ABSTRACT

In this undergraduate research endeavor, several seniors are gathered as an engineering team to utilize the knowledge obtained from all the classes to demonstrate the design and engineering of a two-story steel building. It is essential for the individual member of the team to establish a firm foundation of practicing design and comprehending the architectural and structural engineering processes to obtain the members for beams and columns, as well as the foundation sizes. In the architectural world, the exterior and interior designs are performed with the green building system which analyzes the various factors that influence the performance of a building in terms of water conservation, study of energy conservation, reduction in wastage, study of saving of materials, etc. Typically, the initial cost of construction of a green building is high and it requires advanced technology and skilled laborers, the cost and educational analysis are conducted to get a comprehensive price of the building and the potential growth of the real estate. While green building may be more costly initially, it will significantly reduce the environmental impact and the upcoming operational cost. In this research, a case study of a two-floor structure was performed including its architectural features, structural system, as well as the sustainability performance, to analyze how LEED features affect the short-term and long-term cost.

Keywords: Structural Design; LEED; Green Building; Cost Analysis; Engineering Education.


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1. INTRODUCTION

As civil engineering students of California State University, Northridge, the objective of our senior design project was to utilize the skills and knowledge accrued from our undergraduate studies. We seek to gain valuable real-world experience in architectural, structural, and
environmental engineering. To achieve this, our team was tasked with fully designing a two-story residential home in the heart of California.

An important factor of our project was the incorporation of environmentally friendly and LEED certified elements. These elements influenced the overall design from a very early stage, leading to an integrated design process. Mazza (2007) studied how modern, sustainable construction has altered the engineering process to include not only the engineers and owners, but all potential occupants. As a result, the community as a whole is able to design an environmentally beneficial structure. Additionally, the home is designed from steel, a material widely used in engineering. This allowed some freedom in the structural design due to the sourcing of the material. Reclaimed steel is offered in a large variety of standard sizes that are easily accessible and structurally safe. This is a well-established research topic investigated by many engineers (Gorgolewski et al., 2008). The presence of seismic activity provided its own set of challenges and experience. Its effect on the structure was analyzed and used to alter the final design. Some of these were shown by Vayas et al. (2003) in their study on the fatigue analysis of moment-resisting steel frames.

The most important aspect of this project is the process of learning. For our team, this design process was an entirely new experience. We hoped to spark creativity and utilize teamwork to accomplish a common goal.

2. ARCHITECTURAL FEATURES

The building was designed with many unique architectural features included. The structure features two impressive balconies that have incorporated glass railings to provide a great view of the surrounding flora and hillsides. In an effort to improve the occupants’ lives, a green room was added in the backside of the house. It features full-height glass windows which provide ample natural sunlight entering the room to help nurture all the plants that the owners grow.

Once structural design was underway, it became apparent that a column was needed between the kitchen and living room to support the deck above. In order to prevent a lone column from protruding into the room, an island bar and cabinets were used to help hide the column, making the area more visually pleasant, as well as providing a practical use to the residents. This island bar idea was inspired by a similar design concept featured in Houzz Magazine (2012), shown in Fig. 1.

![Figure 1. Similar design concept (Houzz, 2012)](image)
3. STRUCTURAL DESIGN

The idea for the structural design of the building was based on the architectural since the structure was to be a modern two-story residential home with many large openings. To be able to accommodate for the large openings and spans in the building the group chose to use steel for the framing of the building. The design process began by using the ASCE 7 (2016) code to find the seismic values that would need to be taken into account for the building’s design based on the location that the group chose for the construction. Now due to using steel for the majority of the building, the AISC 360 (2016) code was used as well as the 15th Edition of the AISC steel manual for member sizes. For the simplicity of the design and following common practice, the group designed the building roof and first floor first, for which W-sections were used for both the beams and columns in the building. The two-story structure had four different beam sizes which varied from main beams, girders, and joists due to the varying spans and offset walls of the building. The varying sizes in W10× and W12× beams logically demanded two different column sizes of W10× and W12× to avoid strong beam-weak column connections. Once we had the estimated loads of the building, we then designed the spread foundation by taking the worst-case scenario and applied it to the rest of the structure. Lastly, the resulting foundation based on the worst case scenario was a 36"×36"×36" spread footing with (4)#5 rebars at 8" O.C.. Table 1 provides a summary of the results for structural design.

Table 1. Summary of the results for structural design

<table>
<thead>
<tr>
<th>Structural Element</th>
<th>Design Results</th>
<th>Additional Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beams</td>
<td>W10×33, 10×45,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W12×30, W12×45</td>
<td></td>
</tr>
<tr>
<td>Columns</td>
<td>W10×49, W12×50</td>
<td>11-W10×29, 10-W12×50</td>
</tr>
<tr>
<td>Foundation</td>
<td>36&quot;×36&quot;×36&quot;</td>
<td>21 Total Pads</td>
</tr>
<tr>
<td></td>
<td>Spread Foundation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>w/ (4)#5 Rebar</td>
<td></td>
</tr>
<tr>
<td></td>
<td>@8&quot; O.C. (both ways)</td>
<td></td>
</tr>
</tbody>
</table>

4. DESIGN FOR SUSTAINABILITY AND LEED CERTIFICATION

One of the most important LEED features installed on this building were the cost efficient and environmentally friendly solar panels. For the residence, a 10kW solar panel system installed on 660 square feet on the roof would be enough to supply the home with power. Another important and effective feature was the rainwater collection system and greywater filtration system. Grey water is the used water from sinks, showers and washing machines that does not come into contact with feces. The system would filter and reuse the greywater from the house, which would enormously benefit the garden on the second floor since greywater is also an excellent fertilizer. It is cost effective by lowering the water bill and environmentally friendly because it reduces the water released into the sewer or septic system. Since water is a scarce resource in California, it is necessary to be conscious about its usage and waste. Fig. 2 illustrates a hybrid rainwater-greywater recycling system.
5. COST ANALYSIS

The installation of the LEED features on the conventional building increased the construction cost by 12%. While the construction cost of the building is higher, the installed features will eventually break even in approximately 7.74 years. The cost estimate includes all the various features installed. An example of the cost analysis can be shown for the installation of the solar panels. The installation of a 10-kW solar panel system would cost around $21,000 after taxes (Matasci, 2019). Using the ZIP code of the residence, 91302, an estimation of the solar panels production was researched to be roughly 16,000 kWh of electricity per year, saving the residence approximately $2,800 per year (Sendy, 2018). This means that the homeowner can break even in around 7.5 years, which is close to the national average, being just over 7 years for the U.S. (Matasci, 2019).

A rainwater collection system and a greywater filtration system are also installed, costing around $3,900 and $10,000 respectively. Other factors that contributed to the savings include energy efficient appliances: low-water dishwater, dual flush toilets, a smart thermostat and energy efficient laundry machines can save the house upwards of $1,000 per year. Although the savings on these features are relatively low per year, the savings over longer periods of time can be very attractive.

6. EDUCATIONAL OBJECTIVES

Engineering is known to be a male dominated field. While women have made strides to bridge this gap, the 2017 graph by (“Civil Engineers”) shows that there is much more work to be done. Women across all career paths have been working towards equality and while they make up 51% of the population, they make up less than 20% of this field of work (see Fig. 3).

Not only is there a clear gender gap in engineering but race is also a significant part in these statistics. As a diverse group, these statistics make it clear that we are part of the minority in engineering as the majority is white (see Fig. 4). White males lead the engineering world and having the opportunity to work in such a diverse group this year has made it evident that diversity allows for optimal growth and development in this field.
This undergraduate research project brought many realistic and valuable life lessons. First and foremost, a project of this scale requires excellent teamwork and communication between group members to effectively and efficiently complete the project. The members of this team displayed impressive workmanship and dedication, both individually and as a team. Their creative abilities and innovations resulted in a successful design, and extremely educational and beneficial experience. The project provided a realistic work environment for the members of this research team that come from different ethnic backgrounds, most of whom are recognized as a minority. This allowed for a diverse work environment, where every member provided a unique and creative input, resulting in the sharing and implementation of multiple students’ knowledge and experiences.

7. CONCLUSION
The project is comprised of the design of two floor plans on a site located in the city of Calabasas. Due to the site being on top of a hill, the structural components selected were made of steel and were engineered to take the loading created by the designed building. The team calculated the beams and columns that would be needed on both floors, the sizes of which are in Table 1, and created scaled structural plans that showed both sizes and locations of the structural members. Once these members were selected and the overall loading was calculated, the foundations were designed and placed on the last structural sheet. The group
then took the seismic calculations given the location of the proposed project to ensure the stability of the building and to verify a safe design. Once the structural integrity of the building was established, the group referred to LEED requirements for green buildings which would provide environmental and economical benefits that conventional buildings do not possess. The total financial benefits of green buildings are typically distributed over the lifespan of the building because the initial investment tends to be greater than that of a conventional non-green building. The implementation of added LEED features increased the initial cost of the building by about 12%, but this cost increase was justified by looking at the overall cost savings they provided, which resulted in a break-even time of about 7.74 years. Despite data limitations and the need for additional research in various areas, green building is cost-effective, particularly for projects that incorporate green design early in the design process. It was essential for the team to utilize the engineering and construction knowledge obtained in the undergraduate program in order to design a complete building from the architectural and structural elements. The design of the building helped the group solidify what had been learned and seen in theory at that point in time, and put that knowledge to practice in a real-world scenario where collaboration and diversity in the group was essential in order to create a successful project.

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REFERENCES