IMPACTS OF CONSTRUCTION RISKS ON COSTS IN LEED-CERTIFIED PROJECTS

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ABSTRACT
Construction according to green principles rather than traditional methods poses a new set of risks to project participants. These risks should be appropriately identified and managed in order to prevent cost overruns. This study aims to identify construction risks and their cost impacts in LEED-certified projects. For this purpose, thirteen risks were identified based on a literature survey and were categorized under four groups of issues: (i) consultant, contractor and subcontractor, (ii) material, product and process, (iii) legal, regulatory and contractual, and (iv) financial and economic. A survey was then administered to green building design and construction practitioners in the U.S. to assess the likelihood of occurrence of these risks and their respective impacts on project cost. According to the survey results, the risks associated with consultant, contractor and subcontractor issues have the highest expected impact on costs. The top five risk factors were determined as (1) contractors and subcontractors agreeing to standards that are not within their expertise and competence, (2) high cost of certification, (3) lack of expertise in new products/technologies, (4) doubts about the long-term viability and performance of new and untested products, materials and technologies, and (5) inadequate definition of project parties' contractual roles and responsibilities. Mitigating the cost impact of risks is of great value to owners and designers and contractors. Recognizing the risks associated with LEED-certified projects and their cost impacts can be of benefit to all practitioners.

KEYWORDS:
green construction, LEED certification, risk, cost, green risk management

1. INTRODUCTION
According to the U.S. Department of Energy (2013), buildings produced 40% of carbon emissions in 2009, and the building sector alone accounted for 7% of the global primary energy consumption in 2010 in the U.S. In OECD (Organization for Economic Cooperation

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and Development) countries and Europe, buildings use 25-40% and 40-45% of the total energy, respectively (United Nations Environment Program, 2007). Construction activities are responsible for significant environmental impacts worldwide. It is also evident that the consumption of energy continues throughout the life cycle of all buildings.

Economic development depends on the state of the infrastructure and all constructed facilities in a nation. Since construction is essential in meeting demand for infrastructure and for residential, non-residential and industrial facilities, it becomes important to use limited resources efficiently and to minimize any negative consequences on the environment. As a result, interest in sustainable and environmentally focused design and construction is growing; therefore, the green building concept has gained recognition and certification systems are now routinely used as assessment tools in most countries.

Leadership in Energy and Environmental Design (LEED) is one of the most frequently used systems for the recognition of "green" buildings. According to the U.S. Green Building Council's public project directory (2015), there are 80,279 registered or certified LEED projects worldwide and 60,592 of them are located in the U.S. Green building construction processes involve specific procedures, which require new risk management approaches in addition to traditional ones. The diverse nature of green construction requires that all contractors involved with a project work together (Liming, 2011). It is critical for all parties to understand the processes implied in green building construction contracts (Spencer, 2010).

Environmentally focused design and construction are either incentivized or mandated by many federal, state and local incentives in the U.S. (Anderson et al., 2010). Green building means and methods are becoming contract requirements and the parties involved in green projects are subjected to risks that they did not encounter before (Coglianese, 2009). The potential for unexpected risks can result in undesired problems that can lead to failures in achieving objectives. Despite its environmental and long-term financial benefits, building green rather than traditional construction is challenging most of the time. Understanding the special risks of green construction is essential, as these issues directly affect project cost. Higher upfront costs combined with the additional cost of risks related to green construction material, procedures and technologies require close monitoring and adequate experienced supervision. According to Tollin (2011), the investment premium varies from less than 2% to more than 10% in green buildings when compared to traditional buildings. Similar amounts are also reported by several researchers and professionals, such as Robichaud and Anantatmula (2011), Shrestha and Pushpala, (2012), Alan Matkins/CTG/Green Building Insider (2010), and Kats et al. (2003). These extra costs may constitute a serious barrier to green building investment decisions. This barrier can be removed if extra costs are eliminated or at least minimized.

This study aims to identify the risks incurred in LEED-certified building projects in the U.S. and their expected cost impacts. Based on a literature survey, thirteen likely risks are recorded. A survey is administered to professionals involved in green building design and construction to assess the likelihood of occurrence of each of these thirteen risks and their respective impacts on project cost. Expected cost impacts are calculated by combining the likelihood of occurrence and cost impact responses. The first objective of the study is to determine the perception of practitioners relative to green risks. As for the second objective, it involves understanding the expected impact of individual risks on project cost. The aim is to identify the potentially costly risks and to allocate these risks such that the project is completed within budget.

2. RISKS IN GREEN BUILDING DESIGN, CONSTRUCTION, AND OPERATION

The growing recognition of green building construction requires a comprehensive analysis of the risks related to certification. Managing the liability of risks is important in achieving sustainability goals, allocating budgets, and targeting certification levels. These risks can be associated with a particular design or construction and operational requirements that are mandated by certification systems. With its movement into the mainstream of construction in the U.S., green certification is either demanded by owners, or required/incentivized by government (Coglianese, 2009). For example, in Cincinnati, 100% tax abatement is applicable for 15 years for new residential construction, and 10 years for renovation (U.S. Department of Energy, 2014a). Another incentive program was initiated in Washington D.C. that requires achievement of certification through LEED NC and LEED CS in new construction and major renovation of privately-owned non-residential buildings over 50,000 square feet starting in 2012 (U.S. Department of Energy, 2014b).

In addition to incentive programs, several drivers such as market demand and environmental concerns encourage interest in sustainable construction. Green building investments have become attractive because of their numerous economic and environmental benefits. However, there are several barriers to becoming green such as lack of understanding of sustainability, possibility of cost overruns, and perceived actual upfront costs (Kang et al., 2013). With green risks inherent in projects, some of the requirements of LEED certification present different challenges when compared with design, construction and operation of traditional buildings. A large number of research studies can be found in the literature about traditional construction risks (e.g., Kangari, 1995, Assaf et al. 1995, Hastak and Shaked 2000).

3. RESEARCH METHODOLOGY

A comprehensive literature review was performed to identify the risks that are specific to green projects. Several researchers reported and addressed risks and barriers in sustainable construction. Tollin (2011) discussed litigation risks associated with design, construction, ownership, and operation. Concerns about lack of information and expertise, sustainable material supply chain, responsibilities of project participants, possible additional costs related to green construction and certification were identified as major problems in green building projects (Häkkinen and Belloni 2011, Jackson 2009, Zou and Couani 2012, Li et al 2011, Máté 2007, and Qian 2012). In a series of four interactive forums attended by construction industry executives, Marsh (2009) highlighted five risk categories on the basis of potential cost impact and likelihood of occurrence, namely (i) financial, (ii) standard of care/legal, (iii) performance, (iv) consultants/sub-consultants and subcontractors, and (v) regulatory. These studies and many more papers and reports were systematically reviewed and the most mentioned risk factors were identified. Thirteen risk factors stood out and were used in this study. As seen in Table 1, they were consolidated under four categories: (1) consultant, contractor and subcontractor issues (CCSI), (2) material, product and process issues (MPPI), (3) legal, regulatory and contractual issues (LRCI), and (4) financial, cost and economic issues (FCEI).

A questionnaire was prepared and respondents were asked to estimate the likelihood of occurrence of the thirteen factors listed in Table 1 and their expected impacts on total project cost. The names and email addresses of the potential respondents were obtained from the website of United States Green Building Council (USGBC) because the survey was designed to seek information from professionals who are familiar with the LEED certification system.

The data acquired from the survey were interpreted in three steps. In the first step, the perception of the respondents about the likelihood of occurrence related to each risk factor was analyzed. The responses were designated on a scale of 1-5, where 1 means extremely low, 2 low, 3 moderate, 4 high, and 5 extremely high likelihood of occurrence. The risk factors were ranked by calculating the average values of their likelihood of occurrence. Since these values indicate the probability of occurrence of each risk, they were normalized between 0 -1 (αij). This analysis aims to understand how respondents prioritize potential risk factors.

In the second step, the normalized likelihood of occurrence of risk (αij) was multiplied by the impact value of risk i provided by the n respondents (βij) using Eq. 1, hence getting the average expected cost impacts of risks (Cij). This step aims to understand the respondents' expectations about how risks influence total project cost.

$$C_{ij} = \alpha_{ij} * \beta_{ij} \quad \text{Eq. 1}$$

where:
i = Risk category (i =1, …., 4)
j = Risk ID (j = 1, …, 13)
α_{ij} = Normalized average likelihood of occurrence of risk *j* in risk category *i*
β_{ij} = Average cost impact of risk *j* in risk category *i*
C_{ij} = Average expected impact on cost of risk *j* in risk category *i*

Finally in the third step, the weighted average expected impact on cost for each category (C_i) is calculated using Eq. 2. A category-based risk assessment is made to understand the risk groups on which professionals are suggested to focus on to prevent cost overruns in green building projects.

$$C_i = \frac{\sum_{j=1}^{n}(\alpha_{ij} \times \beta_{ij})}{\sum_{j=1}^{n} \alpha_{ij}} \quad \text{Eq. 2}$$

4. CATEGORIES OF GREEN RISK FACTORS

In this section, the backgrounds of each risk factor are presented to provide a better understanding of why these factors are included in the survey.

4.1. Consultant, Contractor and Subcontractor Issues (CCSI)

This section involves issues related to the experience and qualifications of the consultants, contractors and subcontractors involved in green design and construction, and their compulsion to build to green standards even if they lack the necessary expertise and competence. They are briefly discussed in the following subsections.

4.1.1. CCSI-1: Lack of green design/construction experience and qualification

Some of the processes involved in green construction projects have only slight differences from the processes in traditional projects, while some of them can be completely different. It is important to learn how to perform different and new tasks in green projects even with experienced personnel (Liming, 2011). Many new risks can be encountered when building professionals are not experienced or qualified enough to have a good understanding of contract

TABLE 1. Risk factors and categories

Risk Category (i)	Risk ID (j)	Risk Description
Consultant, contractor and subcontractor issues (CCSI)	CCSI-1	Lack of green construction experience and qualification
	CCSI-2	Contractors and subcontractors agreeing to standards that are not within their expertise and competence
Material, product, and process issues (MPPI)	MPPI-1	Doubts about long-term viability and performance of new and untested products, materials and technologies
	MPPI-2	Faulty performance of HVAC/electrical/plumbing systems and alternative water systems/alternative power generating equipment
	MPPI-3	Failure to receive materials/products in a timely fashion causing delays
	MPPI-4	Lack of expertise in new products/technologies
Legal, regulatory and contractual issues (LRCI)	LRCI-1	Inadequate definition of project parties' contractual roles and responsibilities
	LRCI-2	Inconsistencies between formal regulations (e.g., existing federal, state and local legislation) and LEED
	LRCI-3	Concern that project owners and participants lose potential benefits because of the stringent standards of LEED
Financial, cost and economic issues (FCEI)	FCEI-1	High cost of certification process
	FCEI-2	Scarcity of insurance solutions
	FCEI-3	Rental loss due to delay related to green construction procedures and conditions
	FCEI-4	Failure to use financial incentives (tax/loan discounts, low financing rates) because of delays or lower certification levels than expected

requirements related to green construction and LEED requirements. An inexperienced design team can waste time in researching appropriate energy and water efficient technologies, adding to the cost of design, and sometimes generating less than ideal solutions (KEMA, 2003). The lack of appropriate qualifications and experience on the part of the contractor can result in the use of substandard workmanship and can result in construction defects that can in turn cause numerous claims (Marsh, 2008). The experience and qualification gap in building green can be closed by employing designers who have accumulated green design knowledge from their experiences in past projects, and contractors who employ specialty trade workers who are familiar with green construction. For example, according to Liming (2011), specialty trade workers may require training in installing energy and water efficient appliances or using new techniques. Also, Durmus-Pedini and Ashuri (2010) state that hiring professionals experienced in green buildings and engaging LEED consultants can help to minimize the impacts of such a risk. The performance of project participants can be enhanced by providing training about sustainable materials, means and methods.

4.1.2. CCSI-2: Contractors and subcontractors agreeing to standards that are not within their expertise and competence

A contractor's subcontractors may be involved in special activities that are required for LEED certification. All standards and procedures relative to these activities have to be discussed and agreed upon by the contractor and its subcontractors. Each subcontractor is expected to be sufficiently knowledgeable about special standards and procedures. It is essential that subcontractors do not agree to work with a standard or procedure without prior sufficient expertise on it. Such an action can compromise the expected budget or project duration. Additionally, the contractor may be forced to replace the incompetent subcontractor with another one, facing the challenge of finding a knowledgeable subcontractor at short notice, a costly endeavor.

4.2. Material, Product, and Process Issues (MPPI)

This section involves issues related to the performance and delivery schedule of green materials, the use of green products, and the implementation of green processes. For example, the performance of energy-saving electrical, HVAC and plumbing systems fall in this category. This section also covers the lack of information about new and untested green materials, products, and processes. These issues are briefly discussed in the following subsections.

4.2.1. MPPI-1: Doubts about long-term viability and performance of new and untested products, materials and technologies

Since some green building products have been developed only recently, they have not been in operation long enough for a thorough assessment. As a result, according to Rabkin (2013), the new and untested materials and products used in green building projects may be less durable than traditional materials. Because buildings are designed for a life of 50 years or more, Latham and Watkins (2010) suggest that project participants should not neglect considering the uncertainties related to the performance of new and untested products, materials and technologies. The use of green materials and technologies can give rise to liabilities due to (i) contractor inexperience with installation, (ii) lack of long term evaluation of green materials, (iii) lack of understanding of how new building materials may impact existing traditional building systems, or (iv) warranties provided unintentionally about the durability or effectiveness of unproven materials or techniques (British Columbia Contractors Association, 2011). Therefore, one can anticipate potential claims if recently introduced green materials are used. The case of Chesapeake Bay Foundation, Inc. et al. v. Weyerhaeuser Company is a good example of a lawsuit related to the use of novel green materials. In this case, the design of the project required the use of recycled and environmentally friendly construction materials. Glue-laminated wood members were considered for use in some portions of the building's structural system including its roof truss system, several columns and beams. Instead of the original sealant, a green substitute was used, which consisted of wood waste material. After the project was completed, water intrusion caused rotting in the truss system, causing substantial damage (Buttigieg, 2014).

4.2.2. MPPI-2: Faulty performance of HVAC/electrical/plumbing systems and alternative water systems/alternative power generating equipment

Utilizing advanced systems in green buildings contributes to energy efficiency and to the minimization of negative environmental impacts. Alternatives such as occupant monitoring systems, renewable energy technologies, replacement of plumbing and power generating systems, waterless urinals, and sensor-activated faucets and electrical systems improve energy and water efficiency in operating buildings. However, efforts to increase energy efficiency may lead to additional construction and operation costs and may cause dissatisfaction on the part of users. Additionally, problems may arise if developers misrepresent the facts when promoting a building's LEED certification or performance expectations to prospective owners, tenants, or both (Feichter and Kwiatkowski, 2012). For example, in the case of Steven Gidumal et al. v. Site 16/17 Development LLC in New York City, the project developer was sued by the owner of a condominium unit for damages caused by the building's green heating system failing to provide sufficient heat to their unit along with a variety of other alleged green construction defects (Del Percio, 2010).

4.2.3. MPPI-3: Failure to have materials/products in a timely fashion and causing delays

The timely availability of green materials and products contribute to achieving sustainability objectives on schedule. For example, Griffin et al. (2010) report that finding adequate amounts of certified sustainably harvested wood in Oregon is difficult, and according to Nutter (2012), the availability of fly ash is unpredictable. Such uncertainties inevitably cause delivery delays that often translate into project delays. Also, LEED encourages purchasing materials from local suppliers to earn relevant credits by minimizing energy consumption during transportation. However, the availability of locally produced materials may not always be possible due to the limited capacity of local manufacturers.

4.2.4. MPPI-4: Lack of expertise in new products/technologies

In addition to timely availability and delivery of materials and products, lack of professionals with sufficient expertise in green materials and technologies is another project risk. According to Ofori-Boadu et al. (2012), implementing new or untested green technologies and products can be challenging particularly if the professionals using them have limited knowledge about them. The British Columbia Contractors Association (2011) states that lack of expertise in green products/technologies is one of the reasons that cause liabilities in green building projects.

4.3. Legal, Regulatory and Contractual Issues (LRCI)

This section involves issues related to the roles and responsibilities of project participants as defined in a contract, inconsistencies between local regulations and LEED requirements, and the likelihood of loss caused by green alternatives. They are briefly discussed in the following subsections.

4.3.1. LRCI-1: Inadequate definition of project parties' contractual roles and responsibilities

Contract documents must address each party's role and responsibility in the project particularly related to procedures in LEED certification. Inadequate definition of contractual roles and responsibilities can result in confusion and may create reluctance to sharing the associated risks. It is important to explicitly describe the parties' roles and responsibilities related to "sustainability" efforts in a project. The case of Bain vs. Vertex Architects involves a small residential project that aimed to attain LEED certification. Homeowner Bain sued Vertex Architects for breach of contract for failing to diligently pursue and obtain certification from USGBC (British Columbia Construction Association, 2011). The case of Southern Builders Inc. vs. Shaw Development LLC was also designed to obtain LEED certification, but the contract did not indicate the responsible party for obtaining the certification (Spencer, 2010). Such claims can be prevented if the parties' duties relative to green certification efforts are clearly specified in the contract.

4.3.2. LRCI-2: Inconsistencies between formal regulations (e.g., existing federal, state and local legislation) and LEED

LEED is a voluntarily certification system. It has not been developed as a system that requires compliance through regulations (Prum et al., 2012). However, cities, counties, and states have begun to develop their own green regulations particularly to reduce energy consumption in new construction (Longinotti et al., 2012). According to Rabkin (2009), the parties to a green project are expected to review existing federal, state and local legislation in order to eliminate any inconsistencies between formal regulations and LEED requirements. With the increasing awareness of sustainability and market-driven factors, developers are often encouraged to seek LEED certification for new construction while implementing federal, state, county and local regulations (Tollin, 2011). While meeting LEED's credit requirements, developers, designers and contractors should comply with existing codes and regulations.

4.3.3. LRCI-3: Concern that project owners and participants lose potential benefits because of the stringent standards of LEED

Compliance with LEED requirements is essential for certification, but green building standards have been evolving over the years as LEED certification requirements have been revised several times by USGBC, becoming more stringent at every iteration. Given these stringent requirements, green building delivery processes usually require more design iterations, advanced simulation analysis, and higher construction standards (Pulaski et al., 2006), and include commissioning, energy modeling, and sustainable design and engineering approaches. Meeting all these requirements and using sustainable materials and technologies to improve energy efficiency and water consumption requires extra research and significant time. All these efforts have cost implications, creating concerns on the part of project participants about the potential benefits of certification. An analysis of life-cycle costs is appropriate to decide if the benefits of implementing LEED outweigh the cost and schedule implications of sustainable practices.

4.4. Financial, Cost and Economic Issues (FCEI)

This section involves issues related to the cost of the certification process, insurance alternatives, the rental/resale value of green buildings, and the financial impacts of not being able to achieve certification goals. They are briefly discussed in the following subsections.

4.4.1. FCEI-1: High cost of certification process

The cost of the application process for LEED certification may be significant and constitutes a new financial burden. The cost of documentation and registration for certification varies from project to project depending on several factors such as project type, size, outsourcing for LEED-specific services, the commissioning process, and design properties (U.S. Green Building Council 2014). In a survey administered by Bayraktar et al. (2011), certification fees paid to USGBC and personnel expenses for handling paperwork were identified as an important concern in LEED-certified projects in the U.S. An analysis of the costs incurred in a group of LEED-certified buildings in New York City indicated that the median cost of LEED documentation was between $0.30 and $1.55 per square foot for commissioning (Urban Green Council, 2009), while BuildingGreen.Com (2010) and Kaplow (2010) report that registration and certification fees are expected to be roughly $0.03-$0.05 per square foot depending on the properties of the building. Mapp et al. (2011) studied the costs of LEED-certified and non-LEED-certified bank buildings and found that the additional direct costs associated with LEED certification was less than 2% of the total project cost. While some of this extra cost is incurred because of extra design efforts, most of it is incurred because of LEED documentation, commissioning, and USGBC fees. Contract documents must clearly state the party responsible for the LEED certification process and the associated expenses and fees.

4.4.2. FCEI-2: Scarcity of insurance solutions

Green building risks are recognized by owners, designers and contractors as the sector expands. As a result, the insurance market is aligning its policies with respect to green coverage and pricing (Marsh, 2009). A better understanding of the green building sector leads insurance companies to the creation of new insurance products and solutions in the form of coverage enhancements, policy credits, and loss prevention services that emphasize the differences between green building design and conventional design (Marsh, 2008). As sustainable buildings encompass specific risks, insurance companies offer appropriate insurance strategies to address the new risks involved in the construction and operation of such structures. Advanced insurance products have proliferated as cases of litigation arise between contractors, developers and owners. For example, an insurance company offers coverage named "indoor environmental coverage" and "reputation coverage" for LEED-certified buildings (BuildingGreen.Com, 2014). "Indoor environmental coverage" deals with claims of bodily injury occurring from substances or odors originating from equipment used to improve air or water quality. "Reputation coverage" covers costs related to the management of reputational crises that result from adverse publicity if a building fails to achieve certification under LEED. Another company advertises itself as the first company offering green insurance in the U.S. by providing property and casualty coverage for green construction projects (Fireman's Fund, 2014).

4.4.3. FCEI-3: Rental loss due to delay related to green construction procedures and conditions

Using environment-friendly materials, applying sustainable methods, and going through LEED-certification procedures pose their own set of risks and challenges that can affect project schedule. Fulfillment of certification procedures takes time and can cause delays. For example, the commissioning of a building, which involves testing of the heating, ventilating and air-conditioning systems, plumbing and electrical systems, and other components is a prerequisite for certification (Nutter, 2012). Commissioning is a process that verifies that a building performs in compliance with the design intents and the owner's requirements (Robertson, 2006). As most of the tests performed in the commissioning process are complicated and need considerable time to perform, owners and developers can face late project delivery resulting in late rental income. Hwang and Leong (2013) conducted a survey to compare delays and their causes in traditional and green projects in Singapore and found that while traditional projects were delayed by an average of 16%, green projects fell 32% behind schedule. Several insurance companies offer endorsements related to green building risks including delays due to use of green building methods and supplies. These policies broaden coverage to include loss of net rental income from signed leases as a result of the added delay in construction to meet green standards (HM, 2015). Green coverage extensions are introduced in policies to cover additional construction expenses, additional soft costs, loss of rental income, and loss of net income attributed to an extended delay due to procedures and processes required to retain green certification (Harrington, 2009). It is important to have appropriate contract language that addresses the responsibilities for such delays.

4.4.4. FCEI-4: Failure to use financial incentives (tax/loan discounts, low financing rates) because of delays or lower certification levels than expected

Various financial schemes such as tax discounts, favorable tax rates, utility discounts, loan discounts, and favorable loan rates are available to owners and developers for green building projects (Li et al., 2011; Ozog, 2010). Failure to achieve the expected level of LEED certification prevents the building owner from taking advantage of financial incentives in green building projects. The responsibility for failing to achieve the expected level of certification needs to be explicitly specified in the contract. Similarly, the responsibility for any loss of financial incentive caused by delays that are related to green implementations should also be addressed in the contract documents. Southern Builders Inc. vs. Shaw Development LLC was the first green construction lawsuit in the U.S. where the developer claimed a loss in tax credits under a state-run program due to the contractor's failure to achieve certification in a timely fashion (Spencer, 2010).

5. SURVEY RESULTS AND ANALYSIS

The respondents of the survey consisted of professionals experienced in LEED-certified projects. A total of 402 responses were received from respondents whose names and email addresses were acquired from the 10,704 companies based in the U.S. that are listed in the directory of the U.S. Green Building Council (2015). The rate of response of 4% is low but acceptable in this sort of exploratory study, particularly since it was possible to conduct statistical analysis and develop reliable statistical inference using the relatively large number of responses received. As discussed in Section 3, first the likelihood of occurrence of each risk factor, and then the impact of each risk factor on total project cost were calculated. The average expected impact of each risk factor on project cost was obtained by multiplying these two values using Eq. 1. Each risk factor has a different impact on cost. Finally, the weighted average expected impact of each risk category on cost was calculated using Eq. 2 to identify respondents' rankings relative to the four categories. The results of the analysis are shown in Table 2. These findings are discussed in the following paragraphs.

According to the information presented in Table 2, the top five risk factors that have the highest average likelihood of occurrence (>60%) are (1) consultants, contractors and subcontractors agreeing to standards that are not within their expertise and competence (CCSI-2), (2) high cost of certification process (FCEI-1), (3) lack of expertise in new products/technologies (MPPI-4), (4) doubts about long-term viability and performance of new and untested products, materials and technologies (MPPI-1), and (5) lack of green construction experience and qualification (CCSI-1).

The top five risk factors that have the greatest impact on total project cost (>3.00) are (1) faulty performance of HVAC/electrical/plumbing systems and alternative water systems/ alternative power generating equipment (MPPI-2), (2) consultants, contractors and subcontractors agreeing to standards that are not within their expertise and competence (CCSI-2), (3) doubts about long-term viability and performance of new and untested products, materials and technologies (MPPI-1), (4) high cost of certification process (FCEI-1), and (5) lack of expertise in new products/technologies (MPPI-4).

There seems to be quite an overlap between these two rankings (i.e., likelihood of occurrence and impact on cost) with four out of the five risk factors, namely CCSI-2, FCEI-1, MMPI-4, and MMPI-1 appearing in both rankings.

The risk categories are ranked as (1) consultant, contractor and subcontractor issues (CCSI), (2) material, product and process issues (MPPI), (3) legal and contractual issues (LRCI), and (4) financial, cost and economic issues (FCEI).

TABLE 2. Average response values of all risk categories

Risk Category (i)	Risk ID (j)	Average Likelihood of Occurrence (α_{ij})	Average Impact on Total Project Cost (β_{ij})	Average Expected Impact on Cost (C_{ij})	Number of responses	Weighted Average Expected Impact on Cost (C_i)
Consultant, contractor, and subcontractor issues (CCSI)	CCSI-1	0.61	2.92	1.95	402	3.03
	CCSI-2	0.66	3.12	2.21	401	
Material, product, and process issues (MPPI)	MPPI-1	0.63	3.09	2.01	401	3.01
	MPPI-2	0.52	3.13	1.75	402	
	MPPI-3	0.53	2.78	1.62	398	
	MPPI-4	0.65	3.02	2.08	402	
Legal, regulatory and contractual issues (LRCI)	LRCI-1	0.59	2.81	1.79	400	2.61
	LRCI-2	0.59	2.64	1.73	401	
	LRCI-3	0.48	2.34	1.35	399	
Financial, cost and economic issues (FCEI)	FCEI-1	0.66	3.04	2.19	400	2.57
	FCEI-2	0.52	2.46	1.42	388	
	FCEI-3	0.34	1.77	0.73	397	
	FCEI-4	0.50	2.62	1.47	400	

5.1. Consultant, Contractor and Subcontractor Issues (CCSI)

According to Table 2, this risk category that highlights the challenges related to the characteristics of the project participants has the largest impact on project cost (3.03). Participants' knowledge and competence in the specialized tasks of green building design and construction are indeed of critical importance. *"The lack of green experience and qualifications"* (CCSI-1) can result in failure to obtain the anticipated LEED credits, and failure to achieve the required project objectives, including schedule, quality, and cost. This finding is supported by a study that looked into the cost of building green public schools, research laboratories, public libraries, and multi-family affordable housing in California (KEMA, 2003), which states that green experience and qualifications is one of the top five barriers controlling green construction cost. Also, after analyzing the key processes in a group of green hospitals, Enache-Pommer and Horman (2009) found that participant expertise is one of the most important attributes in sustainable delivery. Such an outcome was also reported by Johnson (2005) based on a survey. Therefore, as the U.S. Green Building Council (2008) states, reliability and availability of experienced service providers, contractors, subcontractors, and commissioning agents are critical for the success of sustainable projects.

Hiring temporary staff for services that require special experience and expert opinion is common in construction projects. Roles and legal responsibilities are described in contracts. As building green requires the use of sustainable materials and techniques, a mutual understanding of certification requirements ensures that project participants have the required expertise and competence. In sum, the overall management and supervision of a green project has to be made by professionals with a thorough understanding of the LEED credit system (Marsh, 2009). The training of the personnel has to cover not only green technologies but also the LEED documentation process as well as quality assurance and quality control throughout the project.

5.2. Material, Product and Process Issues (MPPI)

Sustainable implementation in green construction projects inevitably involves the use of new materials, products and processes. Compared to their traditional counterparts, most green materials, products and processes have been around for only a limited time and have gone through only limited testing. Even though they need to use green materials, products and processes in green design and construction, professionals are generally not fully familiar with new and untested green materials, products and processes. Based on respondents' feedback, the risk category "material, product and process issues" is ranked as the second highest with a 3.01 weighted expected impact on cost. In typical construction projects, material-related risks involve generally shortage, changes, and slow delivery (Assaf et al. 1995, Hastak and Shaked 2000). In addition, the risks involved in materials, products and processes used in green buildings include durability issues, doubts about quality, and performance concerns.

According to the survey results presented in Tables 1 And 2, *"lack of expertise in new products and technologies"* (MPPI-4) has the highest likelihood of occurrence (0.65) among the four risk factors in this category. It also has the highest impact on project cost (2.08). As the demand for sustainable construction increases, engineers, architects and consultants should improve their familiarity with such products and technologies. Klotz and Horman (2010) claim that sustainability training for on-site workers is critical in sustainable construction. Lapinski et al. (2006) suggest educating the project team during design and construction to ensure sustainable goals on site.

"Lack of expertise in new products and technologies" (MPPI-4) is closely followed by *"doubts about long-term viability and performance of new and untested products, materials, and technologies"* (MPPI-1) with an average likelihood of occurrence of 0.63 and an impact on cost of 2.01. Many of the products, materials, and technologies that are used in green building projects are quite new. More time may be needed to remove suspicions about their performance, durability, and quality. This can be achieved by manufacturers and practitioners recording the performance of green products, materials, and technologies systematically in a database. According to a survey administered by Häkkinen and Belloni (2011), 67% of their respondents believed that manufacturers do not put enough effort to improving the performance of sustainable products.

"Failure to receive materials/products in a timely fashion" (MPPI-3) and *"faulty performance of HVAC/electrical/plumbing systems and alternative water systems/alternative power generating equipment"* (MPPI-2) are ranked third and fourth with very close likelihoods of occurrence of 0.53 and 0.52, respectively. Receiving materials on time (MPPI-3) has always been critical in most construction projects, regardless of being green or not (El-Razek et al. 2008, Mahamid et al. 2012, González et al. 2014), but the procurement of sustainable materials and products

might pose additional uncertainties related to availability (U.S. Green Building Council, 2008). Griffin et al. (2010) analyzed the use of sustainable materials in Oregon and found that availability of green structural materials is frequently reported by practitioners as a barrier to the implementation of green practices. Also, shortages in key sustainable materials can be one of the causes of delays. For example, in 2005, a general shortage was reported of fly ash, a waste product used as an additive in concrete, which caused delays in projects (Nutter, 2012). Additionally, sustainable materials may have to be manufactured upon order or may involve special manufacturing standards. The availability and timely delivery of such materials was ranked in Hwang and Leong's (2013) survey second in green building projects but third in traditional building projects. Also, one of the credit requirements in LEED is related to the distance of the material supply source to the project site. Consequently, the risk of delivery delay can increase if the local supplier does not have enough of the necessary material (Nutter, 2012).

Performance-related liability issues are rising as a consequence of the increase in green building practices (Choi, 2009). *"Faulty performance of HVAC/electrical/plumbing systems and alternative water systems/alternative power generating equipment"* (MPPI-2) is closely related to energy efficiency, water efficiency, and indoor air quality in buildings, which are often the major focus in green building design and construction. Typical systems such as carbon dioxide monitors, variable-air-volume systems, occupancy sensors, high-efficiency cooling systems, high-efficiency condensing boilers, as well as newer technologies like solar water and space heating systems, chilled beams for radiant cooling, under-floor air diffusers, and high levels of air filtration are frequently used in green buildings to meet LEED requirements (Yudelson, 2006). The performance of advanced and complicated HVAC/electrical/plumbing systems can give rise to conflicts between manufacturers, owners, contractors, subcontractors and end users as reported in the case of Steven Gidumal et al. v. Site 16/17 Development LLC case in New York City (Del Percio 2010).

5.3. Legal, Regulatory and Contractual Issues (LCI)

This category received third rank with an expected impact on cost of 2.61. The three risk factors in this category refer to contract language, project-specific standards, and existing public regulations. Among them, *"inadequate definition of project parties' contractual roles and responsibilities"* (LRCI-1) and *"inconsistencies between formal regulations and LEED"* (LRCI-2) shared the same likelihood of occurrence of 0.59. These problems appear to be common as evidenced by the litigation examples provided in the previous section (Rabkin 2009, Spencer 2010, The British Columbia Association 2011). Inadequate legal content is frequently observed in some construction contracts resulting in claims (Vidogah and Ndekugri 1997, Zaghloul and Hartman 2003, Iyer et al. 2008). In green projects, however, additional requirements related to LEED certification and the many steps to achieve green performance objectives require additional attention and effort. For example, the responsibility of achieving credits is distributed among multiple parties in LEED projects (The British Columbia Association, 2011), which means that certification depends on the mutual efforts of all contributing parties. A report prepared by Korkmaz et al. (2010) points out that certification level should be a contractual mandate for all team members.

"Concern that project owners and participants lose potential benefits because of the stringent standards of LEED" (LRCI-3) is third and last in this category with a likelihood of occurrence of 0.48. The construction industry in the U.S. has demonstrated resistance to the introduction of requirements for LEED-certified buildings in the form of stringent energy and water

efficiency standards, highlighting the difficulties in adopting the LEED certification system (The British Columbia Association, 2011).

5.4. Financial, Cost and Economic Issues (FCEI)

As seen in Table 2, this risk category was perceived by the respondents as having the least impact on project cost (2.57). Dealing with risks related to financing is rather common in traditional projects and frequently reported to be critical by many researchers in the literature (e.g., Hastak and Shaked 2000, Fang et al. 2004, and Nielsen 2006). Dealing with risks related to financing in green buildings is no exception (Durmus-Pedini and Ashuri 2010, Anderson et al. 2010). Some of the financial risks encountered in green building projects are associated with LEED certification requirements. Four risk factors are listed in this category and the highest likelihood of occurrence of 0.66 belongs to *"high cost of certification process"* (FCEI-1), which also happens to be the second top risk factor (2.19) impacting project cost among all other factors. Typical LEED-specific processes drive up costs in green projects. For example, certification itself involves extra cost since an architect or engineer needs to be paid for the verification of the components required by the rating system (Tollin 2011). According to Johnson (2005), costs related to certification, documentation, practices, and design may amount to substantial sums. Identifying and properly allocating such risks can prevent costly litigation (Latham and Watkins 2010). The project participant who is responsible for such expenses must be explicitly assigned in the contract documents to avoid any responsibility issues.

The second risk factor is *"scarcity of insurance solutions"* (FCEI-2) with a likelihood of occurrence of 0.52. Going green involves not only conventional construction risks, but also unique green risks. This puts contractors, designers, developers, and owners in search of new insurance tools. Traditional insurance solutions can be inadequate for green building projects (Latham and Watkins 2010). Therefore, several insurance companies have developed coverage for green buildings with specific endorsements. For example, coverage for building commissioning can be provided to ensure that all systems in the building will be tested and will operate at peak performance (Ochenkowski and Schinter 2008). Other examples include coverage of costs related to debris recycling according to LEED criteria (Zurich in North America 2010), indoor environmental coverage that deals with claims of bodily injury occurring from substances or odors originating from equipment used to improve air or water quality (BuildingGreen.Com, 2014), and extra expense coverage, which provides additional funds for extraordinary expenditures (Ochenkowski and Schinter 2008). Advances in construction insurance policies are taking place as green construction evolves. New policies are developed to respond to needs in sustainable projects.

The third and fourth ranked risk factors *"failure to use financial incentives because of delays or lower certification levels than expected"* (FCEI-4) and *"rental loss due to delay related to green construction procedures and conditions"* (FCEI-3) are related to delays caused by green requirements. As developers and owners aim to get their return on their investment as soon as possible, they expect to rent or sell the completed building without delay. The LEED certification requirements can cause delays (Zou and Couani 2012, Anderson et al. 2010), which in turn can cause the loss of tax/loan discounts or low financing rates, and can delay rental income (Casale 2011, Spencer 2010). To overcome or to minimize the effects of these factors on project cost, Lapinski et al. (2006) suggest that understanding the marketing opportunities at the early stages of the project is a desirable risk management strategy.

6. CONCLUSION

Sustainable buildings are certified as "green" using different certification systems. LEED is one of the most widely used programs in the U.S. Green building projects are different from traditional projects because they present different challenges. Inherent risks in sustainable projects can become sources of potential claims and possible disputes during the life cycle of the projects. Therefore, a good understanding of these risks is essential in order not to jeopardize project performance. Risk management in LEED-certified green buildings is of special importance for managing project costs.

The objectives of this study are (1) to determine the perception of practitioners relative to the risks incurred in LEED-certified green building projects in the U.S., and (2) to understand their expected impact on project costs. A survey was administered to professionals experienced in LEED-certified projects in the U.S. The survey listed 13 risk factors grouped under four categories, namely (1) consultant, contractor and subcontractor issues, (2) material, product and process issues, (3) legal, regulatory and contractual issues, and (4) financial, cost and economic issues. 402 responses were received from professionals who work in companies familiar with the LEED certification system. All of the companies involved completed at least one LEED-certified project and are listed in USGBC's database. The respondents provided estimations about likelihood of occurrence and impact on project cost for each risk factor based on their experiences.

The survey results revealed that consultant, contractor and subcontractor issues (CCSI) ranked first out of the four categories, closely followed by material, product and process issues (MPPI). The respondents rated legal, regulatory and contractual issues (LRCI) and financial, cost and economic issues (FCEI) as the third and fourth categories respectively. Looking into the risk factors separately, the top five risk factors were determined as:

(1) Contractors and subcontractors agreeing to standards that are not within their expertise and competence (CCSI-2)
(2) High cost of certification process (FCEI-1)
(3) Lack of expertise in new products/technologies (MPPI-4)
(4) Doubts about long-term viability and performance of new and untested products, materials and technologies (MPPI-1)
(5) Inadequate definition of project parties' contractual roles and responsibilities (LRCI-1)

It is important to recognize the potential risks that have serious cost implications in projects that seek LEED certification, and take appropriate measures to mitigate these risks. Based on the results of this study, the following strategies are suggested for all project participants: (1) employing competent technical personnel with expertise in materials, products, technologies, and processes related to LEED certification; (2) preparing an appropriate budget for expenses related to LEED certification processes; (3) developing contingency plans for materials, products, technologies, and processes that do not result in expected outcomes; and (4) being aware of the allocation of risks in the contractual documents. These recommendations translate into the following practical considerations:

- Owners are expected to set up the construction contract such that the sustainability goals are clearly described, all project participants are aware of their respective responsibilities relative to LEED objectives, and "green" risks are allocated in the most cost-effective way. The scope of damages and the participants bearing them need to be clearly stated in the contract to avoid disagreements. Agreement on responsibilities is essential for successful management.

- Sustainable construction is encouraged by financial incentives such as tax discounts and low-interest financing. Owners must take advantage of these incentives. However, such incentives are strictly dependent on schedules and are not applicable when delays occur. Yet, challenges in the supply chain of green materials/products/ services, the commissioning procedures, the use of special technologies, and inadequate experience in green design/construction can cause delays. To mitigate the effect of such delays, owners can make use of special insurance products that provide appropriate endorsements or new coverage options developed by some of the major insurance companies for green buildings.
- It is suggested that designers employ professionals who have extensive experience with LEED-certified building design, and are knowledgeable enough to make sensitive design decisions pertaining to the selection of sustainable materials and technologies to achieve the desired level of LEED certification. Designers are expected to be familiar with and know how to fulfill the requirements of the stringent standards such as those by ASHRAE, ANSI, or IESNA referred to in LEED guidelines.
- It is suggested that contractors also employ professionals who are familiar with sustainable materials, products, technologies, and methods of construction, and recognize their responsibility in achieving sustainability objectives. Contractors have to meet LEED requirements while complying with other formal industry standards to prevent any inconsistencies.
- Manufacturers have to reassure designers and contractors that their materials and products satisfy green standards while being durable by providing them with test results and relevant evidence to eliminate doubts about new materials and products. Of course, practitioners also need to keep up to date with the latest green materials and methods. The main strategy that can be used to mitigate the qualification gap between green building requirements and the existing capabilities of project participants includes continuous training in sustainability-related issues for owners, designers, consultants, contractors, and subcontractors alike. In addition to appropriate training, experts with sufficient experience can be engaged with sufficient resources to explore, investigate, and experiment with special products and tools.

As a developing concept in the construction industry, sustainability is drawing the attention of owners, practitioners and researchers not only in the U.S. but worldwide. Also, the number of green buildings certified by rating systems is continuously increasing. LEED is recognized as one of the mostly used certification systems in the U.S. and other parts of the world. Analyzing the risks of LEED-certified projects and these risks' impacts on project cost can be of benefit to owners, practitioners and researchers. Even though the number of responses (402) was large enough to make reliable statistical inferences in this study, future research that aims for a larger rate of response from the many companies active in LEED-certified building construction would be most appropriate, especially if the critical risks identified in this study are probed in greater depth.

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