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A Civil Engineering Capstone Research Project on the Design of a Green Building

Robert Sukiasian, Joshua Portillo, Julio Lopez, Miganoush Soltavi, Sulwan Almarzouq, Ali Alsaffar, George Hanna, Tadeh Zirakian and David Boyajian

Department of Civil Engineering and Construction Management, California State University, Northridge, CA, USA

Abstract: Using the knowledge obtained from previous courses such as: soil mechanics, structural analysis, steel design, etc., a team of seven students at California State University, Northridge (CSUN) designed a two-story residential steel house for their senior design course. The home was chosen to be located in the city of Pacific Palisades, California. The following paper outlines the design of the home ranging from the architectural plans to the beam, column, and foundation design. California is known to be seismically active, therefore, seismic loading played a large factor into the design of the house. Once the design of the house was completed, a cost estimate of the house was prepared using the estimating platform RSMeans. Additionally, a second estimate of the home was also completed with the addition of LEED (Leadership in Energy and Environmental Design) features such as solar panels, LED lighting, and energy star appliances that make the home environmentally friendly and will give the owner a greater return on their investment in the future.

Key words: Structural design, environmental friendly, clean energy, economical, engineering education.

1. Introduction

In this research project, the major foci were design and selection of steel structural system and LEED features for a two-story residential building. The main tasks of the team included architectural design, alternative designs of steel structural frame, design of the LEED system and determining the cost-value for both normal building design and green building design. By comparing the cost and design, the team is able to select the most beneficial design to the client.

The building design was developed in compliance with the AISC (American Institute of Steel Construction) Steel Construction Manual Code, 15th Edition; and Design of Reinforced Concrete, 9th Edition. In the design phase, the team investigated alternative structural scenarios with different combinations of steel structural member such as member types, member sizes, member spacing, etc. to compare the strength and also the cost of the construction Koken [1]. LEED features were designed in a way to provide a more sustainable structure and self-sufficiency to the building [2]. Some of the energy saving features presented in Refs. [3, 4] were implemented into the design of the residential home such as: photovoltaic systems, LED lighting, and insulation. As a result, the steel residential home was able to achieve a gold certification in LEED. By comparing all the details, it was set forth to select and design a scheme which was determined to offer a beneficial construction, increase integrity, strength, and rigidness of a structure.

This paper presents the design of a two-story residential green building using Refs. [5, 6]. It was designed to meet strength and required serviceability to both gravity loads and lateral loads. For strength design, the Load Resistance Factor Design (LRFD) criteria were used for analysis and to ensure life safety.

Corresponding author: Tadeh Zirakian, Ph.D., P.E., assistant professor, research fields: civil engineering, and engineering education.

2. Architectural Features

The project specifications were to design a two-story, steel moment-resisting residential home consisting of four bedrooms and bathrooms, as well as two kitchens. Additionally, the home was required to have a gymnasium, one garage, and one living room and a great room for children to play in. When generating the architectural design, the main thing the group considered was how and where to conveniently place each room in the home. Displayed below are the first and second floor plans, as well as the exterior elevations of the home.

3. Structural Design

In the proposed design, it followed ACI 318 [7], AISC 360 [8], and ASCE 7 [9] codes and regulations, and it followed the owner's specification of designing steel structure using wide flange steel beams and columns which made the project more environmentally friendly and can take a lot of shear forces and moment [10]. In the process of designing, each section's deflection was minimized by calculating the largest loads combination on a given structure beam in the middle section of the building and applied the calculated size for the rest of the structure which gives it more strength to resist seismic and wind forces [12]. As shown in Table 1, multiple W sections were used for our beams to reduce the weight of the building without compromising its stability and safety.

4. Design for Sustainability and LEED Certification

In the design provided above for this project, it was accompanied with some eco-friendly features to help provide more sustainable structures and self-sufficiency. All the features provided and shown in Table 2 are clean energy supplies. They are capable of generating enough energy and electricity to power up the building without needing an external supply. With all these features, the building is classified as a gold LEED-certified building due to its clean energy and eco-friendly features referring to the U.S. Green Building Council [12].

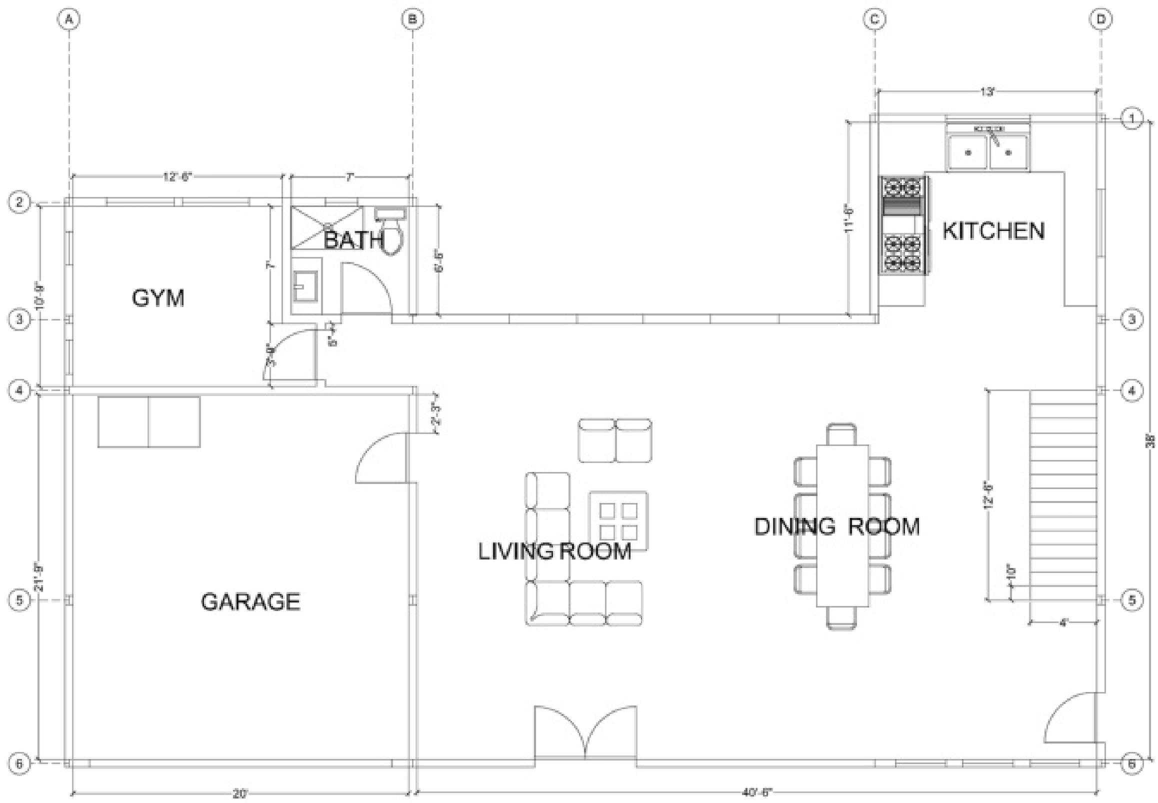

Fig. 1 First floor plan.

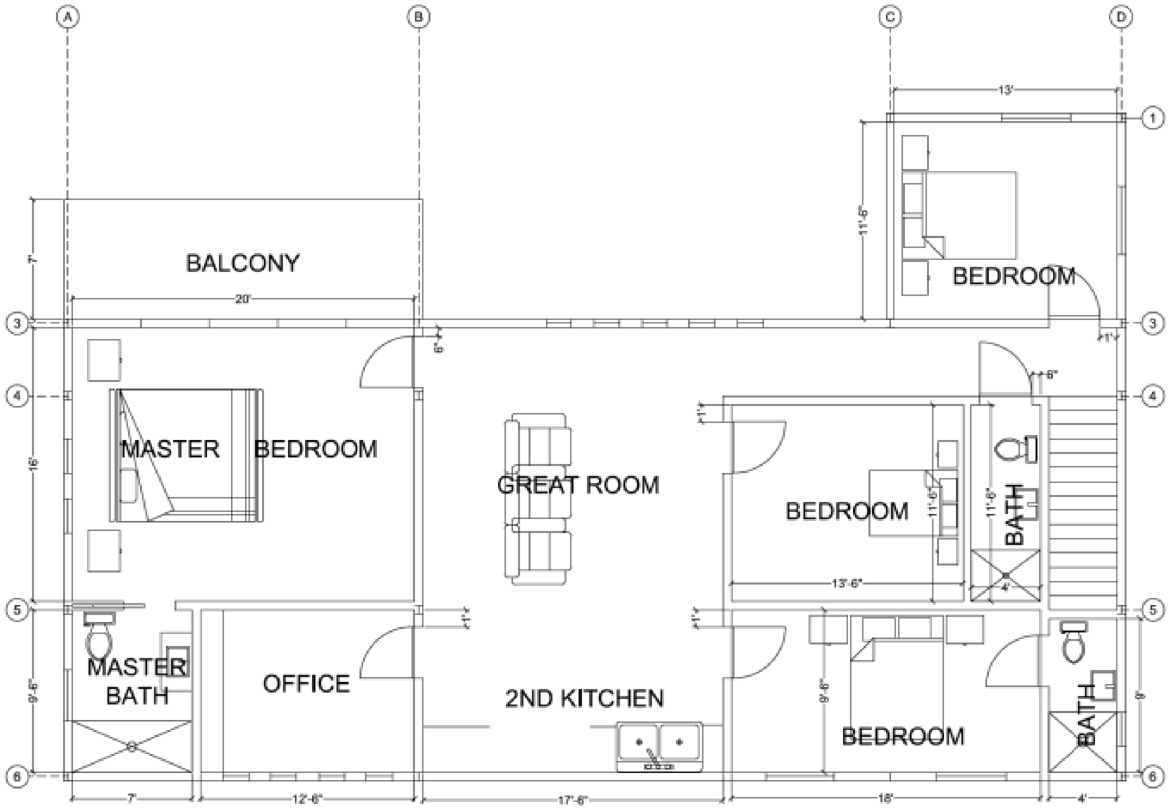

Fig. 2 Second floor plan.

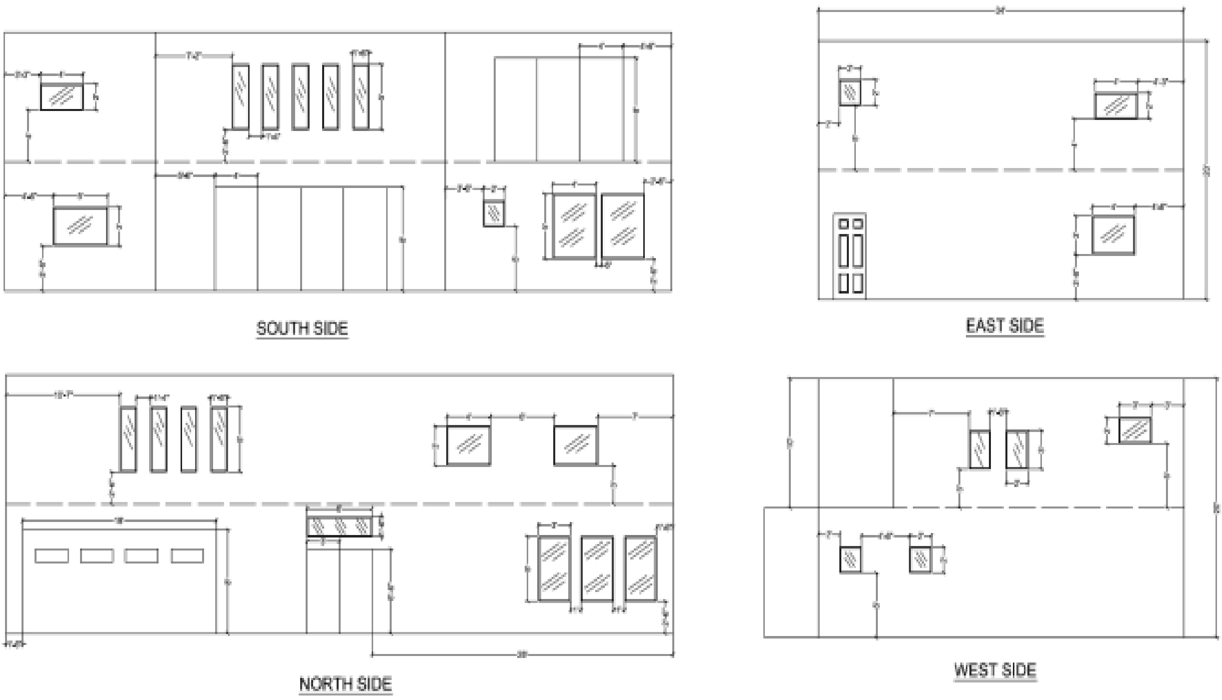

Fig. 3 Exterior elevation views of the building.

Table 1 Summary of the results for structural design.

Structural element	Design results	Additional explanation
Beams	W8×18, W10×22, W12×40, W12×58	-
Columns	W12×53	-
Foundation	9′ × 47.5′ × 2′ 9′ × 42.5′ × 2′ 9′ × 21′ × 2′ 9′ × 9′ × 2′	Using 9 # 8 rebars (Top/Bottom) @ 12″ o.c. and 2 Leg # 3 Stirrups @ 8″ o.c. with 1′ overlap

Table 2 Summary of LEED features added to the project.

Description	Unit price ($)
1. Solar panels	40,000
2. Heat recovery	1,500
3. Energy star appl.	14,000
4. Insulation	2,000
5. High thermal windows	1,500
6. LED lighting	2,000
7. Natural day lighting/skylight	500
8. Automated controlling and monitoring system	250
9. Wastewater heat recovery system	500
10. Low maintenance landscaping	2,000
11. Water saving shower heads	750
12. Low flow toilets	1,500
Total	7,000

5. Cost Analysis

According to research and calculations, it is estimated that the overall cost of construction for a LEED-certified building compared to a conventional building is around 20.5% higher. That number can result in hundreds of thousands of dollars in costs for a single-family residence, and millions for a multi-unit apartment building. Also those numbers can vary depending on scope, location, and level of LEED certification. On a project where the cost of construction is approximately $705,000; 11% is approximately $70,000. However, the amount would be made up over a ten year period, the operating and maintenance cost will offset that up-front investment as shown in Fig. 4.

6. Educational Objectives

This undergraduate research project has been a resourceful learning experience that implements the student-scholar model. Through the use of teamwork, the group was successful in completing the student-scholar model that was put in place. Highlighting everyone's individual strengths was imperative to the group's success. The diversity of the group also served as a good representation of the workforce. Group members were also exposed to several trending topics in industry such as LEED design, which is vital for future planet preservation. The student-scholar model was well implemented in this project as it allowed for learning and researching experience. The model implemented is vital for all engineering students to experience as it truly mirrors real world experience in the field. This group research project allowed group members to take on leadership roles to advance their skills which will only benefit them in the future. This senior research project is imperative for all pursuing engineering education as it helps promote real life applications and simulates real life field experiences both practically and theoretically.

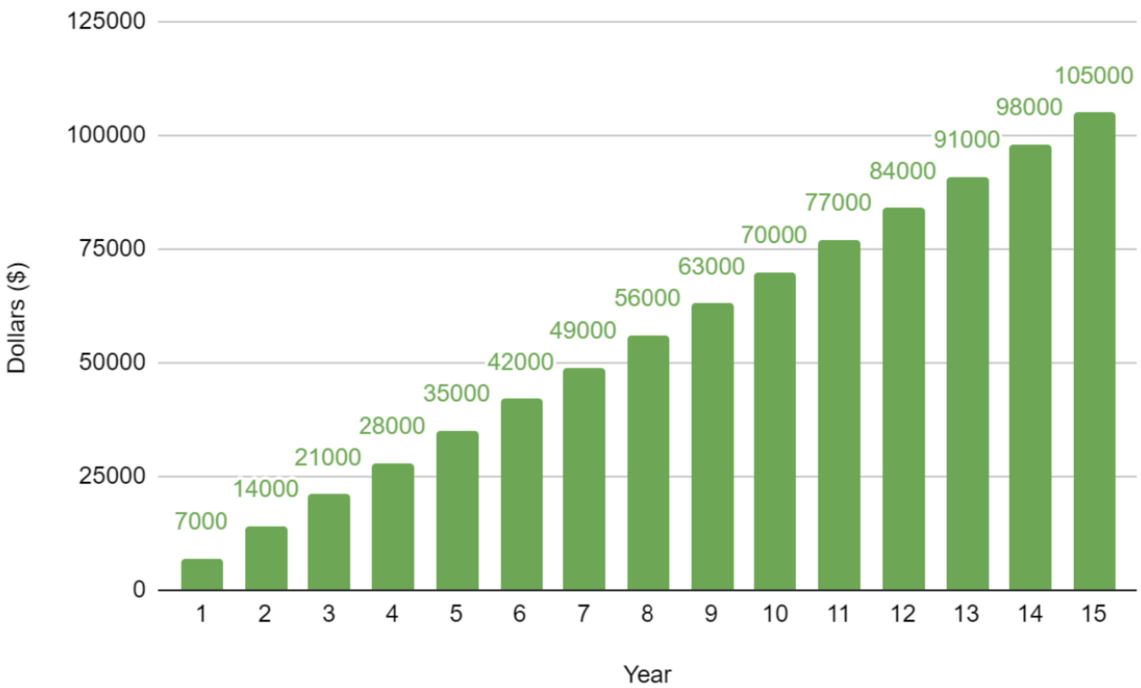

Fig. 4 LEED investment savings over 15 years.

7. Conclusions

The objective of this research project was to apply a student-scholar model in an educational setting for designing and constructing a LEED-certified residential steel home. It was determined after reviewing the cost analysis, there was an increase of 11% of the total cost of conventional building due to the addition of LEED features and it would take ten years to make up for the difference between the cost of conventional building and the LEED building. Having the opportunity to work in a team with such a diverse range of skills and backgrounds gave a glimpse of how the engineering industry works and problems engineers face daily. The project was a collaboration between the engineering and architectural students which further shortened the gap between the student-scholar model and real-life practice. The team was able to gain valuable skills in leadership, creativity, communication, and ethics through the entire process of the design, construction, and presentation of the project. Furthermore, the team was able to apply all the knowledge gained throughout the last years of studying to one project which incorporated all aspects of engineering.

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