Assessing Existing Buildings for LEED Retrofit: Case Study of a University Building

M. Oytun, B.A. Bilginer and G. Atasoy
Middle East Technical University, Civil Engineering Department, Ankara, Turkey
moytun@metu.edu.tr, aykutb@metu.edu.tr, guzide@metu.edu.tr

Abstract

The sustainable built environment concept gained significant attention from the scientific community due to the tremendous increase in the emission of greenhouse gases triggered by the exploitation of natural resources. Changing the conventional way of building construction and retrofit into a greener one is an indispensable step to ensure a sustainable built environment as the buildings cover most of the surrounding. Accordingly, Architecture Engineering and Construction (AEC) industry has started to incorporate green building rating systems like LEED and BREAM in past decades. In this context, accreditation systems have been used in many countries, for both new and existing buildings. The purpose of this study is to assess an existing university building's sustainability potential. First, the current condition of the building is examined using a LEED checklist. Then alternative retrofit strategies, considering potential improvements, are identified from the Life Cycle Cost (LCC) and cost efficiency perspectives. Based on the findings, investing in buildings' sustainability can easily be compensated, as it leads to a remarkable reduction in resource allocation in the long run. Especially, from the cost-efficiency perspective, location and transportation, and indoor environmental quality-related improvements are leading solutions while water and energy efficiency-related improvements are prominent when LCC is considered.

Keywords: *Campus Building Renovation, Green Building Certification, LEED, Life Cycle Cost, Retrofit*

Introduction

In recent years, the soaring emissions of greenhouse gases (GHG) due to the exploitation of natural resources raised a great concern in society. Especially, the use of natural resources in the Architecture Engineering and Construction (AEC) industry is quite extensive. The amount of energy used in the AEC industry accounts for over 35% of global use, and about 40% of the global GHG emissions associated with it (Global Status Report, 2017). The highest portion of this usage arises in the construction, maintenance, and rehabilitation of the structures. This issue reveals the need for radical changes in the built environment. Accordingly, the sustainable built environment concept has garnered significant attention from the scientific community. One of the most important steps to ensure sustainability in the built environment is to transform the traditional building construction and retrofit methods to greener ones. Therefore, green building rating systems like LEED and BREEAM are

established in the early 1990s by the United States Green Building Council (USGBC) and the Building Research Establishment (BRE), respectively.

The USGBC defines a 'green' building as a building that uses energy, water, and other natural resources efficiently during its design, construction, and operation. Green buildings do not only save natural resources but also contribute to the occupants' health and comfort through measures taken in terms of temperature and humidity control, indoor air quality, natural lighting, and waste management (USGBC, 2020). To ensure greater transparency on the sustainability of the buildings, green building certification has become more crucial than ever. Therefore, the exploration of the building rating systems and the green building concept has gained momentum in recent years by both practitioners and researchers. Various studies have been conducted over the world with different concentrations. For instance, some focused on the financial benefits of green construction (e.g., Kats, 2003, 2006; Liu et al., 2018; Winkler et al., 2002). Others studied the building energy performance assessment and energy reduction in green buildings (e.g., Feng & Hewage, 2014; Wang et al.,2012; Zou & Zhao, 2014; Diamond et al. 2006; Sinou & Kyvelou 2006; Fowler et al. 2010). Fuerst (2009) evaluated the investment trends in green-certified buildings in the USA. Da Silva & Ruwanpura (2009) discussed the bottlenecks of the green building certification system's utilization by examining the cases from Canada. As opposed to studies investigating new construction projects, there is limited work on energy efficiency in existing building stock (California Energy Commission 2005; Waide 2007; Holness 2008; Jones et al. 2013).

The green building applications in both new and renovation projects are already consolidated in developed countries, but in developing countries, the importance of these concepts has been recently understood. The percentage of retrofits of existing buildings in developed countries such as the USA, Canada, and Ireland can reach up to 50% of the building stock. Whereas in emerging markets, such as Brazil and India, this value is around 20%, since their focus is on new buildings (Jones & Laquidara-Carr, 2018). Furthermore, in their review of the cases from Turkey, Aktas & Ozorhon (2015) pointed out that the regulation of energy performance in buildings, which became mandatory in 2011, has been used effectively in new constructions while there is still a lack of regulations for existing buildings. This problem is the biggest obstacle for developing countries to achieve sustainability in the built environment since most of the energy is consumed by existing buildings rather than the newly constructed green ones (Energy R., 2010). In this sense, the most appropriate way to reduce these consumptions lies in the renovation of the existing buildings (Construction M. H., 2009).

Nevertheless, sustainable building renovations are one of the most challenging types of construction projects due to several uncertainties. According to Mitropoulos & Howell (2002), these are physical constraints, lack of knowledge, and limited documentation of existing conditions. Thus, the renovation projects are tough to be implemented on the site efficiently. Moreover, there is a perception that sustainable strategies are not as cost-effective as new construction. McKim et al. (2000) stated that renovation projects have worse performance than new construction projects regarding the overall cost, schedule, and quality. Hence, the green building certification programs like BREEAM and LEED are the most pervasive methods of assessing, rating and certifying the sustainability of the buildings. Unfortunately, although the renovation studies are ubiquitous in commercial sectors, there are limited studies concerning the educational buildings in Turkey (Korkmaz et al., 2009). Furthermore, the report of USGBC regarding the country market brief for Turkey confirms this trend. This report reveals that there exist 897 projects with sustainability potential in Turkey as of March 3, 2020. The report indicates that 380 of these projects are currently

certified, while 517 are registered for certification. Moreover, the distribution of these projects according to space type and LEED rating system shows that only 2.56% and 4.46% of the projects are related to the higher education and retrofitting (e.g., O+M). The highest portion is composed of commercial and residential buildings and new constructions (e.g., BD+C). Therefore, considering the potential, the concentration should be diverted to retrofitting existing educational buildings. USGBC has created a LEED project checklist for school retrofit to increase awareness, namely "LEED v4 for Operations & Maintenance: Schools Project Checklist", which is referred to as LEED Checklist from now on.

This study aims to assess the sustainability potential of an existing university building. In this sense, the main building of the Middle East Technical University (METU) – Civil Engineering Department is evaluated for retrofit. First, its current condition is monitored using the LEED Checklist. Alternative retrofit strategies, considering potential improvements, are identified from the Life Cycle Cost (LCC) and cost-efficiency perspectives.

Methodology

The characteristics of the case study building are identified, categorized, and discussed. Then, data is collected for the corresponding categories by a combination of on-site walkthrough observation, document analysis, and administrative staff consultancy. Afterward, the existing condition of the building is assessed based on the LEED Checklist. Finally, the potential improvements for retrofit are examined based on benefit-cost and cost-efficiency analyses.

Analysis of Existing Condition

The characteristics of the K-1 building are presented in this section.

Site and Landscaping: The building, which is positioned to receive daylight from four fronts, is located at the center of the METU Campus. The bus stop right in front of it makes the building easily accessible. It has a 4742 m^2 of the settlement area, 2771 m^2 of parking space, and 2553 m^2 of the green area, mostly covered with more than 30-year-old trees. The nearest building is located at least 100 m away from the building.

The Building Type: K-1 building, a reinforced concrete structure, consists of three stories, basement, entrance, and the first floor. The building's actual views obtained in Google Earth Pro 3D are shown in Figure 1, where the details of landscaping, site layout, and exterior body can easily be perceived trough. The building is referred to as the main classroom building of the civil engineering department. 29% of the building façade is covered with glass as it mainly consists of classrooms and offices. The number (shown in parenthesis) and classification of the rooms in the K-1 building according to their intended use are as follows: study room (3), storage room (2), laboratory (3), classroom (17), conference room (3), office (79), boiler room (1), staff-archive-server (8), and meeting room (4).

Mechanical and Electrical Systems: The mechanical systems of a building can be evaluated considering heating, ventilation, and air-conditioning (HVAC). The building has a central heating system with radiators. There is no mechanical ventilation system in the building, except for the transportation engineering laboratory, so air circulation is typically provided by natural ventilation. Although the building has sensor lights, it is mostly illuminated with

manually controlled fluorescent bulbs. The building provides its energy from the distant power plant through the main distribution line. Energy is transferred to corresponding building systems via the internal electricity distribution network.

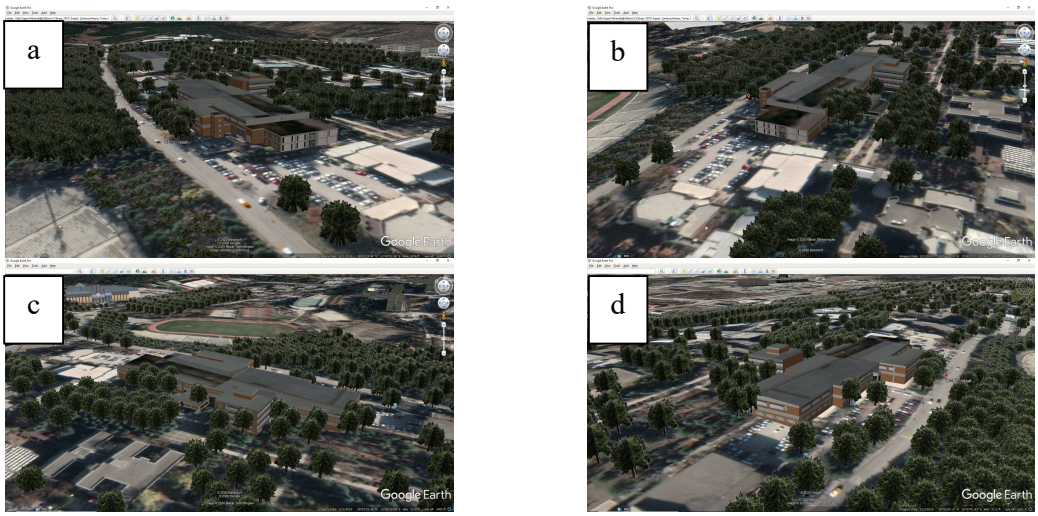


Figure 1. Real images of the building captured counterclockwise from a (south) to d (north)

Data Collection Methods and Objective Identification

The objectives of the study are to assess how sustainable the existing building is and the sustainability potential of the building besides to understand whether retrofitting of the buildings is cost-efficient. Thus, the LEED checklist is reviewed, and possible improvements are identified considering the existing condition of the building. In data acquisition for the analysis of the current condition and the identification of improvements, several data collection methods such as on-site observations and walkthroughs, interviews with the administrative staff, document analysis, and market price analysis supported by retailor consultancy are used. During this process, assumptions are made and categorized into five sections: general, location and transportation, water efficiency, energy and atmosphere, and indoor environmental quality.

General Assumptions: Documentation procedures for green building certification, such as document preparation and policymaking, will be assigned to the department staff. Therefore, no additional costs will be incurred in executing these types of works, such as ongoing purchasing and waste, facility maintenance and renovations policies, and initiating an indoor air quality management program. The expected lifetimes for the possible improvements are detected based on the manufacturer's catalogs. If the information is missing or there is more than one value, the expected service life is acknowledged as ten years.

Assumptions related to Location & Transportation: All members having vehicle stamp travel with their vehicles, and in total, 30 people use motorcycles as a means of transportation.

Assumptions related to Water Efficiency: Since the water supply throughout the campus is done by pumping water from the surrounding water wells, the annual water consumption value of the building can be estimated based on the daily individual water usage values announced by Turk Stat in 2018. It is assumed that (1) out of all building participants, 122 people, including 108 academicians and 14 administrative employees, use the building eight full hours a day, while it is on average two hours a day for students, (2) the total of 900 students visit the building daily, and (3) the building will not be used on weekends.

Assumptions related to Energy & Atmosphere: The share of the building's energy use within the campus total energy consumption is considered the same as the building's natural gas use percent in gas consumption calculations.

Assumptions related to Indoor Environmental Quality: The building's natural ventilation system provides the minimum required indoor air quality condition.

Out of 1500 people using the building, 550 have vehicle stamps, allowing them to access the campus and park their cars to designated parking areas. Also, weekly observations revealed that 30 people use a motorcycle, which does not need a vehicle stamp. It is assumed that all these people provide their transportation by themselves, while the rest use alternative transportation modes. Some were assumed to use the parking spaces of near-by buildings. Furthermore, interviews revealed that the water and energy consumption was measured with a single meter for the entire campus. However, the energy consumption values have been obtained from the relevant transformer of a set of building blocks. Then, the individual consumption values of the K-1 building have been estimated based on the use purposes of these buildings. Similarly, the total water consumption values were also estimated for up to one year. It is assumed that the catalog performance values of the replacement materials such as meters, bulbs, and water-saving faucet aerators can be acquired without any deviations.

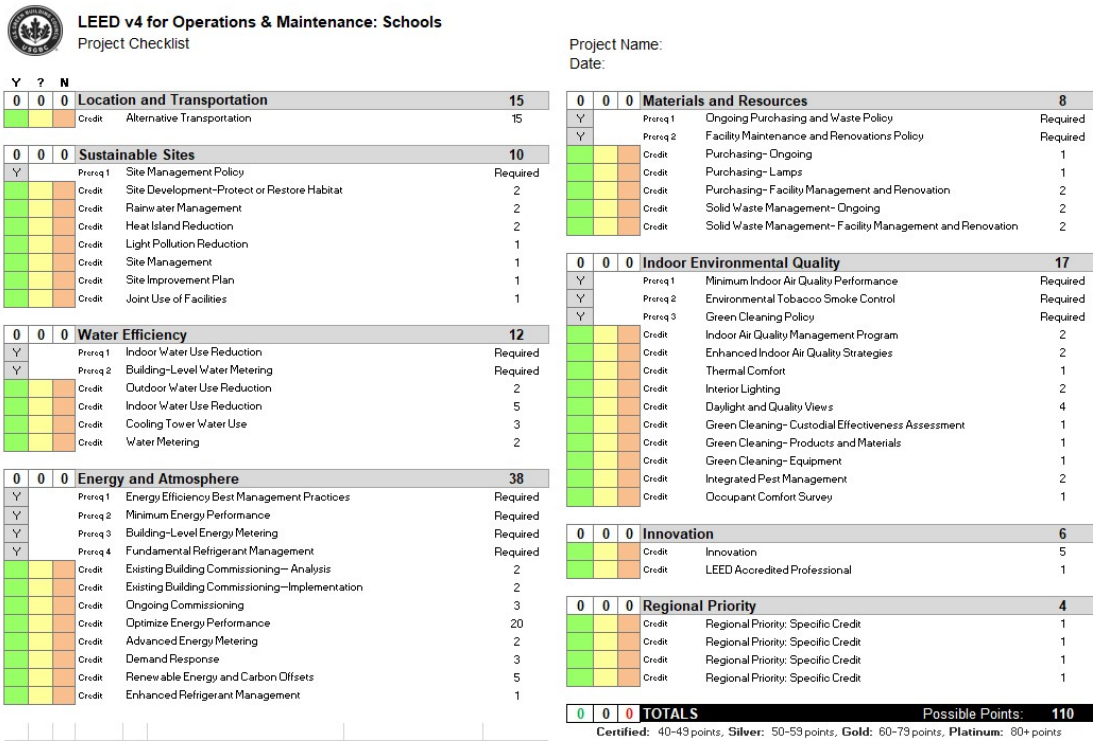
Assessment of LEED Criteria

In this study, the LEED Checklist is used to evaluate the existing condition and identify improvements for retrofitting. This checklist consists of several subjects (Figure 2), and it is used as a guide for assessing the potential of the building to receive LEED certification. To be able to assess through based on the scoring system, some prerequisites specified in the list must first be met. The assessment of the current condition for the K-1 building is performed based on the assumptions given in the preceding part. The acquired score and related explanations are structured according to the categories presented in Figure 2.

Location and Transportation (13 points): Alternative transportation usage percentage is calculated as 63% based on the information obtained from the building administration on the numbers of vehicle stamps and building participants. Alternative means of transportation such as buses, minibuses, and metro are available from the campus. Moreover, bicycles and rings are provided inside the campus.

Water Efficiency (2 points): The water supply of the campus originates from Elmadağ groundwater basin. The water seeps through the lake Eymir and collected in three deep-water wells which are operated by METU. The water level in these wells is monitored daily and conveyed to the central station on campus via three pumps. Since water is free of charge (groundwater), neither campus-wide nor building-based water consumption values are

measured. Building-level water consumption value is estimated as 6,048 m^3 per year in line with the assumptions. Presently, the prerequisites for water efficiency could not be provided for the K-1 building. Also, no water reduction system is deployed outside or inside. Since there is only one water meter station for the entire campus, the building is also insufficient in water metering.



LEED v4 for Operations & Maintenance: Schools
Project Checklist

Project Name:
Date:

Y	?	N				
0	0	0	**Location and Transportation**			15
			Credit	Alternative Transportation		15
0	0	0	**Sustainable Sites**			10
Y			Prereq 1	Site Management Policy		Required
			Credit	Site Development-Protect or Restore Habitat		2
			Credit	Rainwater Management		2
			Credit	Heat Island Reduction		2
			Credit	Light Pollution Reduction		1
			Credit	Site Management		1
			Credit	Site Improvement Plan		1
			Credit	Joint Use of Facilities		1
0	0	0	**Water Efficiency**			12
Y			Prereq 1	Indoor Water Use Reduction		Required
Y			Prereq 2	Building-Level Water Metering		Required
			Credit	Outdoor Water Use Reduction		2
			Credit	Indoor Water Use Reduction		5
			Credit	Cooling Tower Water Use		3
			Credit	Water Metering		2
0	0	0	**Energy and Atmosphere**			38
Y			Prereq 1	Energy Efficiency Best Management Practices		Required
Y			Prereq 2	Minimum Energy Performance		Required
Y			Prereq 3	Building-Level Energy Metering		Required
Y			Prereq 4	Fundamental Refrigerant Management		Required
			Credit	Existing Building Commissioning – Analysis		2
			Credit	Existing Building Commissioning – Implementation		2
			Credit	Ongoing Commissioning		3
			Credit	Optimize Energy Performance		20
			Credit	Advanced Energy Metering		2
			Credit	Demand Response		3
			Credit	Renewable Energy and Carbon Offsets		5
			Credit	Enhanced Refrigerant Management		1

0	0	0	**Materials and Resources**		8
Y			Prereq 1	Ongoing Purchasing and Waste Policy	Required
Y			Prereq 2	Facility Maintenance and Renovations Policy	Required
			Credit	Purchasing- Ongoing	1
			Credit	Purchasing- Lamps	1
			Credit	Purchasing- Facility Management and Renovation	2
			Credit	Solid Waste Management- Ongoing	2
			Credit	Solid Waste Management- Facility Management and Renovation	2
0	0	0	**Indoor Environmental Quality**		17
Y			Prereq 1	Minimum Indoor Air Quality Performance	Required
Y			Prereq 2	Environmental Tobacco Smoke Control	Required
Y			Prereq 3	Green Cleaning Policy	Required
			Credit	Indoor Air Quality Management Program	2
			Credit	Enhanced Indoor Air Quality Strategies	2
			Credit	Thermal Comfort	1
			Credit	Interior Lighting	2
			Credit	Daylight and Quality Views	4
			Credit	Green Cleaning- Custodial Effectiveness Assessment	1
			Credit	Green Cleaning- Products and Materials	1
			Credit	Green Cleaning- Equipment	1
			Credit	Integrated Pest Management	2
			Credit	Occupant Comfort Survey	1
0	0	0	**Innovation**		6
			Credit	Innovation	5
			Credit	LEED Accredited Professional	1
0	0	0	**Regional Priority**		4
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
0	0	0	**TOTALS**	Possible Points:	110

Certified: 40-49 points, **Silver:** 50-59 points, **Gold:** 60-79 points, **Platinum:** 80+ points

Figure 2. LEED Checklist for Operations & Maintenance: Schools

Energy and Atmosphere (7 points)**:** The annual energy consumption value for the entire campus is around 35,300,000 kWh per year consumed from the grid, and around 54,000 kWh per year generated on-site. Building specific annual energy consumption value is estimated as 975,500 kWh per year. Moreover, the buildings on the campus are heated based on the provided steam from the central plant. The thermal capacity of this plant is known to be 40 MW, with annual fuel consumption of 11 million m^3 of natural gas. At the building level, a heat exchanger converts the steam energy to heat water. Similarly, building level fuel consumption is estimated as 295,400 m^3 per year. The prerequisites for energy and atmosphere could not be met. There has been no systematic study on energy metering, optimization, demand response, renewable energy systems, and refrigerant management. The building met only the requirements of the existing building commission - analysis, implementation, and ongoing commissioning items from those given in the checklist.

Indoor Environmental Quality (1 point): Pre-assessment requirements for indoor air quality as (1) minimum Indoor Air Quality (IAQ), (2) control of environmental tobacco use, and (3) green cleaning policy items are already satisfied. The entryway systems (e.g., steel grating doormats) exist at each of the entrances of the building

Sustainable Sites (3 points): Documents related to site improvement and management plans and future goals have been established, and action plans have been prepared on how to evaluate and monitor these processes by the administrative staff. In terms of the shared use of facilities, the building has several alternatives, such as a photocopy room, sports equipment, faculty members' lounge, meeting rooms, and public parking areas.

Materials and Resources (2 points): Only ongoing solid waste management requirements are met within the LEED Checklist evaluation criteria for the building. Finally, no **Innovation** was observed in the assessments, and **Regional Priority** does not apply to the building. The overall score of the current condition is calculated as 28 out of the possible 110 points.

Potential Improvements

Potential improvements were studied after the identification of insufficiencies in the current state of the building. The primary purpose of improvements is to enable the building to obtain a LEED certificate in the most efficient way. At least 40 points from the checklist should be collected to get a LEED certificate. Therefore, potential improvements have been identified, and the most cost-efficient ones were selected for retrofitting. The details for the improvements and the related score potentials are as follows:

Location and Transportation: To reduce the conventional travel rates of building occupants, it is planned to (1) design a carpool matching website, (2) promote ridesharing by labeling preferential parking spaces for rideshare participants, and (3) launch a carpool program in which the information technology assistants of the department and the university staff will play an active role. Based on these three improvements, it is expected to gain two points.

Water Efficiency: There are two prerequisites to be completed: (1) indoor water use reduction and (2) building-level energy metering. To this end, it is planned (1) to modify the faucets, siphons, and urinals in the building with water-saving systems (e.g., water saver faucet caps, water-free urinals, and dual flushes); and (2) to install a water meter to the main water line of the building. The modification of plumbing items, water-free urinals, water saver faucet aerators, and water-saving dual flush systems will reduce annual water consumption by 750, 592, and 637 m^3, respectively. It will lead to getting five more points.

Energy and Atmosphere: Four possible improvements were designated for this item. The first and second one is on energy performance optimization. In the first one, it is planned to replace the traditional bulbs with the led ones and installing solar panels on the roof. These measures are expected to provide 2.6% energy savings. Besides, installing the solar panels will also satisfy the conditions considered under renewable energy and carbon offset. Therefore, this will lead to getting points from two different items with one improvement. The third one is to insulate the building façade, which will provide an additional 30% energy saving. For the last item, advanced energy metering, individual energy meters are planned to be installed in each laboratory in the building. With the improvements mentioned above, the building can be rewarded ten more points.

Indoor Environmental Quality: There are several prerequisites: minimum indoor air quality performance, environmental tobacco smoke control, and green cleaning policy. Mandatory warning signs and directions are available in and out of the building for environmental tobacco and smoke control. For the green cleaning policy, a comprehensive market price

study was conducted, and it was concluded that there was no significant price difference between green and traditional cleaning materials. Hence, it is discerned that updating the cleaning policy towards a greener one will not cause any additional costs. Apart from the prerequisites, several improvements are considered: (1) initiating an IAQ management program covering the issuing documents for standardization of the related processes, (2) installation of air quality alarms to the openings, cafeteria space, management building, and the main entrance for enhanced indoor air quality strategies, (3) improving the interior lightning by replacing room's on-off electric switches with the adjustable ones, (4) measuring indoor daylight intensity, (5) assessing green cleaning custodial effectiveness and purchasing green cleaning products, materials, and equipment, and (6) conducting an occupant comfort survey. Based on the improvements, a total of four additional points can be earned.

Cost-Benefit and Cost-Efficiency Analysis

In this study, Cost-Benefit Analysis (CBA) is used to perform a comparative analysis of potential improvements according to their annual equivalent benefit to cost ratio (BCR) calculated considering different expected service lives. The aim is to identify among the alternative improvements that provide the lowest cost with the highest benefit (e.g., maximum sustainability potential based on LCC) in LEED assessment. Throughout the calculations, the monetary values and the expected service lives related to the improvements are determined based on comprehensive market research. Nevertheless, these values are subject to change.

In conducting CBA, the Annual Equivalent (AE) method is preferred since the improvements have unequal service lives. The analysis is performed by following the steps: (1) the Equivalent Annual Cost (EAC) for the initial investment and the expected incomes are calculated using the finance investment analysis equations 1, 2, 3, 4, and 5, based on the estimated prices, individual expected service lives, and 10% constant interest rate, (2) the LEED score contributions and service lives of the improvements are identified, (3) following the LCC perspective, the EAC value of the expected incomes are divided by the EACs of the initial investments and maintenance costs, to find the BCR for each improvement as in equation 6, (4) the obtained BCRs are compared, and (5) all relevant improvements are identified until reaching the required amount of points (40 points) to get certified by giving priority to the prerequisite improvements and starting from the possible improvement having the highest BCR. The used equations are as follows,

$$NPV = \Sigma(Cash\ Flow_t / (1+r)^t) - Initial\ Investment \quad (1)$$

$$EAC = (NPV \times r) / (1-(1+r)^{-n}) \quad (2)$$

$$P = F \times (1 / (1+r)^n) \quad (3)$$

$$A = P \times ((r \times (1+r)^n) / ((1+r^n)-1)) \quad (4)$$

$$A = F \times (r / ((1+r)^n-1)) \quad (5)$$

$$BCR_s = EAC(Expected\ Incomes / (Initial\ Investment + Maintenance\ Costs))_s \quad (6)$$

where *EAC* is Equivalent Annual Cost, *r* is Discount or Interest Rate, *n* is Number of Years, *NPV* is Net Present Value, *t* is Cash Flow Period, *P* is Present value, *A* is Annual Equivalent, *F* is Future Value, *BCR* is Benefit-Cost Ratio, and *s* is Improvement Alternative Number.

Although this analysis offers the most profitable solutions in the long term, it may not be the cheapest in terms of the initial cost. The reason for this is that some improvements have an initial cost and a point gathering potential in the LEED assessment, but their BCRs are 0 since they do not provide any income in time. Therefore, as an alternative, to identify the cheapest solution set to get certified based on the initial investment cost (i.e., obtain LEED certification with the minimum investment), the total initial cost (TIC) / Point Potential (PP) ratio of each improvement is calculated. Then, starting from the lowest value, all relevant improvements are identified until reaching the total targeted score of 40 points to get certified. The identified improvements for each of the analyses are highlighted in the appendix.

Based on the CBA analysis, the potential improvements are determined to be eligible in the following order; building-level water meter installation, building-level energy meter installation, water-saving faucet aerators installation, water-saving dual-flush system replacement, lighting bulb replacement, building façade insulation, water-free urinal replacement, and solar panel installation. Accordingly, with a 270466.5 TRY initial investment cost, 13 points are gathered, and the building collected a total of 41 points.

Based on the cost-efficiency analysis, the potential improvements are determined to be eligible in the following order; building-level water meter installation, building-level energy meter installation, daylight measurement device installation, advanced energy meters installation, preferential parking delineators installation, air quality alarms installation, replacement of 50% of electrical switches, water-saving dual flush system replacement, solar panel installation, and water-free urinal replacement. Accordingly, with a 48799 TRY initial investment cost, 13 points are gathered, and the building collected 41 points.

The comparison of two analyses reveals that the potential improvements that are profitable in the long run and the ones that provide the cheapest solutions differ. For example, the preferential parking delineators installation costs 600 TRY while it has a potential of two points. However, it does not provide incomes in the long run. On the other hand, the water-free urinal replacement having ten years of expected service life, costs 15000 TRY while it has a potential of one point and 3557.50 TRY of annual income. Thus, ultimately it is determined that investing in sustainable retrofitting items related to water and energy efficiency is the most profitable solution in the long run as they lead to a remarkable reduction in resource allocation.

Conclusion

In this study, the sustainability potential of the civil engineering department's main building in the METU campus, namely the K-1 building, is assessed to develop a better understanding of the LEED certification process of existing campus buildings for green retrofitting. Undoubtedly, the only aim in this process should not be score hunting by omitting the sustainability, but in this study it is aimed to collect the minimum required score to get LEED-certified to raise awareness and form a motivation in educational facilities with limited budgets. Moreover, it is intended to demonstrate that it is possible to perform monetary analysis and attain profitable outcomes for the construction industry, which is predominantly driven by economic decisions. Accordingly, the existing situation of the building is assessed, and the potential improvements are identified. The individual and joint point contributions for the potential improvements are determined. Then, the benefit/cost ratio (BCR) and Total Initial Cost (TIC)/Point Potential (PP) ratio for each of the potential improvements are

calculated. These values are observed to vary from one improvement alternative to another, but to the extent allowed by the budget, it is thought that sustainable options should be implemented with a holistic approach. Nevertheless, the most profitable solution sets based on both LCC and cost-efficiency (cheapest solution set based on initial investments) are presented. The findings show that when the building's sustainability potential is assessed from the LCC perspective, improvements regarding water and energy have the priority. On the contrary, when assessed from the cost-efficiency perspective, the location and transportation, and indoor environmental quality related ones come to the fore. Furthermore, it is comprehended that the initial cost of sustainable improvements could be compensated quickly, and these improvements will subsequently make a profit as they reduce resource usage in the building. Accordingly, this study is quite useful for benchmarking in LEED campus building renovation research. As a future study, the environmental impacts of improvement sets will also be evaluated by conducting a Life-Cycle Assessment (LCA).

References

Aktas, B., & Ozorhon, B. (2015). Green building certification process of existing buildings in developing countries: cases from Turkey. *Journal of Management in Engineering*, *31*(6).

California Energy Commission. (2005). Options for energy efficiency in existing buildings. *Sacramento: California Energy Commission*.

Construction, M. H. (2009). Green building retrofit & renovation rapidly expanding market opportunities through existing buildings. *New York*.

Da Silva, L., & Ruwanpura, J. Y. (2009). Review of the LEED points obtained by Canadian building projects. *Journal of Architectural Engineering*, *15*(2), 38-54.

Diamond, R. (2006). Evaluating the energy performance of the first generation of LEED-certified commercial buildings.

Energy, R. (2010). Energy efficiency trends in residential and commercial buildings.

Feng, H., & Hewage, K. (2014). Energy saving performance of green vegetation on LEED certified buildings. *Energy and buildings*, *75*, 281-289.

Fuerst, F. (2009). Building momentum: An analysis of investment trends in LEED and Energy Star-certified properties. *Journal of Retail & Leisure Property*, *8*(4), 285-297.

Holness, G. V. (2008). Improving energy efficiency in existing buildings. *ASHRAE Journal*, *50*(1), 12-21.

Jones, P., Lannon, S., & Patterson, J. (2013). Retrofitting existing housing: how far, how much?. *Building Research & Information*, *41*(5), 532-550.

Jones, S. A., & Laquidara-Carr, D. (2018). World Green Building Trends 2018—Smart market report. *Bedford (US): Dodge Data & Analytics*, 80.

Kats, G. (2003). *Green building costs and financial benefits* (pp. 2-8). Boston, MA: Massachusetts technology collaborative.

Kats, G. (2006). Greening America's schools: Costs and benefits. A Capital E Report. *Retrieved October*, *1*, 2009.

Korkmaz, S., Erten, D., Syal, M., & Potbhare, V. (2009, May). A review of green building movement timelines in developed and developing countries to build an international adoption framework. In *Proceedings of the Fifth International Conference on Construction in the 21st Century: Collaboration and Integration in Engineering, Management and Technology, Istanbul, Turkey* (Vol. 20).

Liu, Y., Liu, T., Ye, S., & Liu, Y. (2018). Cost-benefit analysis for Energy Efficiency Retrofit of existing buildings: A case study in China. *Journal of Cleaner Production*, *177*, 493-506.

McKim, R., Hegazy, T., & Attalla, M. (2000). Project performance control in reconstruction projects. *Journal of construction engineering and management*, *126*(2), 137-141.

Mitropoulos, P., & Howell, G. A. (2002). Renovation projects: Design process problems and improvement mechanisms. *Journal of Management in Engineering*, *18*(4), 179-185.

Sinou, M., & Kyvelou, S. (2006). Present and future of building performance assessment tools. *Management of Environmental Quality: An International Journal*.

USGBC (2020). Leadership in Energy & Environmental Design. Retrieved September 17, 2020, from *http://leed. usgbc.org/leed.html*.

Waide, P., Amann, J., & Hinge, A. (2007). Energy efficiency in the north american existing building stock. *Energy efficiency series*.

Wang, S., Yan, C., & Xiao, F. (2012). Quantitative energy performance assessment methods for existing buildings. *Energy and buildings*, *55*, 873-888.

Winkler, H., Spalding-Fecher, R., Tyani, L., & Matibe, K. (2002). Cost-benefit analysis of energy efficiency in urban low-cost housing. *Development southern africa*, *19*(5), 593-614.

Zuo, J., & Zhao, Z. Y. (2014). Green building research–current status and future agenda: A review. *Renewable and sustainable energy reviews*, *30*, 271-281.

Appendix: Details of Benefit-Cost and Cost-Efficiency Analysis

Checklist Item	Potential Improvements	Needed Units	Unit Price (TRY)	Total Initial Cost (TIC) (TRY)	Point Potential (PP)	Joint Potential Point	Expected Service Life (yr.)	B / C (Ratio)	TIC / PP (Ratio)
Location and Transportation	Preferential Parking Delineators Installation	5	120	600	2	2	10	0	300
Water Efficiency	Water-saving Faucet Aerators Installation	15	7.9	118.5	0	5	1	44.01	-
	Water Free Urinal Replacement	15	1000	15000	1		10	2.37	15000
	Water-saving Dual Flush System Replacement	15	173	2595	1		10	21.63	2595
	Building Level - Water Meter Installation	1	550	550	0		10	0	-
Energy and Atmosphere	Lighting Bulb Replacement	630	50	31500	0	10	10	17.31	-
	Solar Panel Installation	28	945	26460	2		10	1.01	13230
	Building Façade Insulation	2218	87.5	194075	4		50	15.22	48519
	Building Level Energy Meter Installation	1	168	168	0		10	0	-
	Advanced Energy Meters Installation	3	168	504	2		10	0	252
Indoor Environmental Quality	Air Quality Alarms Installation	3	336	1008	1	4	10	0	1008
	Replacement of 50% of Electrical Switches	60	30	1800	1		10	0	1800
	Daylight Measurement Device Installation	114	1	114	2		10	0	57

	Prerequisite improvements
	Identified improvements based on LCC analysis
	Identified improvements based on cost-efficiency analysis