# On the Design of a Sustainable Steel Residential Building

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**Abstract:-***This paper discusses the design of a 2-story residential, moment-resisting structure using steel by Civil Engineering senior design students. Part of the effort was to include LEED features to the final product and to provide a cost analysis of both versions of the structure to determine the viability of converting an existing building to be LEED certified. It is hoped that the resulting analysis will help the readership better understand the costs associated with becoming a sustainable household, as well as to determine trends in the cost associated with becoming LEED certified. It can also serve as an educational tool to aid other engineers on the flexibility of such a project when considering the diverse background of the students and the culmination of ideas to make such a project flourish*.

**Keywords:** *Steel Structure, LEED, Cost Analysis, Engineering Education, Residential*

## 1. INTRODUCTION

Concern for the environment and the impact from construction and the structure itself have slowly worked their way into the engineering domain. The demand for environmentally sustainable structures has steadily increased, and thus the new generation of engineers will need to take on the responsibility of making sure that these new ideas stay at the forefront of our designs. However, the issue of costs tends to be the limiting factor in choosing how far to take sustainable features seriously. The main goal of this project was not only to act as an educational opportunity on designing a home, but to evaluate these costs and determine the best course of action to fulfil the requirements of becoming a LEED certified structure.

In 2003, in a small town located in Johnson County, Kansas, U.S.A., the city council of Johnson County approved designs for a Gold Certified LEED office building to expand several municipal management departments and provide new workspaces. Prior to approval of these designs, a consultant was hired to assess three scenarios, two of which compared LEED Gold and LEED Silver with a standard Class 2 office building [1]. The consultant found that, although the initial costs of the Gold certified structure would exceed that of the standard, it would have a payback time of roughly 10 years and would nearly double the lifespan of the building. Construction of the building, The Sunset Drive Office Building, was completed in 2006, and opened to welcoming praise amongst the community and city workers that would occupy the building. The structure itself focused on natural lighting and allowing individual workers to control their workspace climate.

Though the structure was designed to occupy offices, it achieved its goals of having the environment in mind and to set a new standard for Johnson County, Kansas. The design of this home can be considered a practice run, a test to view the impact of a potential new series of homes in the United States and across the globe, with the overall goal to achieve at least the minimum certification within the LEED system. It is also purely theoretical, to serve as an educational opportunity for the group to obtain practice in the architectural portion of the project, the design of the structural elements that follow all applicable codes and taking the cost of projects of similar scales into account. With these key points, 3 major aspects of the construction process can be covered and allow this group of diverse students to achieve a new understanding of real-world applications.

## 2. ARCHITECTURAL FEATURES

Our architectural standard for this project was a 2-story home built with steel averaging 1000 ft$^2$ per floor. We approached this design by taking into consideration the plot we chose in the Pacific Palisades overlooking the ocean and studied previous architectural home designs in Los Angeles to design our floor plan.

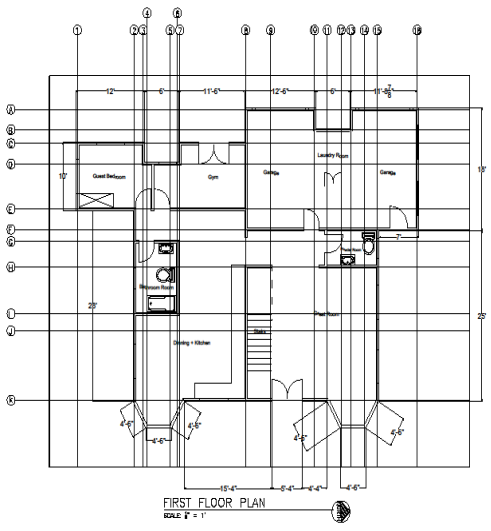


**Fig -1**: First Floor plan

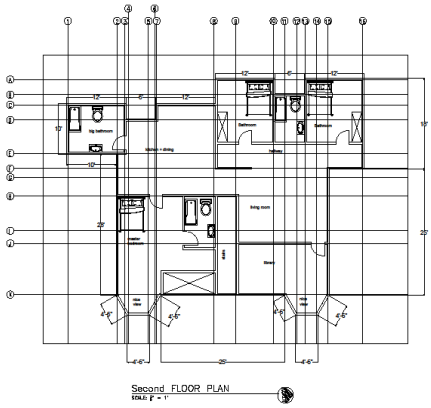


**Fig -2**: Second Floor Plan

## 3. STRUCTURAL DESIGN

The building is a low rise building which consists of 2 stories, at approximately 950 ft$^2$ per floor using A992 Steel. It was decided that it is best to use W8×10 which is the smallest W shaped beam size for joists and made that decision based on the strongest joist, which is on the second floor. As for the beams/girders, it was best to use W12×14 for all beams. We made that decision after calculating the size of the longest span length beam on the2nd floor. The way it was determined to see if those beams would work is to find the maximum required moment strength acting on simply supported beams and joists. Based on the results, AISC fifteenth edition table 3-2 was used to choose the lightest section that satisfies the requirement.

Steel framed residential structures are not a new concept, as represented in Australia, where single-story detached homes are made using either timber or steel. By using steel rather than timber, the natural frequency that the structure can take can be increased by a factor of 2, and significantly increase the lateral strength of the structure [4]. Therefore, so long as this structure is designed in a way to maximize the amount of lateral force absorbed or transferred, choosing steel can be a logical, albeit costly, alternative to using timber. And in a state, such as California, it would be wise to consider the seismic aspect of design into the main structural design elements.

**Table 1.** Summary of the results for structural design

| *Structural Element* | *Design Results* | *Additional Explanation* |
|---|---|---|
| Beams | W8×10, W12×14 | Smaller Size Denotes |
| Columns | W8×31 | Typical for both floors |
| Foundation | Spread Footings, L 3.5′× W 3.5′× H 2′, | |

## 4. DESIGN FOR SUSTAINABILITY AND LEED CERTIFICATION

As Engineers in training entering the industry, we must take into consideration the environmental impact, sustainability, and conservation of energy of our designs. LEED certified buildings has been a hot topic in the construction industry, it is a “verification that a building or community was designed and built using strategies aimed at improving performance across all the metrics that matter most: energy savings, water efficiency, carbon dioxide emissions reduction, improved indoor environmental quality, and stewardship of resources and sensitivity to their impacts”. The components added to our building to help with energy efficiency and sustainability are, solar panels, thermal efficiency windows, energy star appliances, insulation and a high efficiency heat pump.

Solar panels will be an efficient way to use the sun to help power the building by absorbing incoming energy from the sunlight. Wires capture and feed this direct current electricity to a solar inverter to be converted to alternating current electricity which then can be used. High thermal performance windows will keep energy from being lost in the building. The appliances are ENERGY STAR certified, which means that they use less energy than their conventional, non-energy efficient counterparts. Heat pump systems reduce energy consumption associated with the heating and cooling system and can help a project achieve LEED certification. With these LEED features our home has been Silver certified with 41 points.

## 5. COST ANALYSIS

After the LEED additions to our building discussed above, the total cost difference for making our home silver certified would cost an extra $253,315. The LEED costs would be a 25 percent increase in sustainability cost. The costliest features of these LEED upgrades would be the solar panels but would also be the feature that would conserve the most energy and eventually keep saving money. The 25 percent increase would be an initial investment that would be paid off in 12 years saving money afterwards.

**Table 2**. Structural Steel Cost Estimates

| *Item* | *Size* | *Quantity* | *Cost* |
|---|---|---|---|
| Column | W8×31 | 85 | $69,010 |
| Beams | W12×14 | 112 | $32,513 |
| Joist | W8×10 | 168 | $29,030 |

Total Cost: $140,554

**Table 3**. Total Cost Estimate

| *Building* | *Cost* |
|---|---|
| Excluding LEED | $732,097 |
| Including LEED | $985,412 |

## 6. EDUCATIONAL OBJECTIVES

This educational research provided a unique opportunity for undergraduate students in Civil Engineering to work and learn as a collective group. The core objective of this research was designing a two-story residential house with a steel moment frame design. The unique portion of this research was not completing the core objective; instead it was how we worked as a group to complete the tasks on hand. It is important to note that in a group consisting of six students, there were representatives from different cultures and genders. This educational research gave a platform for women in engineering and the minority to showcase their engineering skills. This diversity created a very distinctive atmosphere that allowed creativity and teamwork to thrive. Each member of the team contributed different ideas and as a collective group we were able to infuse those ideas into the final product.

The team came up with an architectural floor plan, structural plans, the seismic design and the foundation design. Most portions of the project we learned from previous classes but this particular project challenged us to apply our knowledge to real life problems. Once the design of the house was completed, the team was challenged with a new problem, making the house LEED certified. This aspect of the project is very important for Civil Engineers in the modern age. Green buildings are becoming a significant part of Civil Engineering and with the knowledge gained from this research; we will be more comparable once we enter into the industry.

## 7. CONCLUSION

The overall reaction of this educational research was a success. The purpose was to design a 2-story residential structure, which the team accomplished accordingly, with minor delays during the design phase. LEED features were also applied to the building, helping the design to achieve certification with 41 points with a 25% increase in overall costs and a 12-year payoff period. The teamwork demonstrated between each member helped streamline the design process, all the while understanding the details of floor plan layouts and structural design. The diversity of the team also contributed to the unique design methods and choices applied to this project, highlighting the value of teamwork between members. Thus, the final project was deemed a success amongst the group, with all major aspects of the design phase covered while adhering to all applicable codes and allowing the creativity of the team show on the building.

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## REFERENCES

[1] Joerke, J., Waters, J., and Gavito, G. (2012). "Gaining Support for LEED®-Certified Facilities in Local Government: The Case for High-Performance Buildings", SAGE Publications Inc, 156-161, 44(2)

[2] AISC (2018). "*Steel Construction Manual*", American Institute of Steel Construction

[3] ASCE (2017). *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-10, American Society of Civil Engineers, Reston, VA.

[4] Gad, Emad F., Chandler, Adrian M., and Duffield, Colin F., (2001). "*Modal Analysis of Steel-Framed Residential Structures for Application to Seismic Design*", Journal of Vibration and Control, 91-111, 7(1)

[5] Lawson, R. M., Ogden, R. G., Pedreschi, R., (2008). "*Developments of Cold-Formed Steel Sections in Composite Applications for Residential Buildings*", Advances in Structural Engineering, 651-660, 11(6)