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# Cost premium prediction of certified green buildings: A neural network approach

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ABSTRACT

Built environment has a substantial impact on the economy, society, and the environment. Along with the increasing environmental consideration of the building impacts, the environmental assessment of buildings has gained substantial importance in the construction industry. In this study, an artificial neural network model is built to predict cost premium of LEED certified green buildings based on LEED categories. To verify the viability of the model, multiple regression analysis is used as a benchmarking model. After validating the prediction power of the neural network model, a global sensitivity analysis is utilized to provide a better understanding of possible relationships between input and output variables of the prediction model. Sustainable Sites and Energy & Atmosphere LEED categories were found to have the highest sensitivity in cost premium prediction. In this study, our goal was to reveal the significant relationships between LEED categories and the cost premium, and offer a decision model that can guide owners to estimate cost premiums based on sought LEED credits.



## 1. Introduction

The construction industry has a significant impact on the environment, economy, and society. Buildings are one of the biggest contributors to greenhouse gas emissions; for which they are responsible for 38% of all $CO_2$ emissions [1]. Increased awareness of the enormous ecological footprint of the build environment has substantially increased the importance and popularity of various green building initiatives as a possible solution to remediate the damages incurred on the planet. Many of these initiatives focus on enhancing biodiversity, improving air and water quality, reducing solid waste generation, and conserving natural resources of buildings. These initiatives are changing the construction industry and increasing the share of the green building market significantly [2]. The value the overall green building market is estimated to be $36 billion to $49 billion with an anticipated market value of $96 billion to $140 billion by 2013 [3]. As of September 2009, commercial buildings certified with *The Leadership in Energy and Environmental Design* (LEED) green building rating system in USA reached to the number of 3855 and accounted for 613 million square foot in total [4].

Along with these market values and increasing trend of the green construction practices, the green market has been promoted to bring major improvements through employing green building practices. Primary drivers cited in the literature for green building adoption include minimizing operating and maintenance costs, increasing employee health, productivity, and satisfaction, and improved indoor environment quality [2,5]. For instance, some green buildings were reported to consume 26% less energy and have demonstrated 13% lower maintenance cost when compared to average commercial buildings [6]. These benefits come with a cost, and with lower first-costs that are competitive with conventional buildings, the attractiveness of green buildings will significantly improve [7]. This is especially true, since the construction firms still perceive that green buildings cost significantly more than their conventional counterparts [2]. But, even if the project is finished with a budget comparable to its conventional alternative, certain project costs would still be correlated with specific green strategies. In this paper, we are concerned with identifying the relationship between the cost premium of green buildings and LEED credits utilizing artificial intelligence techniques to aid decision makers in selecting their green strategies.

Few decision models are found in the literature that specifically target green buildings. Castro-Lacouture et al. [8] proposed a mixed integer optimization model that maximizes LEED credits attained while considering design and budget constraints. Wang et al. [9] developed an object-oriented framework that tackles specific problem areas related to green building design optimization. Through their framework, they utilized multi-objective genetic algorithms to explore the trade-off between life-cycle cost and life-cycle environmental impacts in green building design. In another study, Wang et al. [10] developed a methodology to optimize the

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building shapes using genetic algorithms by using life-cycle cost and life-cycle environmental impact as two objective functions for green performance evaluation.

Although no studies have used Artificial Neural Network (ANN) for cost prediction of green buildings, many studies have utilized ANN to predict building costs during pre-design phase of conventional buildings. ANN models were adapted for many reasons; such as learning by example, parallel processing and fast response, tolerance for fault and noisy data, and better classification and prediction capability than traditional statistical methods [11,12]. For instance, Gunaydin and Dogan [13] developed a neural network model for 30 residential building projects to estimate cost per square meters. Kim et al. [14] used three different prediction models; neural network, regression analysis, and case-based reasoning, to predict the cost of 530 buildings in Korea. In another study, Kim et al. [15] provided hybrid models of neural networks and genetic algorithms for preliminary costs estimation of 498 residential buildings. Emsley et al. [16] developed an ANN model to predict building cost by utilizing project strategic variables, site related variables, and design related variables. Attalla and Hegazy [17] used ANN modeling and statistical analysis for determining the cost deviation of the reconstruction project. Apart from ANN, some studies have utilized multiple regression analysis for cost prediction. For instance, Stoy et al. [18] used regression analysis for determination of the cost drivers of the 70 residential building properties. Although there have been many studies predicting building costs by using ANN modeling, none have utilized green building ratings in cost prediction; a research gap that is aimed to be filled by this study.

The purpose of this study is to predict the cost premium of green buildings based on LEED categories. To reach this goal, a relationship between LEED categories and cost premium is investigated. This is accomplished by ANN modeling and verified by traditional statistical approaches. Sensitivity analysis is then carried on to identify critical LEED categories and offer an intelligent tool for decision makers to aid their decisions during the pre-design stage. The rest of the paper is organized as follows. First, a review of green building systems is conducted. Next, green building associated cost studies are reviewed. Next, the ANN design, data collection and preparation, and ANN results are presented. Subsequently, a regression model is conducted and the ANN results are compared with the regression results. Next, sensitivity analysis of the ANN model is provided to assess the effect of input variables on the output variable. Finally, findings are summarized and future work is pointed out.

## 2. Green building rating systems and cost premiums

Building assessment tools have emerged as an important strategy to mitigate the potential negative impacts of the built environment [19]. The primary purpose of these building assessment tools is to evaluate the environmental characteristics of the buildings by using a set of standards that aim to achieve more environmentally friendly building performance [19]. Many of these building environmental assessments tools have emerged throughout of the world [20,21]. For instance, *BRE Environmental Assessment Method* (BREEM) has been recognized widely in the United Kingdom building industry. *Building Environment Performance Assessment Criteria* (BEPAC) assessment tool has emerged as a voluntary and comprehensive building assessment tool in Canada. Also, through an international collaborative, *The Green Building Challenge* developed a comprehensive method for environmental performance assessment of the buildings. Resource consumption, environmental loading, indoor environmental quality, and service quality are included as major assessment criteria in their assessment tool; GB-Tool software.

In addition to earlier mentioned building rating systems, LEED and Green Globes are considered as the most important assessment tools in the United States [22]. Green Globes, developed by Green Building Initiative, assesses the performance of the buildings with respect to energy, water, resources, emissions, and environmental management. The tool is used widely for new constructions, major renovations, multi-residential structures, and institutional buildings. Yet, the most widely used assessment tool is the LEED rating system that has been developed by the U.S. Green Building Council. LEED includes five major areas of sustainability; sustainable sites (SS), water efficiency (WE), energy and atmosphere (EA), materials and resources (MR), and indoor environmental quality (IEQ). Apart from these categories, it also includes two other categories; innovations in design (ID) and regional priority (RP). LEED can be applied to new constructions and major renovations, existing buildings, commercial interiors, core and shell, schools, retails, healthcare, homes, and neighborhood development.

Several studies have been conducted regarding the cost premium of green buildings. In 2007, Davis Langdon analyzed the Australian Green Star rating system by comparing the cost of the green and non-green buildings to estimate the cost premium of the green rating system on construction costs [23]. The study concluded that a 5-Star green building had a 3–5% premium with respect to a conventional counterpart. In another study, one office building has been assessed for the cost premium study of the BREAM rating and the study revealed that a 6% premium was explained by the sustainable design features for the building [24]. Fowler and Rauch [6] assessed the cost premium of LEED certified buildings and concluded that the cost premiums of the building projects ranged from 1% to 8% with respect to the level of LEED certification desired. Kats [25] conducted a study on 30 green school projects that were built in 10 different states between 2001 and 2006. On the basis of the study results, it was found that green school design provided 1–2% additional cost when compared with a conventional design [25]. In another study, an in-depth analysis of LEED-NC certified buildings revealed that high performance sustainable building projects required higher capital investment and the required capital was proportional to the intended building overall LEED-NC rating [26]. According to this report, the cost premium of the green project is likely to follow the increasing cost trend with respect to the higher levels of LEED certification. On the other hand, Nilson [27] estimated LEED Gold certification to be 0.82% of total construction costs for a New York office building. Also, Stegall [28] estimated a premium of 1–2.8% of the total project cost for a new house that aims to achieve LEED Silver certification. In a study conducted by Packard Foundation [29], they estimated that a premium of 0.9%, 1.3%, 1.5%, or 2.1% of total hard costs is required to achieve LEED Certified, Silver, Gold, or Platinum for an office building, respectively. As can be seen, although the estimated cost premium percentages were different, many studies have concluded that green certification is likely to result in a premium. Also, green building certification related premium costs were expected to change according to the type of green certification, the desired level of green rating, and the nature of the buildings, and would likely increase with higher levels of certification.

## 3. Data collection

74 LEED-NC version 2.2 certified building cases were used for ANN development. The data were gathered from previous case studies published online (see Table 1). Data extracted for each building consisted of construction year, building type, city, and actual construction cost. Additionally, scores achieved from LEED categories; SS, WE, EA, MR, IEQ, and ID were collected. RP was not available in LEED version 2.2, and was not included. Also, buildings