit-specific supplements or a more comprehensive document to address lifecycle safety design and planning.

Throughout 2013 and 2014, the GCCC worked with the NIOSH Office of Construction Safety to develop an online webinar and support negotiations between NIOSH and USGBC regarding the official addition of the pilot credit to the library. In April 2015, the USGBC officially announced the addition of the PtD pilot credit to their Pilot Credit Library and opened it for registration by project teams. At this point, project teams interested in participating in the pilot program were able to enroll in the credit, notifying USGBC of their intent to pursue it.

Process attributes of the LEED PtD pilot credit

As discussed in Part 1 of this report, the strategy of project teams pursuing certification is to seek credits that can be obtained with high levels of certainty and low levels of cost. Many teams routinely review the pilot credit library during early project design to identify potential credits that may align well with their project objectives, and since there is no cost to register for pilot credits, they may register even though their intent to pursue the credit is only preliminary. The period of time that a pilot credit is available for registration is limited, so registering for the credit preserves the option in case the team decides it wants to pursue the credit after the evaluation period for a particular credit has closed. The amount of time a pilot credit is available to project teams varies based on the original uptake of the credit and the issues encountered by project teams during the pilot period.

One indicator of the "popularity" of a pilot credit that reflects the level of dialogue occurring in the user community is the level of discussion occurring in the LEEDuser online forum (Metalitz 2016). This forum is where members of project teams who have questions or comments about the project post their questions and respond to posts from other teams. The LEED technical staff also monitors these forums and may post to the discussion if clarifications are required.

In 2016, after experiencing ongoing challenges in finding projects enrolled in the credit that were open to being included in this study, the research team conducted an interview with LEED Technical Manager Batya Metalitz to identify new strategies to employ. Ms. Metalitz identified the LEEDuser forum as an informal means to evaluate industry interest in the credit. At that point, the research team reviewed the forum and found no comments, posts, or threads about the PtD credit at that time. While this is not necessarily an incontrovertible indicator of interest, it does typically correlate with the level of engagement of teams in determining how best to approach the credit, or how to address challenges encountered. As of the time of this writing, the LEEDuser forum postings were still minimal. There have been no postings in the LEEDuser forum for the PtD credit, compared to 60 total in the Integrative Process pilot credits (PC 5 and 6) that were considered popular enough to be incorporated in v 4.0 of the rating system as IP Credit 1: Integrative Design.

The Integrative Process (IP) credit is considered as a model here because the PtD pilot credit was modeled to a large extent after the design and format of that popular credit, although it was not integrated within the IP credit itself. Given the approach of launching the PtD credit within the pilot credit evaluation system, integration as part of the IP credit was not really an option, since the IP credit had already been formally adopted as part of LEED 4.0. However, the framing of the credit as similar to but still distinct from the process steps mentioned in the IP credit may have affected the perceptions of project teams regarding the level of effort required, specifically the degree of deviation from existing processes.

Diffusion of innovation theory (Rogers 2003) asserts that innovations which are compatible with existing processes and infrastructure have a higher likelihood of adoption and diffusion than those requiring adopters to change their processes and/or infrastructure. This assertion has been applied in the context of the LEED rating system by Langar (2009), who found that credits requiring changes in process on the part of those implementing the credit had a lower level of adoption and routinization among certified projects constructed by four public universities in the U.S. Therefore, those who seek to design widely adopted LEED credits should consider the degree to which implementing those credits requires deviation from existing processes and infrastructure.

In the case of the LEED PtD credit, the overall form of the credit is to require design review meetings at two points during the design phase in which the design itself is evaluated for opportunities to improve safety through the use of PtD. Early iterations of the credit proposed by the GCCC involved two possible points, one for each design review. The reviews were meant to evaluate specific known hazards such as falls from height that were associated with specific green practices and technologies such as vegetated roofs. One review focused on hazards during construction, and one review focused on hazards during operations/maintenance, with the focus in both cases on occupational safety and health rather than safety and health of building occupants per se. Ultimately, the USGBC reduced the number of possible points to one in the pilot credit release, where both reviews were required in order to meet credit requirements.

While the reduction in number of possible points may have diminished the potential interest of some teams in the PtD pilot credit, it still had the potential to remain attractive to teams given that design reviews occur regularly in most if not all projects, and integrative design practice regularly involves later lifecycle stakeholders such as constructors and building operators in design review. However, presenting PtD as a stand-alone credit rather than integrated with the Integrative Process (IP) credit category may have inadvertently led potential adopters to imagine that significant additional resources were required to implement PtD design reviews, when in fact they likely could be easily accommodated by supplementing existing design reviews required by the IP credit.

Ultimately, these decisions resulted in a pilot credit that was distinct from related credits in the Integrative Process category and not coordinated as well as it could have been with the requirements and processes of credits in that category. Ideally, to minimize perceived complexity and enhance compatibility, the credit would be achievable via modifying existing process steps in the IP credit rather than requiring additional meetings. The credit itself could actually be achieved this way, but the naming of steps in the PtD credit as distinct meetings may be a deterrent to teams not reading closely or unfamiliar with Prevention through Design as a concept.

Additional interview data from the European case studies in the early part of the study revealed that the requirements stipulated for formatting submittals to the USGBC to document the PtD credit are substantially different from the format commonly followed in EU and related countries where safety reviews are already conducted in the design phase by law. The project managers who were interviewed from these projects commented that the USGBC format seemed arbitrary and caused them additional effort to reformat the same information prior to submittal. Allowing documentation formatting to match the form already used in areas where PtD is required by law will further reduce the effort required to obtain the credit in these areas, and may therefore further increase the uptake in these areas while not negatively affecting projects in areas where PtD is not standard.

Finally, the timing of process steps for the PtD pilot credit requires that steps be taken early in design and not later than the schematic design phase. This is essential to ensure that the cost of changing the design is minimized and does not adversely affect the design of other systems after extensive design effort has already been expended. From the standpoint of Szyemberksi's time/safety influence curve (1997), this timing makes great sense. However, it also means that projects beyond schematic design can no longer qualify for the credit, which was the reason some of our potential case studies were unable to participate.

This same issue was also problematic in earlier versions of LEED for EA Prerequisite 2: Fundamental Commissioning, which required involvement of commissioning activities at the Basis of Design point of the process. Many projects did not establish interest in pursuing certification this early, and because the requirement was a prerequisite, they therefore were disqualified from being certified. Over time, however, project teams became more aware of this early requirement and were careful to incorporate it if there was a chance the project might seek certification. This same effect may also occur with the PtD pilot credit if it eventually is included in a new release of LEED.

The historical perceptions of safety as a construction-phase issue play a role in the process changes required to implement the pilot credit. Currently, as revealed in our studies of potential pilot credit adopters, the most ardent advocates for PtD are from the construction phase, which are not automatically included in the design phase processes where PtD has to be implemented. Clearly positioning the credit as a design-phase credit rather than a construction phase credit may help with resolving this issue. However, in the U.S., the distinct separation between designers and construction-phase means and methods is clearly established in the case law to screen designers from budget and schedule liability. Therefore, in the U.S., a fundamental paradigm shift will be required for designers to understand and embrace their potential power to influence construction and operational safety and health in a proactive way.

Framing PtD as a credit vs. a prerequisite

The last major structural issue to consider was largely beyond the control of the working group developing the pilot credit: the decision whether to make PtD an optional credit or a mandatory prerequisite. The process for releasing and evaluating pilot credits essentially requires pilot credits to be optional. Only in cases where significant evidence and broad precedent exists for adoption does a credit become a prerequisite. In fact, until version 3.0, the Water Efficiency credit category contained no prerequisites at all.

Nevertheless, framing PtD as a credit instead of a prerequisite creates the impression that this process is optional and may be pursued at the discretion of the project team. While accidents can and do happen on job sites, the culture of zero accidents has widely pervaded the US construction industry, and high profile green projects such as Las Vegas CityCenter with multiple fatalities have raised the question of whether ANY project with such abysmal safety outcomes is truly a green or sustainable project (Pearce et al. 2017).

While prerequisites are designed to cause penalties when they are not met, i.e., disqualifying the project from any level of certification, credits may be selected for implementation based on any line of thinking that makes sense to the project team, and the broad palette of credit options allows teams to choose from those with the highest likelihood of success. As noted earlier, credits may also fall short of requiring actual verification of long term outcomes, focusing instead on measures taken that are correlated with desirable outcomes.

The PtD pilot credit is structured in such a way that it requires execution of a process to identify hazards and propose controls, along with documentation of actual controls or design changes that were implemented in the design. However, no evidence is required to demonstrate that these controls actually mitigate the identified hazards to achieve the credit. Even if the PtD pilot credit remains an optional credit, strengthening it to require evidence that no accidents occurred during construction and through some period of operation would be similar to the latest requirements to monitor and report actual energy consumption of certified buildings.

At the most aggressive level, making PtD a prerequisite within the IP credit category would show a strong commitment to improved processes that increase the likelihood of safe projects over the lifecycle. This measure, along with requiring follow-through assessment and documentation of safety outcomes during and following construction, would increase the significance with which project teams take PtD and their responsibility for safe and healthy buildings resulting from their work.

Outcome 3: Studies of Potential Credit Adopters

Having explored to the extent possible case studies of teams actually implementing the LEED PtD Pilot credit, the next outcome targeted stakeholders who might *potentially* adopt the credit in hopes of developing an understanding of what factors influence adoption and might represent barriers to diffusion of the credit. Three specific groups of potential adopters were considered:

- Participants in the USGBC's PtD webinar used for LEED professional credential maintenance
- Members of the ANSI PtD Standard Development Committee
- Architects nationwide who participated in a Dodge Data Analytics survey on Prevention through Design.

Study of USGBC PtD webinar participants

According to our USGBC contact as of October 20, 2016, 75 participants watched a PtD Pilot Credit Continuing Education Course developed jointly by NIOSH and USGBC. A web-based survey was sent to these participants by our USGBC contact on November 10 and a reminder on December 2, 2016. The purposes of the survey were to understand why people enrolled in the webinar and to generate contacts who would be willing to participate in an interview on why they pursued or did not pursue the Pilot Credit. Table 8 shows the questions used in the survey.

Table 8: Survey questions for USGBC PtD webinar participants

1. What is your profession or job title?
2. How much influence do you have on the credits that get pursued on a LEED Project?
3. Are you a LEED AP?
4. Did you take the USGBC PtD Pilot Credit course for credential maintenance?
5. Did you consider this credit for a LEED project?
6. Did you pursue the credit?
7. If you did not pursue the credit on a LEED project, why not?
8. If you did or did not pursue the credit, would you be willing to engage in a 20 minute interview with the researchers, Annie Pearce and Mike Behm? Please contact us at behmm@ecu.edu or place your email in the area below and we will contact you. Thank you.

Only twelve people responded to the survey out of a population of approximately 70 people who had completed the webinar. Only one respondent said "yes" to questions 5 and 6. However, no details were provided in that person's response, and they did not provide information with which we could contact them to follow up. For Question 2, four respondents said they have a great deal of influence on the credits that get pursued on a LEED Project: two owners, one Director of Sustainability, and one Architect. Two respondents reported having no say at all - a Safety

Manager and one respondent who did not provide a job title. Only two webinar survey participants who took our survey both provided contact information and responded to email follow-up from the research team. Both were construction professionals who stated they were not in a position to influence the project regarding which credits to pursue.

Study of ANSI PtD Standard Development Committee

There are 29 PtD enthusiasts working on a PtD ANSI standard. Investigator Mike Behm is part of the group, which includes three other academics and twenty-five industry participants. The twenty-five industry participants were asked via email to complete the survey questions listed in Table 9. The survey was generated to elicit general information about PtD and possibly locate projects who applied for the credit but did not receive it. The objective of the questions was to better understand current PtD practice in the U.S. in relationship to the credit's language and intent.

Table 9: Survey Questions for Construction-phase Enthusiasts

1. Has your involvement to date been primarily with PtD in the design phase or in the construction phase?
2. If your involvement has been in the design phase, what tools or processes are you using, and what are the drivers to make that happen?
3. Have any projects you've been involved with attempted or explored the LEED PtD Pilot Credit? [Yes/No]
4. If Yes to Q3, answer a through c below, please.
    a. Did you actually register with USGBC for LEED PtD credit?
    b. What has been the response from designers? Did they push back, or were they enthusiastic?
    c. When did the discussion start about implementing the credit, meaning when in the project lifecycle?
5. If No to Q3, please explain why not.

Only six of the twenty-five working group members (24%) responded to the survey. No respondent reported that they were involved in design phase PtD-like processes (Q1). No projects they have been involved with attempted the PtD Pilot Credit (Q3). The remaining responses were vague. One respondent said that architects are not aware of PtD or the LEED credit so neither are really pursued. Another respondent even reported never having heard of the credit until this email.

One respondent said he knew of two projects that considered but did not receive the PtD Pilot Credit due to timing issues of not being involved early in the design phase (schematic design) to adequately meet the credit's requirements. One of the projects was his organization, a large insurance company, and another was one of their clients. He reached out to the project managers of both projects but neither responded to our survey or to our request for an interview.

Our conclusion from this exercise is that the ANSI PtD group is construction-oriented and construction PtD driven. There are no architects involved in the development of the standard, and no one in the group has been part of a PtD-like design process review as has been specified in the LEED PtD credit. This, along with data from the USGBC showing country of adoption for projects pursuing and achieving the PtD credit, supports our notion that PtD has not yet evolved in the US to support a design oriented credit such as the LEED Pilot Credit. While people know and understand design reviews and lifecycle safety and health, their combined practice has not yet taken hold even among PtD supporters. PtD remains a constructor-driven approach that occurs after design. The credit itself has not provided sufficient impetus to shift PtD practice into conceptual and detailed design in the US. More needs to be done to diffuse PtD into the design community.

Exploring the Designer's Perspective

CPWR and Dodge Analytics conducted a nationwide architecture survey in the summer of 2017. As part of this grant, we developed questions about LEED and the Pilot Credit with the goal that these questions may yield greater insight into barriers from the designer perspective.

Of the 1699 surveys sent, 108 architects responded for an overall response rate of only 6%. Although 79% of respondents were from architectural firms, approximately 40% of respondents were principals of firms with less than nine employees, reporting a fairly even distribution of 2016 estimate gross billings. The types of building projects reported they have engaged in over the past years were low-rise (1 – 3 floors) commercial (94%), low-rise residential (63%), and high-rise commercial (47%).

Respondents were provided the NIOSH definition of PtD. Twenty (19%) were aware of the concept of PtD, and based on the definition, 56% reported their company is practicing PtD. They were asked about four practices, as well as “How frequently do you do the following as part of your design practice?” Results are shown in Table 10.

Table 10: How frequently do you do the following as part of your design practice? (as %)

PtD Practice	Never	Occasionally	Frequently	Always
Perform safety design reviews before the completion of schematic design to explore how the completed building will be operated and maintained over its expected lifetime.	32.4	38.9	20.4	8.3
Use a life-cycle safety approach to explore how to reduce hazards and improve efficiency and well-being for building operations and maintenance personnel	34.3	35.2	25.9	4.6
Perform safety constructability reviews before the completion of schematic design to explore and plan how safety and efficiency can be optimized during construction	49.1	26.9	19.4	4.6
Work with the general contractor and key trades before the completion of schematic design to identify opportunities for prefabrication	16.7	54.6	25.9	2.8

Respondents were largely unfamiliar with the USGBC Pilot Credit (Table 11). Ninety said they were not at all familiar, and eight responded with a 2 value. One respondent reported they have used the credit.

Additional questions were asked about barriers to implementing credits in general (Table 12) and the PtD Pilot credit (Table 13). Barriers associated with cost were reported as hindrances when considering all credits. The potential liability as a designer was reported highest when considering the PtD credit, with too much effort for the points received also seen as preventing adoption. Eleven respondents (10%) reported they were likely to use the PtD credit on a future project (Table 14).

Table 11: How familiar were you with the USGB's PtD pilot credit?

	Frequency	Percent
1 Not at all familiar	90	83.3
2	8	7.4
3 Somewhat familiar	7	6.5
4	2	1.9
5 I've used it on a LEED project	1	0.9
Total	108	100.0

Table 12: To what degree are the following barriers to pursuing the Prevention through Design (PtD) Pilot credit on a project pursuing LEED certification?
1 = Not a barrier, 5 = Would prevent adoption

	N	**Mean**	**S.D.**
Added cost for documenting credit achievement (e.g., modeling costs)	108	4.05	1.195
Added cost of materials/systems/ construction to meet credit requirements	108	3.93	1.213
Nature of documentation required to achieve the credit (amount required compared to normal practice, way in which documentation is organized)	108	3.78	1.285
Degree of difference in design compared to what would be conventionally done in a project	108	3.07	1.243

Degree of difference in construction methods required compared to conventional practice	108	3.05	1.300
Ambiguity in the wording of the credit/lack of precedent to know what will count	108	3.02	1.360

Table 13: To what degree are the following barriers to pursuing the Prevention through Design (PtD) Pilot credit on a project pursuing LEED certification?
1 = Not a barrier, 5 = Would prevent adoption

	N	Mean	S.D.
Using Prevention through Design (PtD) increases my liability as a designer	108	4.19	1.523
Documenting the credit requires too much effort for the number of points received	108	4.06	1.452
Incorporating Prevention through Design (PtD) in my projects is too difficult or too expensive	108	3.97	1.603
The timing of the required reviews does not fit my schedule	108	3.83	1.538
I don't know about or understand Prevention through Design (PtD	108	3.61	1.490
I don't see the benefits of considering Prevention through Design (PtD)	108	3.16	1.719

Table 14: How likely are you to use the Prevention through Design pilot credit on a future project?

	Frequency	Percent
1 Not at all likely	27	25.0

2	16	14.8
3 Neutral	54	50.0
4	6	5.6
5 Likely	5	4.6

Outcome 4: Design-phase vs. Construction-phase Risk Assessment Comparison

In the second half of the study, we also conducted an exercise to compare the outcomes of a PtD-based risk assessment from our European case studies with construction-phase risk assessments from the same projects to evaluate whether there are significant differences in the risks identified. We used the Hierarchy of controls to classify interventions recommended by these two types of assessments to test the hypothesis that design phase PtD results in a greater number of interventions higher up the hierarchy of controls than a construction phase risk assessment.

We analyzed the project's risks assessment register to classify controls as either a lower order or a higher order control. The research team's impression of the risk register was that with few exceptions, most of the items in the risk registers were boilerplate or standard practice that would be applied to all projects and were not unique to this particular project. Most "design mitigation measures" were determined to be standard mechanical and electrical practices that do not change the design or the way work is organized. Two construction based risks assessments (facade works and enabling works designers) were compared to the main works designer's risk assessments using Fisher's Exact Test for 2 x 2 tables (Design / Construction - Lower Order / Higher Order). Table 15 shows results from SPSS. Results of the comparison are highly significant ($p < 0.001$), and indicate that higher order controls are more likely to be identified when conducted in design phase compared to construction phase.

There is a relationship between the level of controls that can be identified and applied and when the risk assessment occurs. Higher order controls are more likely to be identified and applied in design compared to construction risk assessments. This finding is in line with the seminal study by Lingard et al. (2015) and further discussed in Sanders et al. (2016). In this study researchers from Australia (RMIT) and the US (Virginia Tech) found that the greater the proportion of risk controls selected during the pre-construction stages of a project compared to the construction phase, the better the risk control outcomes and the more opportunity to utilize higher order controls.

This study by RMIT and Virginia Tech is the first to look at evaluating the Szymberski curve with empirical data. Our study supports that notion as well. It is therefore very difficult for construction phase risk assessments to truly "design out" and reduce hazards compared to the design and pre-construction phases. This thinking is in line with European and Australian regulations and the LEED Pilot Credit. However, it is in contrast to current practice in the US. The evidence found in this analysis of the LEED Credit and the Lingard et al. study support the notion that the US will not experience the efficacy of PtD until the design professions accept it as part of their standard practice. Moreover, based on our research of the LEED credit and its lackluster success in the US, we can infer that the current constructor-led PtD effort may be actually hampering and acting as a roadblock to designer acceptance, since designers perceive that these issues are being taken care of by construction-phase stakeholders.

Table 15: Statistical analysis of design and construction phase controls vs. level in hierarchy of control

DesORConstRA * LowerHigher2 Crosstabulation

			LowerHigher2		
			Lower Order Controls	Higher Order Controls	Total
DesORConstRA	Design Risk Assessment	Count	27	15	42
		Expected Count	33.7	8.3	42.0
	Construction Risk Assessment	Count	38	1	39
		Expected Count	31.3	7.7	39.0
Total		Count	65	16	81
		Expected Count	65.0	16.0	81.0

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	14.020[a]	1	.000		
Continuity Correction[b]	12.006	1	.001		
Likelihood Ratio	16.459	1	.000		
Fisher's Exact Test				.000	.000
Linear-by-Linear Association	13.847	1	.000		
N of Valid Cases	81				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 7.70.

b. Computed only for a 2x2 table

To promote broader diffusion of PtD and the attendant benefits thereof, examples need to be developed and disseminated that are designer-led and are about the whole building and its permanent features, rather than the design of temporary works, selection of tools, and going beyond simple examples such as the height of parapet walls. Design for Safety examples are needed to which architects can relate and understand. To avoid potential liability issues as mentioned earlier in the report, these examples should be differentiated from dictating means and methods of construction and should focus on creativity, aesthetics, and other drivers of design. See for example a recent paper by Behm et al. (2017) which focuses on safe design and creativity.

In summary, this study sought to understand the effects of the LEED PtD Pilot Credit on health and safety in capital projects and to identify the barriers and enablers affecting its adoption and diffusion. Contrary to the original assumptions of the study, the PtD credit has *not* been broadly adopted to date, and comparatively few projects have even pursued the credit, let alone achieved it. At this point, adoption is more widely occurring in locations where regulatory requirements already mandate design-phase consideration of risks. The results of the four study outcomes suggest that achieving PtD in the US may require a paradigm shift among designers with regard to their role in project health and safety. The next section details the conclusions resulting from the study and recommendations that have emerged as a result.

Conclusions and Recommendations

Based on the four outcomes developed in this study, we present three major conclusions and associated recommendations for future research and practice regarding safety and health in green projects.

Overarching issues about motivating designers to champion PtD

As a result of our studies of potential PtD credit adopters and our analysis of design phase vs. construction phase risk assessments, we conclude that the most significant advocate for PtD in construction projects is construction phase professionals. Given that these individuals are the ones most strongly pushing for PtD on projects, we believe that the wrong group is leading the effort. The safety professional and constructor led PtD effort has worked to a point in making the construction profession aware of higher order controls. However, it falls short of reaching and influencing architects and designers of the built environment who are ultimately responsible for the design of the project, as we found in our surveys of design phase professionals.

At this point, we suggest that a continued effort that does not include architects may in fact be detrimental to further evolution and implementation of PtD in practice. In our efforts to collaborate with US-based LEED AP's and project leads who were attempting to utilize the PtD Pilot credit, we were unable to speak to any designers, despite multiple efforts using multiple modes of communication. All contacts we found were safety professionals and construction professionals, who, in the end, were unable to successfully initiate the PtD Pilot Credit on their projects.

We believe that two main approaches could be used to motivate designers to take the lead in the PtD process: incentives or "carrots", and penalties or "sticks". Using the integrative process credit as a precedent, we know that cost is a major driver of adoption of green practices. While historically designers did not close the loop on projects with post-occupancy evaluation, new contracting methods such as design-build-operate-maintain along with integrative processes and relational contracting have led design teams to care far more seriously about the performance of their projects in reality. Multiple cost studies have been conducted to evaluate the marginal cost of green projects (see Pearce et al. 2017). Concurrently, as discussed earlier in this report, several key studies brought to light the performance discrepancies between modeled and actual performance of green buildings, particularly with respect to energy consumption. Professional reputations were at stake, and indeed the whole notion of green building certification was called into question by some as a result.

Having hard evidence to establish both the costs and benefits of PtD would help show both the seriousness of impacts that can be prevented using these methods. Further imposing penalties, such as by requiring zero accidents a prerequisite for project certification, would motivate design teams to seriously consider measures to prevent risk. The ultimate effect would be to hold designers morally if not legally responsible for incidents that could have been avoided with PtD. For PtD to evolve to a design phase intervention, we find a fundamental gap between NIOSH and PtD enthusiasts and actual designers that would need to champion the PtD process for effective implementation. Most significantly, any effort to diffuse PtD must create opportunities for architects and designers to take the lead in PtD and own the processes involved. We recommend that NIOSH should consider targeting an external research grant focused on the architectural community to better understand how this stakeholder group could adopt PtD in general and/or PtD within the LEED Pilot Credit. A part of this should involve a detailed review of tort law and implications for integrative process on legal responsibilities of different members of the project team.

Possibilities for restructuring how PtD is incorporated into LEED

As discussed in the outcomes of the structural credit review, there are multiple possibilities for increasing the leverage of PtD to effect change within the rating system itself. From requiring net zero accidents as a prerequisite for certification, to piggybacking the PtD process as part of the already successful Integrative Process credit, *how* PtD is incorporated in the rating system may make a significant difference in its diffusion and the positive impacts it can yield.

At a minimum, we recommend that required documentation be revisited in light of the findings from our European case studies, where existing law specifies a format and process that is already widely used in the European community. Designing the documentation requirements to conform to existing language and formats can help credit diffusion by reducing the possibility for misinterpretation of credit requirements and reducing the burden for format conversion by the project team.

We also recommend that documentation requirements be expanded to include not only documentation of the PtD process during design and the measures implemented, but also follow-on during and after construction to document the relative prevalence of incidents and near misses. Requiring this data would go well beyond what is presently tracked as part of typical US construction projects, where incidents may remain undocumented unless medical claims or fatalities occur. The resulting information could serve as the starting point for a better understanding of how the culture and climate on green projects relates to safety culture and climate.

Specifically, we recommend that PtD be included as part of the Integrative Process credit in LEED, with similar construction and post-construction documentation of outcomes that can be associated with it. We recommend considering that projects should be disqualified from certification or otherwise penalized if incidents occur, particularly fatalities. Alternatively, the credit could be enhanced by requiring a comparison with average incident rates on comparable conventional projects as a baseline, similar to the requirements in energy and water credits for exceeding code requirements.

Some rating systems such as Living Building Challenge require that projects demonstrate net zero energy and water performance for one year of operation before awarding certification. If PtD is to take into account the operational as well as construction phase of operations, a similar time frame should also apply for measuring health and safety outcomes.

We also believe that significant advances can be made by establishing working relationships with USGBC to gain access to actual project data as more registered projects begin to submit documentation. USGBC's practice is to limit access to project data to its own employees and contractors, which meant that our project team had to pursue project stakeholders directly after they identified themselves as volunteers based on USGBC outreach efforts using our contact information. Finding ways to allow more direct access to data, even if it is significantly sanitized for confidentiality, could open the door to pursue significant new research questions.

Understanding the effects of PtD implementation process on safety and health outcomes

Our comparative study of risk registers generated during the design and construction phases of one of our case study projects, although preliminary, provides some evidence that higher order controls are more likely to be identified during design than during construction. However, many of the items on the risk registers were boilerplate and did not represent detailed project-specific measures in response to unique project features. The credit documentation package submitted to the USGBC would at least have identified measures associated with specific green features, which may have provided unique insight as to how the pilot credit stimulated different behaviors on the part of the project teams. We attempted to obtain the credit documentation for this project, but due to USGBC confidentiality requirements and turnover in project management staff for the project case, we were unable to see the final documentation package compared to the original risk assessment data.

While projects in some contexts are already required to perform health and safety risk assessments by law, in other countries these requirements do not yet exist. Exploring ways in which project teams go beyond local requirements may offer insight for improving implementation of PtD in other contexts. We recommend further study to follow up with the case study projects to compare their original risk registers with both the required LEED documentation as well as construction and operational health and safety outcomes to assess whether desirable impacts were achieved.

With regard to classifying controls in our case study risk registers, we faced methodological challenges in finding clear operational definitions for identified controls. Hazards are messy, complex, and multidimensional. Even with operational definitions and discussing methodology with the Lingard and Kleiner research team we had much difficulty in assigning a particular control level to each hazard identified in the design and construction risk assessments. We originally attempted to place a numerical value (1 - 5) on each control. A second option we considered was to trifurcate the data as eliminate, other higher order control, or lower order control. We believe this might be the most efficient and accurate way to classify controls. However, our case study project had very few instances where controls would completely eliminate hazards without introducing other hazards, making analysis difficult if not impossible.

We also find value when hazards are recognized in design, and the designer simply communicates the hazard to the constructor. We did not account for this "prevention through recognition" approach in our methodology simply because we think this needs a more focused effort and evaluation of how the hierarchy of controls is analyzed in research and practice. Even though they may not be making a design change, designers are actually changing their practice by interacting more closely with constructors via the design risk assessments. We believe this is positive for eventual site safety and will allow constructors to better estimate, plan, and organize their work.

Our initial pilot study of design phase vs. construction phase controls was limited to existing risk registers from one case study in Europe. This project was enrolled for the LEED PtD pilot credit and therefore should have been employing a more rigorous process than required by regulations. However, based on the experience of the research team, the case study revealed a process that seemed in reality to be more the standard process with some modification rather than a more rigorous attempt to employ PtD methods and best practices “from scratch” to the project. With our limited pilot data, we were unable to determine whether this is typical, although we hypothesize that adapting existing processes to incorporate PtD requirements is more likely to be successful over time than creating completely new processes. Future research should examine a larger population of projects with a controlled process in place for design-phase and construction-phase risk assessment to explore the effect of timing in developing usable higher order controls.

In this study, considerable effort was focused on evaluating the hierarchy of controls, establishing how to classify controls, and testing approaches to analyze them. We believe a paper with Lingard and Kleiner on the topic of “How not to abuse the Hierarchy of Controls by using it as a research methods yardstick” would be a significant contribution to safety science. Most fundamentally, assigning numerical values and using mathematical manipulation on an ordinally scaled system like the Hierarchy of Controls should be avoided from a validity standpoint. In reality, most hazards are controlled with a combination of controls. The hierarchy assumes each control is more effective than the next, and the assumption is that a hazard is independent of other hazards, which is not usually true in the real world. Moreover, the purpose of the hierarchy of controls is not to fit controls neatly into boxes but rather to encourage stakeholders to think more broadly about measures that can be taken.

Ultimately, we believe that the findings of this study provide a point of departure for a better understanding of mechanisms to improve project health and safety through involvement of design stakeholders. Building on this initial work, we hope that future research will begin to answer some of the questions raised in this study.

References

Adegbile, M. (2012). “Development of a Green Building Rating System for Nigeria.” *Proceedings, Sustainable Futures: Architecture and Urbanism in the Global South.* Kampala, Uganda, 27-30 June.

Ahn, Y. H., and Pearce, A. R. (2007). “Green Construction: Contractor Experiences, Expectations, and Perceptions.” *Journal of Green Building,* 2(3), 106-122.

Ahn, Y.H., Choi, Y.O., Koh, B.W., and Pearce, A.R. (2011a). “Sustainable Design Process for Learning Environments: Lowering Energy Consumption in a K-12 Facility.” *Journal of Green Building,* 6(4), 112-137.

Ahn, Y.H., Pearce, A.R., and Ku, K. (2011b). “Paradigm Shift of Green Buildings in the Construction Industry,” *International Journal of Sustainable Building Technology and Urban Development,* 2(1), 52-62.

Alyami, S. H. and Rezgui, Y. (2012). “Sustainable building assessment tool development approach.” *Sustainable Cities and Society*, 5(0), 52–62.

Artman, H. (2000). “Team situation assessment and information distribution.” *Ergonomics*, 43(8): 1111–1128.

Attia, S. (2014). “The usability of green building rating systems in hot arid climates.” *Proceedings, First International Conference on Energy and Indoor Environment for Hot Climates*, Doha, Qatar, February.

Banani, R., Vahdati, M.M., Shahrestani, and Clements-Croome, D. (2016). “The development of building assessment criteria framework for sustainable non-residential buildings in Saudi Arabia.” *Sustainable Cities and Society,* 26, 289-305. http://dx.doi.org/10.1016/j.scs.2016.07.007

Baum, F., MacDougall, C., and Smith, D. (2006). “Participatory Action Research.” *Journal of Epidemiology and Community Health,* 60(10), 854-857.

Behm, M., Culvenor, J., and Genn, K. (2017). Safe Design: A Source for Innovation in the Built Environment. *Practice Periodical on Structural Design and Construction*, 22 (4).

Behm, M., Culvenor, J., and Dixon, G. (2014). Development of Safe Design Thinking among Engineering Students. *Safety Science*, 63, 1-7.

Behm, M. and Powell, D. (2014). SH&E Problem Solving: Are Higher-Order Controls Ignored? *Professional Safety – Journal of the American Society of Safety Engineers*, 59 (2), 34-40.

Behm, M. and Boughton, C. (2013). PtD - Architectural Design and Construction – Educational Module and Instructor's Manual. Dept. of Health and Human Services (NIOSH) Publication Number 2013-133. http://www.cdc.gov/niosh/docs/2013-133/

Behm, M. (2012). Safe Design Suggestions for Vegetated Roofs. *Journal of Construction Engineering and Management*. 138:8, 999-1003.

Behm, M. and Kleiner, B.K. (2011). “Integrating occupational safety and health into the U.S. Green Building Council LEED New Construction credits: A preliminary report.” National Occupational Research Agenda Construction Sector Council Green Construction Coordinating Committee, NIOSH Office of Construction Safety and Health, Washington, DC. July 29.

Behm, M. and Poh, C.H. (2012). Safe Design of Skyrise Greenery in Singapore. *Smart and Sustainable Built Environment*. 1:2,186-205.

Behm, M., Culvenor, J., and Genn, K. (2011). “Can Safe Design be a Source for Construction Innovation?” *Prevention: Means to the End of Construction Injuries, Illnesses, and Fatalities*, Proceedings of the International Council for Research and Innovation in Building and Construction (CIB) W99 Conference, Washington, DC, Aug. 24-26, 2011.

Behm, M. (2008). “Rapporteur’s Report: Construction Sector.” *Journal of Safety Research*, 39 (2), 175-178.

Behm, M. (2005). “Linking Construction Fatalities to the Design for Construction Safety Concept.” *Safety Science*. 43:8, 589-611.

Berardi, U. (2011a). “Sustainability Assessment in the Construction Sector: Rating Systems and Rated Buildings.” *Sustainable Development,* DOI: 10.1002/sd.532.

Berardi, U. (2011b). “Beyond Sustainability Assessment Systems: Upgrading Topics by Enlarging the Scale of Assessment.” *Int. J. of Sustainable Building Technology and Urban Development,* 2(4), 276-282. DOI: 10.5390/SUSB.2011.2.4.276

Bluff, L. (2003). “Regulating safe design and planning of construction works: a review of strategies for regulating OHS in the design and planning of buildings, structures, and other construction projects”, Working Paper No. 19, The Australian National University, Canberra.

Bower, J., Howe, J., Fernholz, K., and Lindburg, A. (2006). *Designation of environmentally preferable building materials—fundamental change needed within LEED*. Dovetail Partner Report.

Branche, C. M., Gillen, M, and Behm, M. (2013). “Life Cycle Safety: How it Supports Social Equity Goals.” Greenbuild International Conference. Philadelphia, PA. November 20, 2013.

Branche, C. M. (2012). “Making Green Jobs Safe: Integrating Occupational Safety and Health into Green and Sustainability.” *NORA Symposium Michigan Safety Conference, Grand Rapids, Michigan.* National Institute for Occupational Safety and Health (NIOSH). (April 17).

Bray, J., and McCurray, N. (2006). “Unintended Consequences: How the Use of LEED Can Inadvertently Fail to Benefit the Environment,” *Journal of Green Building,* 1(4), 152–165.

BRE - Building Research Establishment (2004). *Assessment of Sustainability Tools.* Building Research Establishment, Glasgow, UK.

Burdova, E.K. and Vilcekova, S. (2015). “Sustainable Building Assessment Tool in Slovakia.” *Energy Procedia*, 78, 1829-1834.

CASBEE for New Construction. (2010). *Technical Manual*. Institute for Building Environment and Energy Conservation, Japan.

CERF - Civil Engineering Research Foundation. (1996). *The Foundation for a New Approach to Implement Building Innovation*. CERF Report #96-5021, Civil Engineering Research Foundation, Washington, DC. January.

CERF - Civil Engineering Research Foundation. (2000). *Guidelines for Moving Innovation into Practice*. Background Material and Working Draft for International Symposium & Innovative Technology Tradeshow, Washington, DC.

Cole, R.J. (2005). “Building environmental assessment methods: Redefining intentions and roles.” *Building Research & Information,* 35(5), 455-467.

Conte, E. and Monno, V. (2012). “Beyond the *building centric* approach: A vision for an integrated evaluation of sustainable buildings.” *Environmental Impact Assessment Review,* 34, 31-40.

Darus, Z. M., Hashim, N. A., Salleh, E., Haw, L. C., Rashid, A. K. A., and Manan, S. N. A. (2009). “Development of rating system for sustainable building in Malaysia.” *Proc. of Conf. on WSEAS Transactions on Environment and development*, 5(3), 206–272.

Darus, A.Z. and Hashim, N.A. (2012). “Sustainable Building in Malaysia: The Development of Sustainable Building Rating System.” In C. Ghenai (Ed.) *Sustainable Development - Education, Business and Management - Architecture and Building Construction - Agriculture and Food Security*. InTech Europe, Rijeka, Croatia. 113-144.

Dibner, D.R. and Lemer, A.C. (1992). *The role of public agencies in fostering new technology and innovation in building*. National Academy of Sciences Press, Washington, DC.

Ding, G.K.C. (2008). “Sustainable construction- the role of environmental assessment tools.” *Journal of Environmental Management,* 86, 451-464.

Dixon, T, Colantonio, A., Shiers, D., Gallimpre, P., Reed, R., and Wilkinson, S. (2007). *A green profession: an audit of sustainability tools, techniques, and information for RICS members.* Royal Institute of Chartered Surveyors, UK.

DuBose, J.R., Bosch, S.J., and Pearce, A.R. (2007). “Analysis of Statewide Green Building Policies,” *Journal of Green Building,* 2(2), 161-177.

EEC (1992) Council Directive on the implementation of minimum safety requirements at temporary or mobile construction sites. 92/57/EEC. EEC. Brussels, Belgium, EEC.

Ehrenkrantz Group/Gershom Meckler Assn. (1979). “A study of existing processes for the introduction of new products and technology into the building industry.” U.S. Institute of Building Sciences, Washington, DC.

Forsberg, A. and von Malmborg, F. (2003). “Tools for environmental assessment of the built environment.” *Building and Environment,* 39, 223-228, doi:10.1016/j.buildenv.2003.09.004.

Fortunato III, B.R., Hallowell, M.R., Behm, M., and Dewlaney, K.S. (2012). “Identification of safety risks for high performance sustainable construction projects.” *Journal of Construction Engineering and Management*, 138(4): 499-508.

Fowler, K.M. and Rauch, E.M. (2006). *Sustainable Building Rating Systems Summary.* PNNL-15858, Pacific Northwest National Laboratory, U.S. Department of Energy, Richland, WA.

Gambatese, J. (2009). “Don’t Leave Safety Out of Sustainability.” *ENR.* (November 18).

Gambatese, J. A., Rajendran, S., and Behm, M. G. (2007). “Green Design & Construction: Understanding the Effects on Construction Worker Safety and Health.” *Professional Safety,* 52(5), 28-35.

Gambatese, J., and Tymvios, N. (2012). “LEED Credits: How They Affect Construction Worker Safety.” *Professional Safety,* 42-52.

Gambatese, J., Behm, M., and Hinze, J. (2005). “Viability of Designing for Construction Worker Safety.” *Journal of Construction Engineering and Management*, ASCE, 131(9), 1029-1036.

Gibberd, J., 2005. Assessing sustainable buildings in developing countries—the sustainable building assessment tool SBAT and the sustainable building lifecycle SBL. Proceedings of the World Sustainable Building Conference, Tokyo, Japan, pp. 1605 1612.

Goh, C. S. and Rowlinson, S. (2013). "The roles of sustainability assessment systems in delivering sustainable construction." Proceedings, 29th Annual ARCOM conference, 1363–1371. Association of Researchers in Construction Management, Reading, UK.

Gu, Z., Wennersten, R. ,and Assefa, G. (2006). "Analysis of the most widely used Building Environmental Assessment methods." *Environmental Sciences,* 3(3), 175-192.

Haapio, A. and Viitaniemi, P. (2008). "A critical review of building environmental assessment tools." *Environmental Impact Assessment Review,* **28**, 469-482.

Haro, E. and Kleiner, B.M. (2008). "Macroergonomics as an organizing process for systems safety." *Applied Ergonomics,* 39(4), 450-458.

Hinze, J. and Wiegand, J. (1992). Role of designers in construction worker safety. Journal of Construction Engineering and Management 118 (4), 677–684.

Jia, A. (2015). Personal electronic communication with Michael Behm. April 26, 2015.

Kajikawa, Y., Inoue, T., and Goh, T.N. (2011). "Analysis of building environment assessment frameworks and their implications for sustainability indicators." *Sustainability Science*, 6, 233-246.

Khese, S.R., Hedaoo, M.N., and Konnur, B.A. (2016). "A Comparative Study of Rating Systems in Green Building." *International Journal of Engineering Research,* 5(1), 134-136.

Kelly, H. (1986). "Technology and the construction industry." *Proceedings, Technological Change and U.S. Building Construction Industry*, Office of Technology Assessment, AIA Press, Washington, DC, 1-10.

Keysar, E. and Pearce, A.R. (2007). "Decision Support Tools for Green Building: Facilitating Selection Among New Adopters on Public Sector Projects," *Journal of Green Building*, 2(3), 153-171.

Klein, G. (1998). *Sources of Power: How People Make Decisions.* MIT Press, Cambridge, MA.

Kleiner, B.M. (2006). "Macroergonomics: Analysis and design of work systems." *Applied Ergonomics*, 37, 81-89.

Kuhn, E.A., Sattler, M.A., and Mello Neto, R.L. (2012). "A review of methods and tools available for environmental assessment at local territorial scale." *Proceedings, PLEA2012 Conference – Opportunities, Limits, & Needs*, Lima, Peru, 7-9 November.

Lingard, H., Pirzadeh, P., Blismas, N., Wakefield, R., and Kleiner, B. (2014). "Exploring the link between early constructor involvement in project decision-making and the efficacy of health and safety risk control." *Construction Management & Economics*, 32 (9), 918-931.

Lorent, P (1987) Les conditions de travail dans l'industrie de la construction - Productivité, conditions de travail, qualité concertée et totale. Brussels, Comité National d'Action pour la Sécurité et l'Hygiène dans la Construction.

Malin, N., Melton, P., and Roberts, T. (2012). *New Concepts in LEED v4.* BuildingGreen, Inc., Brattleboro, VT.

Mao, X., Lu, H. and Li, Q. (2009). “A Comparison Study of Mainstream Sustainable/Green Building Rating Tools in the World.” *Proceedings, Conference of Management and Service Science*, 1–5.

McCoy, A.P., Ahn, Y.H., and Pearce, A.R. (2012). “Towards Establishing Diffusion Barriers for Innovative Green Building Products: A Survey of SIPS Builders.” *Journal of Green Building*, 7(2), 153-176.

McGraw-Hill Construction. (2010). *Green Outlook 2011- Green Trends Driving Growth*, McGraw-Hill, New York, NY.

Meadows, D.H. (1999). *Leverage Points: Places to intervene in a system*. Sustainability Institute, Hartland, VT.

Mlecnik, E., Visscher, H., and van Hal, A. (2010). “Barriers and opportunities for labels for highly energy-efficient houses.” *Energy Policy,* 38(8), 4592-4603.

National Association of Home Builders Research Foundation (NAHBRF). (1972). *Constraints to builders’ adoption of cost-saving innovations.* NAHBRF, Upper Marlboro, MD.

OSHA - U.S. Occupational Safety and Health Administration. (2017). Alliance Program Construction Roundtable, Products Developed Through the Roundtable. https://www.osha.gov/dcsp/alliances/roundtables/roundtables_construction.html#!2B Accessed 16 July 2017.

Oster, S M. and Quigley, J.M. (1977). “Regulatory barriers to the diffusion of innovation: Some evidence from building codes.” *Bell J. Economics*, 8(2), 362-377.

Pearce, A.R. (2008). “Measuring the Sustainability of Infrastructure Systems: Information Requirements and Desiderata,” *Proceedings of the International Conference on Sustainability Engineering and Science*, New Zealand Society for Sustainability Engineering and Science, Auckland, New Zealand, December 9-12.

Pearce, A.R. (2008). *Systems-Based Sustainability Analysis at the Installation Scale: Proof of Concept and Demonstration at Fort Belvoir.* National Defense Center for Environmental Excellence, Concurrent Technologies Corporation, Inc., Washington, DC.

Pearce, A.R. (2009). “Changing the checklist mentality: Recommendations for outreach and education as part of the US Air Force’s Sustainable Design & Development Initiative,” A-5 Spiral Initiative, HQ Air Combat Command, Langley AFB, VA.

Pearce, A.R. and Ahn, Y.H. (2013). “Strategic entry points for sustainability in university construction and engineering curricula,” *International Journal of Sustainable Development*, 16(3/4).

Pearce, A.R. and Fiori, C.M. (2011). *Sustainable Construction Supervisor.* Pearson/Prentice Hall, Upper Saddle River, NJ.

Pearce, A.R. and Fiori, C.M. (with Shenoy, S.B.) (2009). *Your Role in the Green Environment, 2nd ed.* Pearson/Prentice Hall, Upper Saddle River, NJ.

Pearce, A.R. and Fischer, C.L.J. (2001). *Systems-Based Sustainability Analysis of Building 170, Ft. McPherson, Atlanta, GA.* Summary analysis report to the Army Environmental Policy Institute, Atlanta, GA, May.

Pearce, A.R. and Kleiner, B. (2014). *Construction in the International Green Economy: A Systematic Review.* Final Project Report, National Institutes for Occupational Safety and Health, Washington, DC, June 28.

Pearce, A.R. and Kleiner, B.M. (2015). "Safety and Health in Green Buildings: An Occupational Case Analysis and Evaluation of Rating Systems." *Proceedings, Engineering Sustainability Conference,* Pittsburgh, PA, April 19-21.

Pearce, A.R., Ahn, Y.H., and HanmiGlobal, Inc. (2017). *Sustainable Buildings and Infrastructure: Paths to the Future, 2nd ed*. Taylor & Francis/Earthscan Publications, London, UK.

Pearce, A.R., DuBose, J.R., and Bosch, S.J. (2007). "Green Building Policy Options in the Public Sector," *Journal of Green Building,* 2(1), 156-174.

Pearce, A.R., McCoy, A.P., Smith-Jackson, T., Edwards, M., Pruden, A., and Bagchi, R. (2011). "Designing a Sustainable Built Environment: A Hazards Analysis and Critical Control Points (HACCP) Approach." *Proceedings, CIB W099 Conference 2011: Prevention - Means to the End of Safety and Health Injuries, Illnesses, and Fatalities,* Washington, DC, August 24-26.

Pearce, A.R., Sanford-Bernhardt, K, and Garvin, M.J. (2010). "Sustainability and Socio-Enviro-Technical Systems: Modeling Total Cost of Ownership in Capital Facilities." *Proceedings, 2010 Winter Simulation Conference*, Baltimore, MD.

Poston, A., Emmanuel, R., and Thomson, C. (2010). "Developing holistic frameworks for the next generation of sustainability assessment methods for the built environment." Proceedings, 26th Annual ARCOM Conference. Leeds, UK, 6–8 September, 1487-1496.

Pulaski, M.H. and Horman, M.J. (2005). "Continuous Value Enhancement Process." *Journal of Construction Engineering and Management,* 131(12), 1274-1282.

Rajendran, S., Gambatese, J. A., and Behm, M. G. (2009). "Impact of Green Building Design and Construction on Worker Safety and Health." *Journal of Construction Engineering and Management,* 135(10), 1058-1066.

Reed, B. (2007). "Shifting from 'sustainability' to regeneration." *Building Research & Information,* 35(6), 674-680.

Reed, R., Bilos, A., Wilkinson, S. and Schulte, K. (2009). "International comparison of sustainable rating tools." *J. Sustainable Real Estate*, 1(1), 1–22.

Reijnders, L. and van Roekel, A. (1999). "Comprehensiveness and adequacy of tools for the environmental improvement of buildings." *J Clean Prod*, 7(3), 221–225.

Rogers, E.M. (2003). *Diffusion of Innovations, 5th ed*. Free Press, Simon & Schuster, New York, NY.

Rumsey, P. and McLellan, J.F. (2005). "The green edge—the green imperative." *Environmental Design and Construction,* 55-56.

Saunders, L.W., McCoy, A.P., Kleiner, B.M., Lingard, H., Cooke, T., Mills, T., Blismas, N., and Wakefield, R. (2016)," International benchmarking for performance improvement in construction safety and health", Benchmarking: An International Journal, 23, 4: 916 - 936

Schendler, A. and Udall, R. (2005). "LEED is Broken; Let's Fix It." *Grist Environmental News & Commentary*.

Scheuer, C.W. and Keoleian, A. (2002). "Evaluation of LEED Using Life Cycle Assessment Methods." National Institute of Standard and Technologies, NIST GCR 02-836, Gaithersburg, MD.

Sev, A. (2009). “How can the construction industry contribute to sustainable development? A conceptual framework.” *Sustainable Dev*. 173(3), 161-173.
Sev, A. (2011). “A comparative analysis of building environmental assessment tools and suggestions for regional adaptations.” *Civ. Eng. Environ. Sys*. 28(3), 231-245.
Sinou, M. and Kyvelou, S. (2006). “Present and future of building performance assessment tools.’ *International Journal of Management of Environmental Quality*, **17**(5), 570-586.

Slaughter, E.S. (1998). “Models of construction innovation,” *J. Constr. Engrg. And Mgmt.*, 124(3), 226-231.

Slaughter, E. S. (1993a). “Builders as sources of construction innovation.” *J. Constr. Engrg. and Mgmt*., 119(3), 532-549.

Slaughter, E. S. (1993b). “Innovation and learning during implementation: a comparison of user and manufacturer innovations.” *Res. Policy*, 22, 81-95.

Tatum, C.B. (1984). “What prompts construction innovation?” *J. Constr. Engrg. and Mgmt*., 110(3), 311-323.

Tatum, C.B. (1986). “Potential mechanisms for construction innovation.” *J. Constr. Engrg. and Mgmt.*, 112(2), 178-191.

Tatum, C.B. (1987). “Processes of innovation in construction firms.” *J. Constr. Engrg. and Mgmt*., 113(4), 648-663.

Taylor, J., Dossick, C., and Garvin, M.J. (2011). “Meeting the Burden of Proof with Case-Study Research.” *Journal of Construction Engineering and Management,* 137(4), 303-311.
Todd, J.A., Crawley, D., Geissler, S., and Lindsey, G. (2001). “Comparative assessment of environmental performance tools and the role of the Green Building Challenge.” *Building Research and Information*, 29(5), 324-335.

Toole, T.M. (1994). *Task and environmental uncertainty and adoption of technological innovations by home builders*. Doctoral dissertation, Massachusetts Institute of Technology, Cambridge, MA.

Toole, T.M. (1998). “Uncertainty and homebuilders’ adoption of technological innovations.” *J. Constr. Engrg. and Mgmt*., 124(4), 323-332.

Toole, T.M., and Tonyan, T.D. (1992). “The adoption of innovative building systems: A case study.” *Build. Res. J*., 1(1), 21-26.

USGBC - US Green Building Council. (2011). “Pilot Credit Library Summary.” USGBC, April 19.

USGBC. (2013). Become a Greenbuild Exhibitor, website. http://www.greenbuildexpo.org/expo/interested-in-exhibiting/become-an-exhibitor.aspx. Accessed on June 4, 2-13.

USGBC. (2013). *Reference Guide for Building Design + Construction, LEED Version 4.0*. US Green Building Council, Washington, DC. (updated July 1, 2014).

USGBC. (2015). “Pilot Credit: Prevention through Design (PtD).” < http://www.usgbc.org/credits/preventionthroughdesign>

Ventre, F.T. (1980). “On the blackness of kettles: Inter-industry comparisons in rates of technological innovations.” *Policy Science*, 11, 309-328.

Wadsworth, Y. (2001). “The Mirror, the Magnifying Glass, the Compass, and the Map: Facilitating Participatory Action Research,” in Reason, P. and Bradbury, H., eds., *Handbook of Action Research.* Sage, New York, NY.

Work Cover New South Wales (NSW). (2001). “CHAIR: Safety in Design Tool.” < http://www.workcover.nsw.gov.au/formspublications/publications/Documents/chair_safety_in_design_tool_0976.pdf> (June 10, 2013).

Xiaoping, M., Huimin, L., and Qiming, L. (2009). “A comparison study of mainstream sustainable/green building rating tools in the world.” *Proceedings, International Conference on Management and Service Science (MASS 2009),* Wuhan/Beijing, China, Sept. 20–22. doi:10.1109/ICMSS.2009.5303546.