

Comparison Analysis of Construction Costs according to LEED and non-LEED Certified Educational Buildings

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Abstract:

The efforts for sustainable development in building construction are widely applied by global organizations, governments, etc. However, according to the researchers, if the green rating systems on the building, it is reported that construction costs and durations are increased compared to conventional buildings. In this respect, the objective of this study is to identify the construction costs between LEED and non-LEED buildings. The scope of this study is limited in 21 university buildings of Canada. The methodology is as follows: First, the data of LEED and non-LEED buildings are collected in every university building. Second, the average construction costs per square meter are collected and a normality check is conducted. Third, to identify statistical significance, the difference of average construction costs is analyzed by using a T-test. As a result, it is concluded that the construction costs of LEED buildings are increased by approximately 3.8% more than non-LEED buildings. In the future, the results of this study can be applied to analyzing the additional costs according to the LEED grade in educational buildings.

Keywords: Sustainable Building Certification, LEED Certification Costs, Green Building In Education, LEED Certified Schools, Construction Cost Analysis LEED, Green Building Benefits, Educational Facility Sustainability, LEED Vs Non-LEED Construction Costs, Energy Efficient School Buildings, Green Building Certification Systems.

1. Introduction

Background and Purpose of Research

Currently, both domestically and internationally, efforts are being made to enhance building efficiency from a sustainability perspective by evaluating factors such as energy, raw materials, and pollutant emissions throughout the entire life cycle (design, construction, maintenance, and demolition) to improve environmental preservation, occupant comfort, and health. Representative examples include the UK's Building Research Establishment Environmental Assessment Method (BREEAM) initiated in 1991, and the USA's Leadership in Energy and Environmental Design (LEED) that started in 1998. In South Korea, the Green Building Certification Criteria (GBCC) has been implemented since 2002. These certification systems not only promote the spread of green buildings but also enhance public awareness of environmental conservation and foster the development of green technologies. For educational facilities, Shendell (2004) found that increased CO₂ levels in classrooms correlate with higher student absenteeism. The United States Environmental Protection Agency (USEPA) reported in 2000 that indoor air quality, affected by pollutants, temperature, and humidity, significantly influences students' health and academic performance, underscoring the importance of green buildings in educational settings. Research on green buildings is

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being conducted across various fields, particularly regarding changes in construction costs compared to existing buildings. In South Korea, active research includes studies on cost variations according to LEED certification levels for office facilities (Kim Jaemun et al., 2012) and additional construction costs for new buildings seeking LEED certification (Lee Won-ki, 2013). Internationally, studies include research on LEED costs for office buildings (GSA, 2004) and cost analysis of LEED certification for bank buildings (Chad Mapp et al., 2011). However, these studies predominantly focus on commercial and residential buildings rather than educational facilities. Therefore, this study aims to conduct a comparative analysis of construction cost changes due to LEED certification for educational facilities. The results of this study will be used for future research on cost prediction models based on LEED grades for educational facilities.

Scope and Methods of Research

The Canada Green Building Council (CaGBC) modified the contents of LEED-NC2.1 developed by the US Green Building Council (USGBC) to suit Canadian conditions and implemented its own green building certification system called LEED Canada in 2003. However, as of June 2017, it discontinued this and adopted USGBC's LEED. Accordingly, this study focuses on buildings certified with LEED, not LEED Canada, in the Canadian region.

To analyze the construction cost changes for educational facilities due to LEED certification compared to existing costs, the study follows the methodology illustrated in Figure 1. First, out of 352 universities in Canada with LEED-certified buildings, 21 universities were selected as samples where the certification criteria align with those in Korea. Second, data on the construction costs of LEED-certified and non-certified buildings at the selected universities were collected. Third, to conduct statistical analysis, the collected data were first subjected to a normality test to ensure they were suitable for statistical analysis. Then, a T-test was performed to analyze whether the differences in construction costs per square meter were statistically significant. Finally, based on the analysis, the results comparing the construction costs with and without LEED certification were derived.

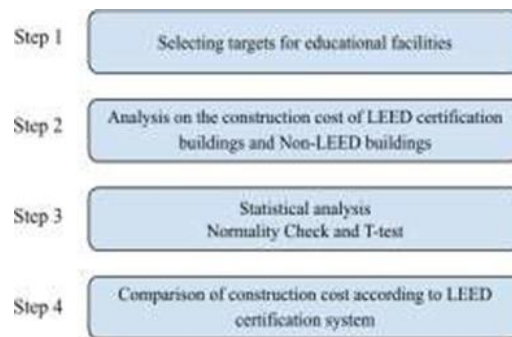


Figure-1 Methodology

2. Literature Review

Overview of LEED for Schools

In the United States, the US Green Building Council (USGBC) has been implementing LEED green building certification evaluations since 1998, with revisions made over time. As a result of these efforts, the number of LEED-certified buildings grew from just 60 in 2000 to over 50,000 by 2017.

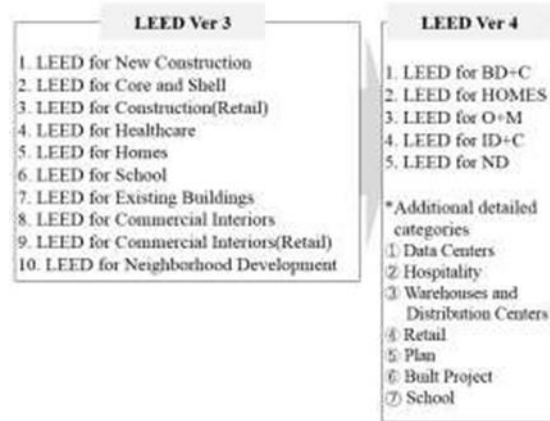


Figure-2 Guideline

Figure 2 illustrates the revision process of LEED since 2009. In 2009, LEED Ver 3, which comprised 10 independent evaluation systems, was revised to LEED Ver 4 in 2013, consolidating the systems into five. The types of revised evaluation systems include LEED for BD+C (Building Design and Construction), LEED for ID+C (Interior Design and Construction), LEED for O+M (Building Operations and Maintenance), LEED for ND (Neighborhood Development), and LEED for Homes. Newly added subcategories include Healthcare, Data Centers, Hospitality, Warehouses and Distribution Centers, Retail, Schools, Plan, and Built Project. The LEED Ver 4 BD+C (School) rating system currently categorizes certification as Certified (40-49 points), Silver (50-59 points), Gold (60-79 points), and Platinum (80-110 points).

Table 1 shows the changes in the scoring criteria for the LEED for BD+C (School) system. The revised version reflects the following updates: the total score increased from 79 points in Ver 2 to 110 points in Ver 3, with the addition of a new Regional category allowing for extra points based on regional environmental characteristics. The Sustainable Sites category now includes items related to alternative transportation methods, such as access to public transport and bicycle storage, to reduce pollutant emissions.

The most significant increase was observed in the Energy & Atmosphere category, while the Indoor Environmental Quality category experienced the largest decrease. Other categories showed changes of 1-3 points, reflecting adjustments based on the evolving importance of each category.

Table-1 Changes in school points and section

Section	Application and Credits					
	Ver 2		Ver 3		Ver 4	
	Total	%	Total	%	Total	%
Integrative Process	-	-	-	-	1	1
Location and Transportation	-	-	-	-	15	13.6
Sustainable Sites	16	20.3	24	21.8	12	10.9
Water Efficiency	7	8.9	11	10	12	10.9

Energy & Atmosphere	17	21.5	33	30	31	28.2
Materials & Resources	13	16.5	13	11.8	13	11.8
Indoor Environmental Quality	20	25.3	19	17.3	16	14.5
Innovation	6	7.6	6	5.5	6	5.5
Regional Priority	-	-	4	3.6	4	3.6
Total	79	100	110	100	110	100

In transitioning from Ver 3 to Ver 4, the Integrative Process category was added, and the Sustainable Sites category was split into Sustainable Sites and Location and Transportation. The 7 points assigned to Transportation in Ver 4 are similar to the 4 points in Ver 3, suggesting that this is more of a reclassification rather than a change in weighting, with a new emphasis on Location. Other categories also saw changes of 1-3 points, indicating partial adjustments over time.

Review of Previous Studies

Zhonghua Gou et al. (2010) composed questions regarding market readiness and policies for green buildings, focusing on benefits, motivations, obstacles, and policies. They conducted interviews with 11 local green building researchers, who largely agreed that initial costs for green buildings are higher than those for conventional buildings. The reasons included increased design costs, the purchase of green materials, and the introduction of energy-saving systems.

In the residential sector, Kim Young-Man (2010) conducted a feasibility analysis for green building certification of apartment complexes. The study targeted five apartment complexes in Seoul that received excellent grades (pre-certification) under the domestic green building certification system in 2008. The additional costs per category, particularly in the energy sector, aimed at achieving 25-30% energy savings. This analysis used the Korea Institute of Construction Technology (KICT) report's standard of energy savings of 25-30%. The total additional costs were calculated by multiplying the project area by the unit cost of energy savings.

The analysis revealed an average additional cost of 5.32%, with increases in Indoor Environmental Quality (2.8%), Water Efficiency (1.18%), Energy (0.56%), Materials (0.32%), Ecological Environment (0.12%), and Traffic (0.08%). The high additional costs for Indoor Environmental Quality and Water Efficiency were attributed to the large quantities of materials such as windows and water-saving installations, as well as high-cost items like rainwater utilization systems. Additionally, as the floor area increased, the unit cost of additional construction decreased due to bulk material orders and economies of scale for special facilities and high- efficiency boilers.

For office buildings, Kim Jae-Moon (2010) estimated additional construction costs for LEED certification based on the certification levels. The study selected a total construction cost of 36.977 billion won for an office building completed in June 2011. Scenarios were set for Certified (43 points), Silver (53 points), Gold (64 points), and Platinum (82 points), with the building applying LEED Ver 2. Additional construction costs were calculated for each of the six categories and 54 prerequisite and credit items. The lowest additional costs per item were applied to achieve each certification level, and design changes for LEED certification were also implemented.

As a result, the cost changes for each certification level were as follows: Certified -0.08%, Silver 0.40%, Gold 2.57%, and Platinum 5.79%. The most influential items for each level are as follows: For the Certified level, the additional construction cost was reduced by optimizing the capacity of mechanical equipment, resulting in savings of -297,970,000 KRW, or 0.08%. For the Silver level, the most significant cost impact was from the Energy & Atmosphere (EA) category, accounting for 43% of the additional costs, primarily due to energy-saving measures. Similarly, for the Gold level, the EA category accounted for 65% of the additional costs, and for the Platinum level, it accounted for 77%, indicating that the EA category had the most significant cost impact for all LEED certification levels.

In the case of educational facilities, a study by US Green Building (2006) analyzed the cost-benefit of 30 LEED-certified schools in 10 states over six years (2001-2006). The study found that while implementing efficient systems, design, and modeling for green certification could increase construction costs, it also resulted in savings of \$71 per square foot due to energy and water savings, productivity improvements, and health benefits from improved indoor air quality. The savings could offset the additional construction costs or even result in a net gain.

However, in South Korea, research on green building certification for school facilities has mainly focused on case analysis and certification criteria, rather than construction costs. Studies include the analysis of green building certification evaluation items and cases for school facilities (Kim Chang-sung, 2013), research on selecting mandatory items for green building certification criteria for schools (Kim Yong-seok et al., 2009), and comparative analysis of evaluation results for green-certified schools (Jung Ji-na et al., 2009).

T-Test

A T-test is a parametric statistical test used to determine if there is a significant difference between the means of two populations. In this study, a one-sample T-test will be used to test whether the observed meaning differs from a specified value. This method requires the dependent variable to follow a normal distribution. If the sample size for each category is generally 30 or more, the data can be assumed to be approximate normality according to the central limit theorem.

The null hypothesis (H_0) and the alternative hypothesis (H_1) for this test are as follows

$$H_0 : \mu = \text{mean}$$

$$H_1 : \mu \neq \text{mean}$$

Where:

m = sample mean

mean = population mean

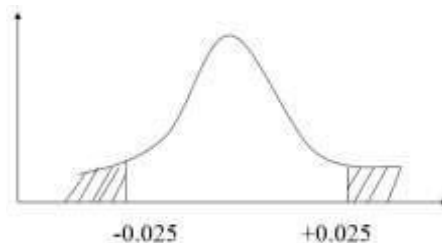


Figure-3 T Distribution graph

3. Statistical Analysis

Selection of Subjects

According to the Canada Green Building Council (CaGBC), there are a total of 3,038 LEED-certified buildings, of which 336 are educational facilities, accounting for 11%. Additionally, as shown in Figure 4, the number of LEED-certified buildings in universities across Canada has been increasing since 2005. This trend is attributed to the Canadian government's implementation of the Green Energy and Green Economy policy in 2009 and the growing interest in the impact of green buildings on educational environments.

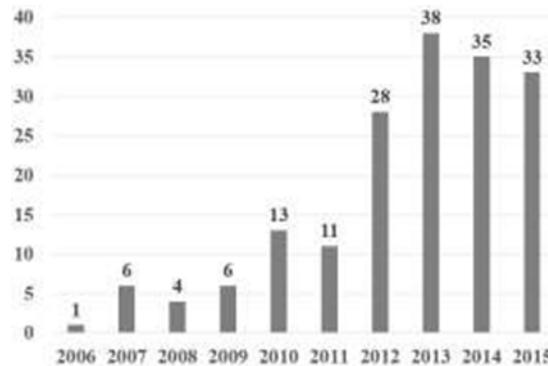


Figure-4 LEED certification numbers in universities of Canada

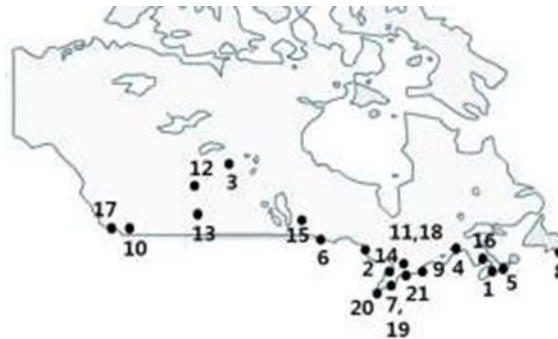


Figure-5 University Location

For this study, data were collected from the Canadian Universities Reciprocal Insurance Exchange (CURIE) insurance company, focusing on 21 universities with LEED-certified buildings in Canada, as shown in Figure 5. CURIE is a nonprofit organization established to manage insurance and risk management for universities across Canada. The data were obtained directly from CURIE and included detailed information such as university names, locations, construction years of auxiliary buildings, number of floors, total floor area, construction costs, and LEED certification status as of the end of 2016.

Data Collection

Data Collection Procedures: The purpose of this study is to compare the construction costs of LEED-certified and non-LEED buildings. However, as the size of a building increases, so does the total construction cost. Therefore, the cost per unit area (C\$/m²) is used to conduct the analysis. The following steps were taken:

First, the unit cost per square meter for LEED-certified buildings at each university was selected as the experimental group and defined as B_{ij} . Second, for each LEED-certified building sample, three samples of non-LEED buildings' unit costs per square meter were collected and defined as A_{ik} . Since the unit cost per square meter is influenced by various factors such as size, design, structure, and finishes, it is necessary to minimize these variables. Therefore, when selecting the control group (non-LEED vs. LEED buildings), buildings with the same use, construction year ± 3 years, and floor area $\pm 20\%$ were chosen. Data meeting these conditions were available for three or more buildings at each university, and three were selected to ensure data homogeneity, defining them as A_{ik} . Third, the B_{ij} and A_{ik} values for each university were analyzed to determine whether there were significant differences in construction costs based on LEED certification.

Table-2 Data Analysis

S. No	Content	N	Ave.	BVI _{ij}	S.NO	Content	N	Ave.	BVI _{ij}
1	LEED	1	570	1.06	12	LEED	5	416.26	1.025
	Non-LEED	3	537.57			Non-LEED	15	406.09	
2	LEED	1	356.06	1.049	13	LEED	9	422.3	1.03
	Non-LEED	3	339.27			Non-LEED	27	410.09	
3	LEED	1	300.85	1.029	14	LEED	2	411.51	1.018
	Non-LEED	3	292.26			Non-LEED	6	404.17	
4	LEED	2	289.39	1.031	15	LEED	3	448.57	1.063
	Non-LEED	6	280.72			Non-LEED	9	421.82	
5	LEED	6	324.92	1.043	16	LEED	1	377.03	1.021
	Non-LEED	18	311.57			Non-LEED	3	370.25	
6	LEED	1	465.02	1.012	17	LEED	2	348.12	1.058
	Non-LEED	3	459.7			Non-LEED	6	328.98	
7	LEED	9	311.11	1.035	18	LEED	1	363.3	1.02
	Non-LEED	27	300.53			Non-LEED	3	356.25	
8	LEED	3	322.39	1.063	19	LEED	3	427.05	1.033
	Non-LEED	9	303.7			Non-LEED	9	413.29	
9	LEED	4	485.39	1.021	20	LEED	6	325.23	1.051
	Non-LEED	12	475.28			Non-LEED	9	309.51	
10	LEED	1	552.6	1.053	21	LEED	4	562.27	1.049
	Non-LEED	3	524.68			Non-LEED	12	536.06	
11	LEED	1	422.43	1.058					
	Non-LEED	3	399.23						

i = university

N = the number of samples

Ave = average sample

Data Collection Results: To analyze the differences in construction costs between the two groups, the Building Value Index (BVI) was defined. BVI is the ratio of B_{ij} to A_{ik} , indicating the relative value of LEED-certified buildings compared to non-LEED buildings. The formula for BVI is as follows:

$$BVI_{ij} = \frac{\sum_{i=1}^i A_{ik}/i}{\sum_{i=1}^i B_{ij}/j}$$

Where:

i = university ID

j = LEED-certified building ID

k = non-LEED building ID

B_{ij} = Average LEED-certified building value

A_{ik} = Average non-LEED building value

BVI = Average (B_{ij}) / Average (A_{ik})

The analysis results according to the formula are shown in Table-2.

Normality Test

In this study, a T-Test was used to determine whether there is a difference in construction costs between the two groups. For the T-Test to be valid, the dependent variable must satisfy the assumption of normal distribution. Therefore, the collected data were subjected to a normality test to analyze whether they followed a normal distribution. As shown in Figure 6, the data exhibited characteristics of a normal distribution. Additionally, the Kolmogorov-Smirnov test was performed to statistically confirm normality. Assuming a confidence interval of 95%, the p-value was found to be 0.200, which is greater than 0.05, indicating that the collected data followed a normal distribution.

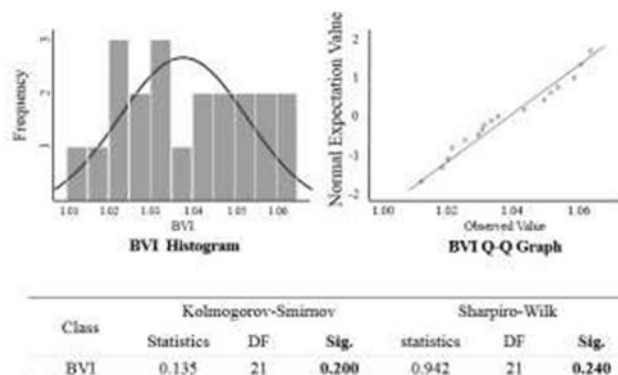


Figure-6 Normal

Next, descriptive statistics were used to further verify normality by analyzing the skewness and kurtosis, as shown in Table 3. The mean was 1.038, the median was slightly lower at 1.035, the skewness was 0.039, and the kurtosis was -1.339. According to Kline's criteria, skewness less than an absolute value of 3 and kurtosis less than 10 do not pose significant problems, indicating that the data satisfied the normality assumption (Kline, 2005).

Table-3 Descriptive Statistics

Class Collected Data	Value
N	21
Mean	1.038
Std. Dev.	0.015
1st Decile	1.012
Median	1.035
21st Decile	1.063
Skewness	0.039
Kurtosis	-1.339

Analysis Results

To statistically determine whether there is a significant difference in construction costs between LEED-certified and non-LEED buildings, a one-sample T-Test was conducted. The null hypothesis (H_0) and the alternative hypothesis (H_1) were established as follows:

$$H_0: LCB = NLB$$

$$H_1: LCB \neq NLB$$

Where:

LCB: Construction cost per unit area of LEED-certified buildings

NLB: Construction cost per unit area of non-LEED buildings

Under the null hypothesis, the test statistic value $T(X)$ was found to be 11.103. With a sample size of $n=21$, the degrees of freedom were 20. At a 95% confidence level, the T-distribution table indicates a critical value range of $-2.086 \leq t \leq 2.086$. As shown in Figure 7, the rejection region is the shaded area, and the test statistic value $T(X) = 11.103$ falls within this region, leading to the rejection of the null hypothesis (H_0) and the acceptance of the alternative hypothesis (H_1). This indicates that the results of the T-Test are significant. Consequently, it was found that the construction cost per unit area of LEED-certified buildings is statistically significantly different from that of non-LEED buildings. The average BVI value was 1.038, indicating that LEED-certified buildings had a 3.8% higher construction cost compared to non-LEED buildings.

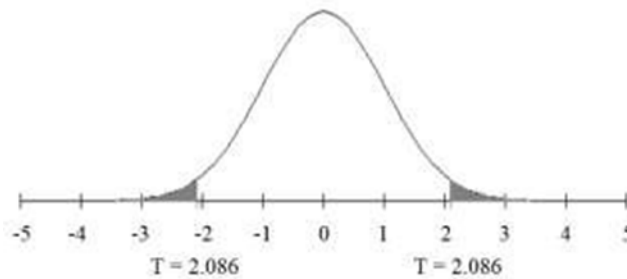


Figure-7 T Distribution curve for a degree of freedom of 21

Although the variables affecting construction costs were minimized in this study, future research should collect more detailed data on various factors (materials, construction methods, scale, etc.) to analyze their correlations. According to the results of this study, the 3.8% increase in construction costs is attributed to increased initial design costs, the use of relatively expensive green materials, and material supply.

However, according to US Green Building (2006), LEED-certified school buildings, compared to non-certified school buildings, provide long-term benefits that can offset additional construction costs in four aspects:

- Energy usage
- Pollutant emissions
- Water usage
- Reduced incidence of asthma and respiratory diseases.

First, in terms of energy usage, green facilities show higher energy efficiency compared to existing buildings, and reduced energy demand can indirectly lower energy prices. Second, in terms of pollutant emissions, reduced energy demand leads to decreased fossil fuel consumption. Third, green buildings utilizing rainwater and greywater systems show reduced water usage compared to existing buildings, leading to savings in direct pollution control costs and the infrastructure required for wastewater transportation and treatment. Fourth, improved indoor air quality from green facilities is expected to reduce the incidence of asthma and respiratory diseases compared to existing buildings

4. Conclusion

Efforts to achieve sustainable development in building construction are being widely implemented by international organizations, governments, and green building certification bodies. However, according to several researchers, applying green building certification systems increases construction costs and durations, making them less economical compared to conventional buildings. Therefore, this study aimed to compare the construction costs of educational facilities based on the presence or absence of LEED certification.

Data were collected from 21 universities in Canada, selecting three non-LEED buildings for each LEED-certified building. The average construction cost per unit area was calculated based on LEED certification status, and the normality of the data was verified through a normality test, which confirmed that the data followed a normal distribution. Additionally, descriptive statistics and T-Test results indicated that the construction costs of LEED-certified buildings were 3.8% higher than those of non-LEED buildings. The increase in construction costs for educational facilities can be attributed to additional costs incurred from the implementation of efficient systems, design, and modeling, as indicated by the study by US Green Building (2006).

According to the analysis method in the report, the 3.8% increase in construction costs for green building certification can result in savings of \$71 per square foot through energy and water savings, productivity improvements, and health benefits from improved indoor air quality.

This study's results were based on buildings that applied the LEED certification system, so there might be some differences when applying domestic green building certification systems. Therefore, further research on the construction costs of domestic, green-certified buildings and additional studies to verify this study's results are needed. However, since each certification system shares the ultimate goal of promoting sustainability and has similar evaluation items, it is expected that applying domestic green building certification systems will yield similar results.

Therefore, this study serves as a foundational study for establishing an analysis model for additional construction costs according to LEED certification levels for educational facilities. The results of this study will be utilized for future research on predicting construction costs by LEED certification levels for educational facilities.

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6. Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

7. Funding

No external funding was received to support or conduct this study.