Case Study on the Cost Analysis of a Residential Green Building

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Abstract: *In this educational research study, a group of Civil Engineering students proposed a moment resisting structural steel design of a two-story residential house. Leadership in Energy and Environmental Design (LEED) features were implemented in the design of the house in order to estimate the construction cost with and without LEED implementations. The main objective of this project is to utilize the knowledge gained throughout core Civil Engineering courses in order to improvise future residential house designs and to inspire students in engineering to be involved in sustainable design projects. Research as well as cost analysis and estimation were performed to show the cost efficiency of the green building. This research endeavor serves to educate students about the importance of LEED features, raise awareness of environmental degradation, and reduce the average operating cost and energy consumption.*

Keywords: *LEED features, Green building, Steel residential house, Structural design, Engineering education*

I. Introduction

During a general engineering design process, newly hired engineer is required to consider several key factors including the safety of the building, compliance with code requirements, project cost and to fulfill the general purpose of the structure. Conventional residential houses are built relatively at the lowest cost possible in order to attract more consumers to invest on these projects. However, these conventional residential units have had higher maintenance and utility cost, which eventually made the residential units to be less-cost effective in the long run. One of the practical solutions is to pursue one of the four levels of Leadership in Energy and Environmental Design (LEED) certification for a new residential house. The construction and materials cost-work analysis was further performed on both LEED and non-LEED certified residential house to identify on the benefits and disadvantages of LEED implementation. To utilize such analysis in educational purposes and to obtain accurate results, students were required to study construction management, concrete and steel design engineering courses to understand the benefits of the structure to be LEED certified.

Structural Engineering is a very traditional profession that has been developed many years ago and continues today to be improved with further cutting-edge technologies to somehow reduce environmental impact and energy consumption. Therefore, engineers shall consider various methods in building design and construction to reduce energyconsumption and consider future effects on the environment. To achieve such challenging goal, engineers developed what is referred to as “LEED”, A Leadership in Energy and Environmental Design Certificate, that differentiate in between an environmentally friendly building, “Green Building” and the traditional old-fashion building[1]. The contemporary design process requires a change, but the change must start not in practice but throughout educatingfuture architects and engineers[2]. Energy and water savings can be predicted with reasonable precision, measured, and monitored over time[3].

The objective of this project was to provide students with a taste of what is structural engineering by creating a LEED report. Throughout this report, students were able to present work within the following projects, which showed evidence of

understanding the design of beams, columns, and seismic portions of a steel residential building. In addition, student took into consideration how different energy and water saving methods can be implemented to create a LEED certified building. Furthermore, students compared and contrasted prices between a LEED certified building against a designed building without the chosen LEED features. Upon completion of this project, these ethnically diverse students were able to influence others upon their understanding of structural engineering through an educational LEED report and show employers understanding upon the subject.

II. Structural Design

This project consisted of designing and analyzing the two-story steel framed residential houselocatedin Northridge, California. Each floor was designed to have approximately 2000 square feet of floor space. The architectural plan of the first and second floors are shown in Figures 1 and 2. The structural design consisted of a gravity system and a lateral system. Beams and columns were designed in accordance with AISC (2014) [4] and ACI (318-14) [5] building code requirements to withstand the foreseeable dead and live loads using the Load Resistance Factor Design (LRFD) method of analysis.The gravity system is composed of steel (Grade A992) beams and columns. W-shaped steel columns and beams were selected for the entire structure. All beams were designed to be W14×30 in size, while columns for first and second floors were W12×65. The seismic values were found to be S_s =2.186 and S_1 =0.696 in the Northridge area, in accordance with ASCE 7-10 standard [6]. Furthermore, foundation design for the house included single and combined footing to transfer the gravity and lateral loadings from the columns into the ground [7].

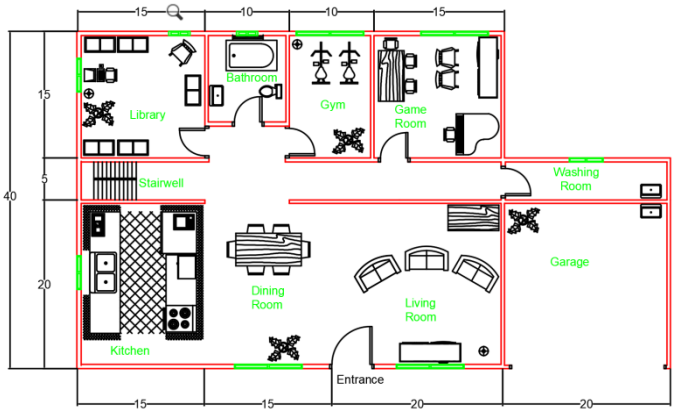

Figure 1. Architectural plan of the first floor

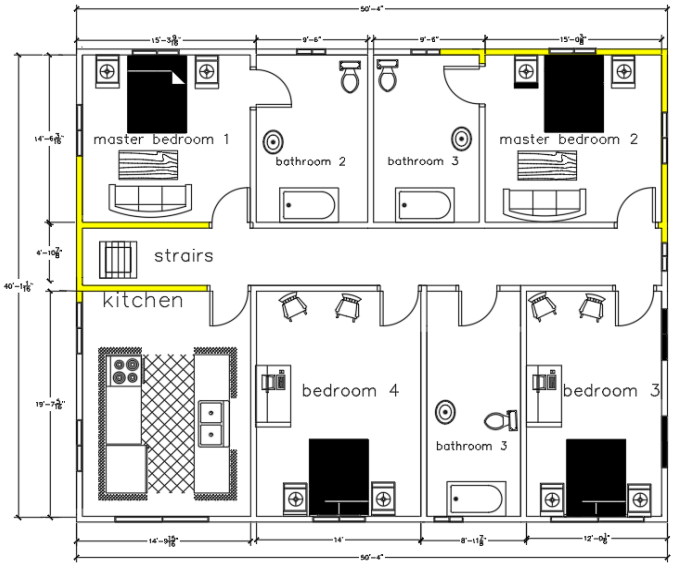

Figure 2. Architectural plan of the second floor

III. Sustainability Design

Conservation of energy and reduction of pollutants are the most important criteria in modern civil engineering designs. Therefore, many countries around the world encourage more sustainable and environmental-friendly residential and commercial buildings. Thus, LEED [8] certification is considered vital in any modern infrastructure design. This certification program assessed building design and construction in terms of energy efficiency, water usage, air quality and choice of building materials. The LEED program was developed by the United States Green Building Council (USGBC). Building projects that participate in the program can be awarded LEED certification on four levels, based on the total points earned. Since the objective of this research paper is to identify the pros and cons of designing a LEED Certified residential building in comparison to a traditional design, latest available LEED features were implemented in the two-story residential house design.

The first LEED feature to be considered in the design was the usage of solar roof instead of traditional high-end roofs. Tesla solar roofs were chosen for high efficiency, accessibility, and durability. Despite having a high initial cost compared to traditional roof, Tesla roofs, as shown in Figure 3, would be able to generate a great amount of energy, which is very beneficial economically and environmentally. Additionally, consumers would be able to enjoy tax credit benefits by supporting Tesla solar roofs.

Figure 3. Teslasolar roof [9]

The next considered LEED features were high performance windows [10]. Premium double pane windows were ought to be used for the LEED design. Double pane windows have two panes of glass that are separated by a void and filled with argon and krypton gas. The gas-filled void helps to deaden the sound from the surrounding to enter the residential building. Moreover, the heat exchange between the inside of the house and the atmosphere could be reduced effectively. This results in much more energy efficient windows than the traditional single pane windows.

Conservation of clean water and harvesting rainwater were the next implemented LEED features to the house design. Due to rapid development in the Los Angeles region, infiltration of rainwater into the subsoil has decreased dramatically, and recharging of groundwater has diminished. The usage of clean water could be minimized by the installation of greywater and rainwater catchment systems as shown in Figure 4, in which the system recycled water for irrigation or lavatory usage. Despite high initial cost, the rainwater harvest system helped to collect filtered rainwater and reduced the usage of clean water in the long run. Furthermore, the rainwater harvest system could contribute in supplying sufficient water for irrigation all year long, which was essential to keep the landscape of the house green, moist and beautiful.

The final LEED feature that was implemented on the design was a vegetative garden on top of the garage roof [11]. The 500 square foot flat roof surface was suitable to be transformed into a vegetative and herb garden. This eco-friendly garden helped in regulating the air quality to the surrounding of the house, while providing a source of fresh organic food supply. Additionally, the garden received water supply from the rainwater harvest system, and thus was considered fully sustainable. Easy vegetation and herbal plants maintenance were also considered for this garden in order to reduce the effort and the cost. Furthermore, after the implementation of desired LEED features in the design, out of four LEED certification levels of designation, the residential house was awarded a rating of a Certified green building based on the total points earned.

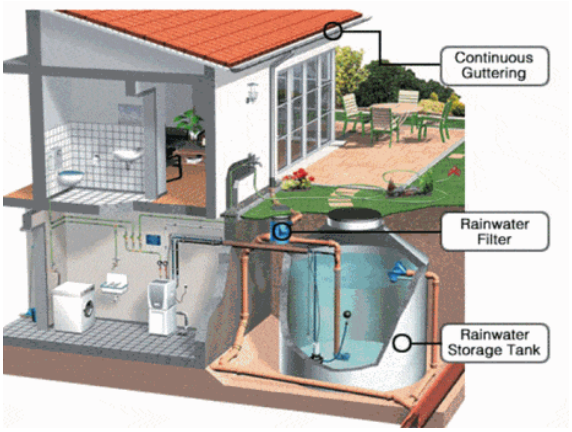

Figure 4. Water recycling system [12]

IV. Cost Analysis

Once the preliminary design of the two-story house was completed, cost-work calculations were performed to estimate the total cost of the project. RSMeans [13], a software which stimulated the cost of constructions based on location, was used in order to estimate the total cost of the house at higher accuracy. An additional research was done in surveying the best fit LEED features for the house to satisfy the purpose of the residential unit. The cost of the selected LEED implementations was researched, tabulated and added to the cost of the traditional house. Cost-work analysis was done on both LEED and traditional designs. In the case of LEED-certified residential unit, the two-story house was estimated to cost $480,722.60, while traditional design was estimated to cost $401,553.10. Hence, there was a 19.7% ($79,220.00) increase in the total cost of the building when LEED features were added on. The solar roofs were able to generate electricity for at least 30 years of occupancy, which would save up to $2,800.00 per year. All LEED features and cost are shown in Tables 1 and 2.

Table 1. Cost analysis of the traditional house

Item	Description	Cost
1	Steel Beams and Columns	$148,969.00
2	Concrete and Reinforcement	$31,752.05
3	Windows, Doors and Walls	$90,160.76
4	Flooring, Joist and Plates	$47,556.00
5	Roof	$42,262.92
6	Landscape and Paint	$8,336.83
7	Appliances and Interior	$32,515.54
Non-LEED Design Cost		$401,553.10

Table 2. Cost analysis of LEED and traditional features of the house

Item/Cost	LEED Features	Traditional Features
1	Tesla Solar Roof	Asphalt Shingles
Total Cost	$82,300.00	$31,868.00
2	High Performance Windows	Traditional Windows
Total Cost	$14,460.00	$922.50
3	Rainwater Harvest System	-
Total Cost	$5,500.00	-
4	Roof Garden	-
Total Cost	$9,750.00	-
Overall Cost	$112,010.00	$32,791.00
Difference in Cost	$79,220.00	

The rainwater harvest system was able to supply enough water for vegetation and cleaning usage, which helped to save up to $850.00 per year. The high-performance windows were added to the design in order to provide more sound, thermal and ultraviolet insulation, catering the occupants a more comfortable living environment, while conserving on electrical energy. Roof garden was implemented to provide the house with better aesthetics, and act as a greenhouse to generate some heat to the house during cold seasons. Considering all savings, LEED implementations led to a saving of $4,200.00 per year. Based on a minimum of 30 years warranty of all LEED features, the total savings for the three decades period was approximated to be $126,000.00. Beside benefiting from savings, LEED features contributed immensely in energy conservation and pollution reduction.

V. Educational Objectives

For this educational research, students managed to extend their knowledge in Steel Design, Foundation Design and Cost-work calculations. The students from different genders, culture and backgrounds were able to work as a team in performing this research successfully. The steel moment frame design of the residential unit was done based on AISC Steel Manual and local building code requirements. Hence, the students were able to oversee the real-world problems to be faced in designing a house. The students were passionate on learning more on environmental-friendly designs due to the benefits that these designs were able to offer to the ecosystem. This knowledge was essential for the students to gain the ability to critically analyze, improve and implement eco-friendly policies in the future. As more countries are advocating eco-friendly designs, these future civil engineers are ought to discover the potentials available in the market in constructing highly-efficient infrastructures.

As a team, the students managed to cultivate their personal skills and professional ethics by dedicating their time and effort in the project. The knowledge and experience gained by the students from the extensive research were important in pursuing their career as civil engineers. By the end of this case study, the students were able to understand the fundamentals of steel design cost-work analysis. After completing this research, students became eager to learn more about eco-friendly and sustainable designs in order to contribute in creating a better tomorrow.

VI. Conclusion

The objective of this study was to focus on energy sustainability of a designed steel structure, which was located in Northridge, California. Students used civil engineering design to investigate the efficiency of a green residential building covering structural and environmental design, as well as construction cost analysis. The cost estimation results and findingsof this study showed the difference between the two designs and clarified the advantage of LEED certified building not only to homeowners, but also to environmental protection. The construction cost of the traditional residential house was calculated to be $401,553. Meanwhile, the construction cost of the LEED certified residential house was calculated to be $480,722. Taking into account an additional 19.7% of the cost by adding such green features on the building, 19 years of occupancy would have to be considered for the project to be economically feasible based on an estimated annual saving of about $4,200 for a 30-year span study. Cost analysis of the building with LEED features versus a traditional one was compared with one another to help students understand the cost efficiency of an eco-friendly LEED certified residential building. In the analysis done over LEED certification, the proposed design managed to acquire the minimum level of LEED-certification scoring at 42 points. In conclusion, a finding of this study was that green features should be selected carefully to justify the initial construction costs.

References

[1] Ochsendorf, J.A. "Sustainable Engineering: The Future of Structural Design". MS. Massachusetts Institute of Technology/Cambridge MA, Cambridge, MA ,2005.

[2] Yeager, Amanda, "The Role of the Structural Engineer in the Contemporary Design Process" (2016) Syracuse University Honors Program Capstone Projects. 922.

[3] The Costs and Financial Benefits of Green Buildings: A Report to California's Sustainable Building Task Force by Greg Kats, Capital E

[4] American Institute of Steel Construction, AISC *Steel Construction Manual*.14th Ed.,2011.

[5] American Concrete Institute, ACI Committee 318. Building Code Requirements for Structural Concrete: (ACI 318-14). Farmington Hills, 2014.

[6] American Society of Civil Engineers, ASCE Standard 7-10 Minimum Design Loads for Buildings and Other Structures. Virginia: ASCE/AEI.

[7] Lindeburg, Michael R. *PE Civil Reference Manual*. 16th ed., Professional Publications, Inc, 2018.

[8] Leadership in Energy and Environmental Design (LEED). n.p., n.d. Web. 23 Apr. 2019.<http://leed.usgbc.org/leed.html>.

[9] Tesla Solar Roof. *Tesla, Inc*. n.p., n.d. Web. 23 Apr. 2019.<https://www.tesla.com/solarroof>.

[10] Double Pane Windows Cost.*Double Pane Windows Cost | Replacement Windows Prices*. n.p., n.d. Web. 23 Apr. 2019.<http://www.replacementwindowsprices.com/costs/double-pane-windows-costs.html>.

[11] Ayres, Crystal. "7 Pros and Cons of Green Roofs",*Green Garage*, 14 Jan. 2017.<https://greengarageblog.org/7-pros-and-cons-of-green-roofs>.

[12] Components or Elements of Green Building-Material, Water, Energy Health. *TheConstructor*. n.p., 02 Dec. 2016. Web. 30 Apr. 2019.<https://theconstructor.org/building/elements-of-green-building/5375/>.

[13] RSMeans (2019). RSMeans Data, Gordian, Rockland, MA.