# Research on the Design and Green Certification of a Residential Steel Building

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**Abstract:** *In an ever-advancing world, sustainable structures are an important factor in modern design. Civil Engineers being environmentally conscious must consider many things when designing a structure in their practice. From the Fundamental Canons of the National Society of Professional Engineers (NSPE) Code of Ethics, engineers must hold paramount the safety, health, and welfare of the public. In considering the welfare of the public, an engineer must consider the future of the public. Civil Engineering students at California State University, Northridge (CSUN) researched and designed a two-story, 4,000 Square feet (sf) steel framed residential home. In considering sustainability, the Leadership in Energy and Environmental Design (LEED) Certification guidelines were researched to explore methods to reduce power consumption, waste, and increase efficiency. The main purpose of this project was to design and to research the cost of achieving a LEED certified building and determining when the features would create a return on investment. This research serves to educate others about the benefits of LEED certification, not only in the short term but over the life of the building.*

**Keywords:** *Engineering education, Sustainability, Steel residential, LEED certification, Green building*

## INTRODUCTION

Residential buildings are built with few if any LEED features to reduce cost in order to attract customers, however utilities cost more. The purpose of this research is to design a 4,000 sf, two-story residential steel building featuring LEED standards to help make the building more environmentally friendly and estimate how many years it takes to pay off the extra cost of including LEED features in this building.

This project required designing a residential building from scratch. Designing this structure included selecting the right beam and column size in order to meet the architectural concepts and safety standards. A cost estimate was also generated so we could compare the price of the building with and without LEED features.

This project was challenging in that all the members of this group are still undergraduate students, so a lot of additional research and self-taught strategies had to be implemented to meet the project standards and deadlines. Additional resources such as advice from respectable professors and the internet assure that we overcame the challenges posed by this project and successfully designed a residential building.

## ARCHITECTURAL FEATURES

Capturing the best that nature has to offer was the driving force behind the design of this two-story 4,000 sf residence. The layout of the space is centered upon a large open space that is divided among the entry foyer, great room and dining area. The rear of the home maintains a curved wall of glass, which is unimpeded from the entry area. The ocean and the surrounding coastal hills are viewed from the rear glass and oneness with nature is promoted.

The entry is abutted with curved stairways which ascend decoratively to the upper floor. The ground floor is balanced by a formal living room that allows open passage to the kitchen and nook area. The living room as well as the nook has views of the hills as well as visible ocean to the north. The kitchen and nook share the rear view. Social interconnectivity is promoted with the openness between the great room, dining area, kitchen and living room as seen in Fig. 1.

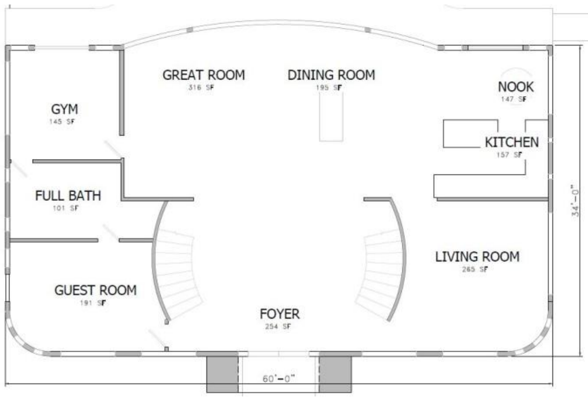


**Fig. 1.** *Ground floor plan*

The upper floor as seen in Fig. 2 maintains the living quarters. The master suite is situated between the rear glass wall and the landing of the stairs. The suite has private access to the NW balcony, walk-in-closet and master bathroom. It has access to the SW balcony which is shared by the library (optional bedroom 5). The floor is served by full bathrooms on either side of the building. There is a kitchenette and utility room that also serve the living quarters.

The maximization of windows as seen in Fig. 3, permits nature to be in full view and gives much needed natural lighting. The privacy of the bathrooms is maintained by using smaller windows and portcullis openings high in the rooms. The garage is detached with two spaces accessed from a rear pedestrian entry as well as an 18 ft double door. The entry is accentuated by an arch mounted on pillars which enclose a glass superstructure that houses the primary portal.

The exterior of the home maintains a marble veneer which cooperates with the glass to emit a clean and modern look. The roof is outlined by an 18 in cornice. A private access door affords direct entry to the guest room. There are sliding glass doors and French doors that afford access to the balconies and patios.

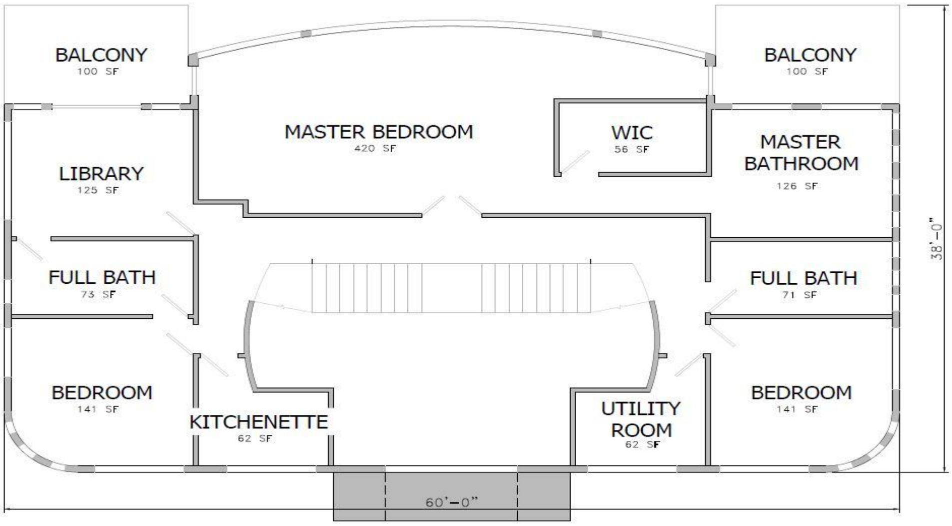


**Fig. 2.** *Second floor plan*


**Fig. 3.** *Building exterior elevations*

The cantilevered balconies are lined by a glass barrier. The front of the residence has a five-foot radius fillet with a trio of windows arrayed symmetrically on either side on both floors. This combined with arch topped windows on the front elevation soften the lines with the use of curves. There is ample space in the center of the residence for art and furniture to accent the natural spectacular views.

## STRUCTURAL DESIGN

The structure shown is a two-floor residential structure with a height of 22 ft (each floor is 11 ft high). According to the ASCE (2005) code for residential structures the live load to be used is 40 psf. The beams chosen are strong enough to hold that weight safely because it was designed using Load and Resistance Factor Design (LRFD) which has a safety factor of 1.6 on the live load and 1.2 on the dead load. The columns were designed next, which was designed to hold the beams with the applied loads on it and with a height of 11 ft, it was also designed using the LRFD method. The information needed to choose the geometry of the steel beam and column was found in the American Institute of Steel Construction (AISC) Steel Manual 15th edition, and were W8 or less because it is preferred for residential buildings and smaller structures to have smaller beams and columns. The foundation used is a concrete foundation with steel reinforcement, the foundation is a simple spread footing under each column. Beams, columns and foundation information shown in the table below:

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

| Structural Element | Design results | Additional explanation |
|---|---|---|
| Beams | W41×13 | - |
| Columns | W8×31 | - |
| Foundations | Width=5′11″ Length=8′ Height=1′5″ | #6 steel rebars 9″o.c. each way |

The garage was designed separately from the house itself because it is located underground. The garage is underground therefore a retaining wall was designed with a height of 14ft and a depth of 3 ft, giving a space of 11ft which is also the same height as any of the residential floors. The retaining wall designed is a cantilever retaining wall and is one of the most commonly used resting walls. The base of the retaining wall is 9ft, the tie is 2ft and 2ft thick, the thickness of the stem at the base is also 2ft. We used 135 pcf as the unit weight of the saturated soil. The garage roof was designed as a concrete slab with a thickness of 15ft because of its long length of 24ft minimum thickness requirement is L/20. #4 steel reinforcement used was also applied to the concrete slab with a spacing of 6in o.c. 5,000 psi concrete was used which is the strongest available for residential buildings.

## DESIGN FOR SUSTAINABILITY AND LEED CERTIFICATION

LEED is the most widely used green building rating system in the world. The system framework for homes was used for this project. The United States Green Building Council (USGBC) maintains the rating system. Paramount in modern construction is a holistic design that combines safety, sustainability, efficiency and intelligent apportionment of useful space per Haasl and Heinemeier (2006). Traditional energy and water use efficiency are very much a part of green design. Selections of materials and rated devices are a large factor in the accreditation process. Credits are accumulated and LEED awards are based on these scores per Vierra (2011). There is LEED Certified, LEED Silver, LEED Gold and LEED Platinum.

**Table 2.** *Summary of the results for LEED design*

| Earned | Category | Maximum |
|---|---|---|
| 6 | Location and Transportation | 15 |
| 6 | Sustainable Sites | 7 |
| 10 | Water Efficiency | 12 |
| 34 | Energy and Atmosphere | 37 |
| 7 | Materials and Resources | 9 |
| 18 | Indoor Environmental Quality | 18 |
| 2 | Innovation | 6 |
| 0 | Regional Priority | 4 |
| 83 | Total | 110 |

The rating system for homes is divided into eight categories. Each category has prerequisites that must be fulfilled before credits are earned. The credits are earned on design features, and accredited actions being accomplished. A predesign pair of points are earned in the integrative process. The following was accomplished in the design of this building.

The first category, Location and Transportation, points were earned on the prescriptive path due to the hillside location not being in protected or sensitive lands. In Sustainable Sites, no invasive plants or toxic pest control were used and rainwater management was designed to fulfill the criteria. Rainwater is not permitted to cause erosion or undermine the structure. Non-toxic pest control was achieved by spacing the foundation and walls from ideal pest living areas. In Water Efficiency: the measures involved devices to control the flow of water, use of materials to minimize leaks and backflow and additional efficiency control devices. Energy and Atmosphere: The prerequisites required education of the builder and homeowner, uses of meters as well as

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minimum energy performance of devices used in the residence. The credits were earned by the use of enhanced efficiency hot water heaters and distribution systems to minimize waste of water before showering or faucet use. In addition, energy tracking devices as well as communication of data to third party sites earn points. This building is in Climate Zone 3.

Materials and Resources prerequisites are durability management and no use of tropical woods. This category qualifies materials based on recyclability as well as environmental sustainability. Use of these materials are primarily in the partition walls, wood framing between the columns and beams. The windows, doors and appurtenances were all installed per the qualified list and under durability management verification. Indoor Environmental Quality prerequisites involve venting and management of devices that emit exhaust or have the potential to pollute. Having a detached garage, not installing wood stoves or fireplaces contributed to the prerequisites and credits. Using enhanced pollutant and combustion venting by Energy Star rated devices. Innovation is a category that is rated upon review. It is not rated by the design team or the client. Regional Priority: There are special points to be earned by approval of one of the six regional councils of the USGBC. The result from our analysis is that 83 points are possible under full implementation of LEED design, maintenance methods and devices. This means that LEED Platinum is possible.

## COST ANALYSIS

The cost analysis for this residence yielded a building projection of $413,930 (RSMeans) for the building alone, not including any LEED features. This amount covers raw materials and labor costs as outlined on RSMeans, however it does not take into account the cost of the site. Table 3. Shows the largest expenses from our cost analysis and the total building cost, not including any LEED features.

**Table 3.** *Building Cost Analysis (Non-LEED Estimate)*

| Item | Amount | Unit | Cost | Item | Amount | Unit | Cost |
|---|---|---|---|---|---|---|---|
| Columns | 418 | LF | $30,710 | Marble Floor | 3500 | SF | $44,135 |
| Beams | 920 | LF | $24,564 | Concrete | 1512 | PCF | $14,530 |
| Plumbing | | All | $14,669 | Electrical | | All | $13,509 |
| Landscaping | | All | $5,620 | HVAC | | All | $9,757 |
| Roofing | | All | $9,757 | Exterior Wall Framing | | SF | $14,609 |
| | | | | **Total Cost To Build** | | | **$413,928** |

The LEED cost estimation was based on average values and prices specific to the chosen location. The list of LEED features and costs is too extensive to be included here, however the total cost of these green alternatives was determined to be $220,000 which represents roughly 53% of our initial building cost. This number may seem a bit high but it includes plenty of green amenities such as solar panels and a rainwater harvesting system, which over time will pay for themselves.

**Table 4.** *LEED vs Non-LEED Construction Costs Comparison*

| Total Building Cost (Non-LEED) | LEED Cost | Total Building Cost (LEED Included) | % of Total Building Cost Designated for LEED features |
|---|---|---|---|
| $413,930 | $220,000 | $633,930 | 53% |

The energy yearly cost for our residence which includes electricity and gas was estimated to be around $2,000. This energy demand will be covered by our solar panel system. At this energy consumption rate and with an initial cost of $5,000 our solar panel system will take about 3 years to pay for itself. On the other hand, our water yearly demand calls for roughly 90,000 gallons at an estimated cost of $600 (Californians' water use). This water consumption rate will be met by out water harvesting system which costs $5,600, (Pre-filtration) at this rate it will take about 9 years for our rainwater harvesting system to pay for itself. The remaining green features will also have a positive impact on energy efficiency and cost savings, however, much smaller than the two discussed above.

The LEED estimates are designed to ensure sustainability, efficiency and to decrease the negative output of our residence. Although it increases our building cost by a considerable amount, it is a sound investment that offers benefits that far outweigh the negatives and most importantly, the LEED features will ultimately pay for themselves.

## EDUCATIONAL OBJECTIVES

In researching and designing for this educational project, students increased their knowledge of many aspects of design including steel design, concrete foundation design, cost analysis, architectural design, and seismic design. Following AISC, American Concrete Institute (ACI), and American Society of Civil Engineers Region 7 (ASCE 7) guidelines, students were able to create a modern two-story house that meets the environmental standards of a green building and is therefore able to contribute to current and future conservational efforts.

Settling at a simple design was not sufficient. Creating a sustainable and serviceable structure was the challenge that the students were eager to solve. As a team, the students researched what is required to follow LEED guidelines. Passionate about minimizing the carbon footprint that is generated, the students researched features that can be implemented. The information acquired is crucial to know as a civil engineer that can be applied on future projects to increase sustainability.

With great leadership, the team applied their existing and newfound knowledge along with their work ethic into the design of a 4,000 sf steel residential building. By the end of the design phase, the students acquired a fundamental understanding of what is required from present-day civil engineers. The students were confident in their desire to learn more about steel-framed LEED design.

## CONCLUSION

The house was designed to be built at Newport Beach, California. Hence, the structural and seismic calculations of the residential building were done with respect to the location. The cost analysis of the building was done based on both LEED and without LEED implementations. The cost of the residential building without LEED is estimated at $413,930 while the cost of the building with LEED implementations would cost $633,930. The $220,000 LEED implementations on the residential building would help in conserving energy and reducing pollution. The 53% rise in cost due to LEED features is considerably high, however it would be a great benefit in the long run as the residential building is expected to be used for 50 years. In conclusion, green building is a great first step toward preserving the future of our planet.

## Acknowledgment

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