

# Undergraduate Design and Analysis of a LEED Certified Building

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**Abstract:** In this technical and educational research endeavor, a diverse group of civil engineering students took on the role of creating the means and methods of producing a successful building design. Architectural, structural, and environmental designs were primarily performed. This was followed by detailed cost analysis with the intent of providing a realistic cost comparison by pricing the intended building, using traditional material and typical building methods, versus pricing the building using recycled material and new present-day technology. Some green features needed to achieve a LEED (Leadership in Energy and Environmental Design) gold certification were considered and applied. It is shown that producing a green building is more costly in present circumstances; however, the additional cost due to greenification pays itself off throughout the years giving in return saving features. Even though the design of a green building comes with detailed planning and costly material, it does generate benefits for the building owner, the society, and most importantly the environment.

**Key words:** Structural design, LEED certification, green building design, cost analysis, engineering education.

## 1. Introduction

With the rise in human population and rapid urban development in the last two decades, buildings have become liable for higher energy demands globally and in the U.S. Buildings account for 39% of global energy use and 68% of electricity consumption nationally [1]. Furthermore, studies have shown that commercial buildings contribute negatively to the environment [2] thus, environmentally friendly buildings continue to spearhead innovation in architectural and structural design. With this in mind, this paper will explore the literature surrounding green buildings, current existing LEED (leadership in energy and environmental design) certified structures, and the implications of these findings showcase how they intertwine with the design of our own residential building. For the purposes of this paper, the terms “environmentally friendly” and “green buildings” will be used interchangeably.

Designing a green building requires a fundamental understanding of the LEED system and requires a thorough project cost analysis. LEED is a holistic rating system founded by the USGBC (U.S. Green Building Council) used to encourage innovation and act as a template at the conceptual and transformative stages for green building design [3]. Green buildings are globally recognized as an alternative solution to negate high energy demands from all types of buildings by efficiently using natural resources, reducing waste, and reducing the depletion of essential resources [1]. The holistic aspect of the LEED system is further solidified with the growing evidence in literature that building green can positively impact the health and well-being of the individuals residing in the building [4]. These positive effects on population health and the environment are shown in already existing green residential buildings. For example, The Visionaire, located in New York, is certified LEED Platinum and features a waste water reduction system, a criterion for indoor air quality, and maximizes the views and natural light of the building itself [5].

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Residents of the Visionaire have access to higher air quality and natural light, thus promoting their health and well-being. Additionally, the Visionaire was designed to reduce energy consumption by 35% during peak hours to reduce the energy it draws from New York's electrical grid infrastructure [5]. The Elleven South Lofts located in Los Angeles, California further propagates the positive impact a green building can have by including various green features such as an energy and water efficiency systems and operable windows. Though it is financially upscale, it showcases multiple returns in the form of increased occupancy rates (3.5%), building value (7.5%), and a return on investment (6.6%) [6]. Lastly, a certified LEED silver building, The Eastern Village Cohousing Condominium, located in Maryland, is a building that was built in the late 1950's but was refurbished into a green building in 2004. The condominium features a storm drainage system, a green roof, a multitude of energy star appliances, and planted balconies that provide air circulation and cool the building [7]. These existing buildings display how green buildings are beneficial at the economical and environmental scale, and promote population health and wellness. As such, future engineers have a holistic duty to uphold when designing future residential buildings.

Found within this paper is a presentation of the research and the proposed design of a residential three-story residential green building done by undergraduate civil engineering students. The initial stage of the project begins with the design of the floor and elevation layouts of the building itself. Finally, the structural design is then modeled using the RAM structural system and is presented for further review. To attain LEED certification, the building features the addition of various environmentally friendly features to make the building sustainable and efficient. The amalgamation of the preliminary stages together with a detailed cost analysis of the proposed additions, will undoubtedly be used as the backbone for future LEED

certified building designs.

## 2. Architectural Features

A set of guidelines were given to start the architectural design process. The building had to be three stories and have a minimum square footage per floor of 2,000 square feet. It was decided to make the floor plan contain two bedrooms and one bathroom, along with a kitchen, dining room, and living room. The first floor contains a mail room for guests, which required the first floor's residents' suite to not include the dining room space. There is a staircase located on the top right corner of the building going upwards throughout the three floors. A laundry room was included for all guests' residents on all three floors. Fig. 1 shows the typical floor plan that the second and third floors of the building replicate. Fig. 2 shows the RAM model for the proposed building.

Along with these features, additional modern and LEED features were incorporated. These include a large dining room, kitchen, and living room design, along with windows that are featured on all sides of the proposed building. These are not only added for aesthetic, but also help incorporate natural lighting into each floor of the building. In addition to these features, a flat roof with natural vegetation was incorporated in order to provide space for residents to enjoy.

## 3. Structural Design

The two main structural design guidelines that were followed were that the building be designed as a steel frame structure and that the lateral resisting system be designed to moment frames. The moment frames of the building were designed to be bolted connections, following the design specifications listed in the AISC (American Institute of Steel Construction): *Steel Construction Manual* [8]. The use of bolted connections was selected given that bolted connections add flexibility to the connections during load transfers, allowing more movements with less stress on the building (Seismic Design Categories considered).

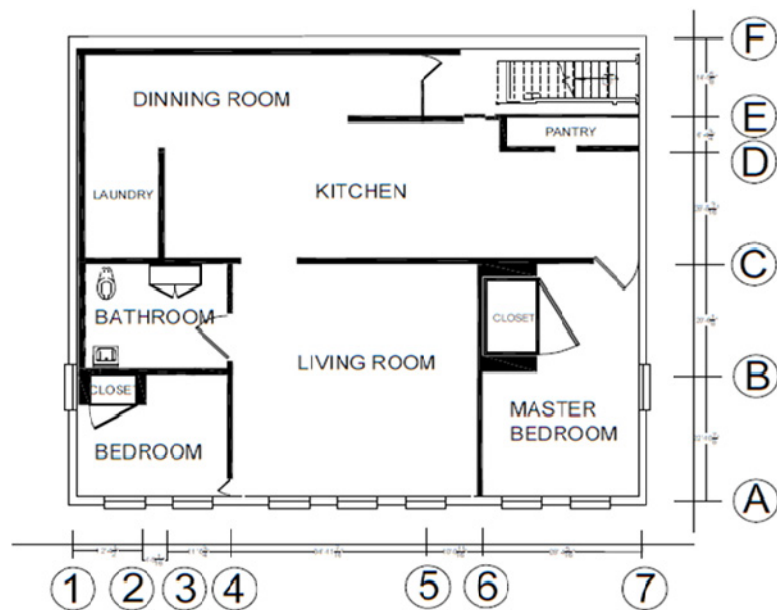


Fig. 1 Typical floor plan.

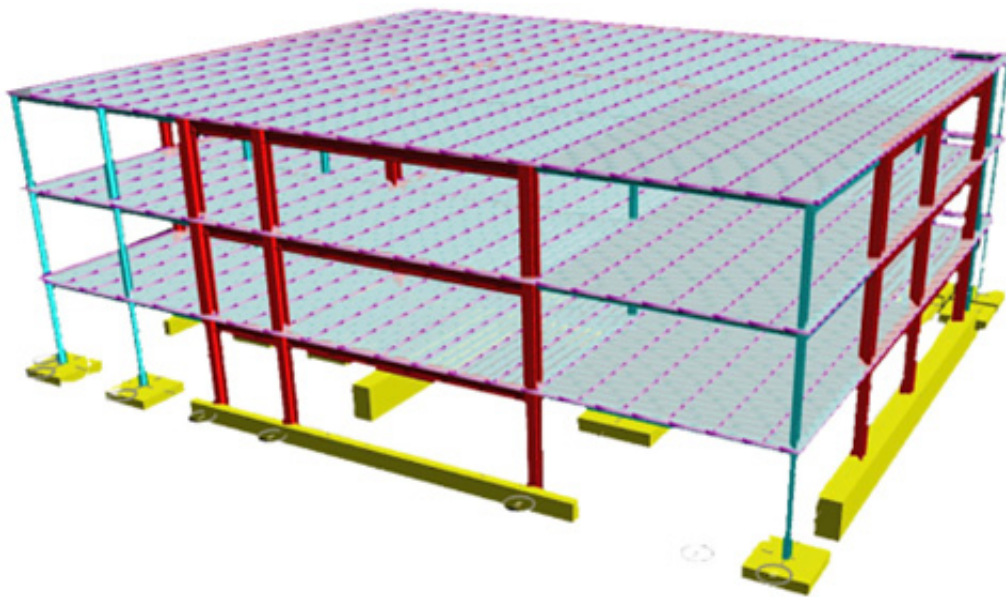


Fig. 2 RAM structural model of green building.

The three main gravity beams that were selected were W18×192, W14×22 and W12×16. Intermediate beams were also added spaced 18 in. O.C from the girders, the size of these beams was designed to be W10×12 and W8×10. The columns were spliced after the second floor in order to optimize the economical efficiency of the building. The columns on the first two floors were designed to be 12×65, and the third-floor column sizes were 10×45. The gravity

column foundation was designed to be a spread footings, 5'×5' with #6 bar sizes spaced 12 in O.C.

#### 4. Design for Sustainability and LEED Certification

By 2014, residential and commercial buildings made up 14% of total energy consumption in the United States [9]. Many activities make up this consumed energy from transportation and manufacturing

materials to construction and daily operation of the building. As a result, technology and science continue to find new ways to reduce negative environmental impacts by expanding on green buildings and sustainable design. There are multiple systems used for green building development throughout the world such as, LEED (Leadership in Energy and ENVIRONMENTAL design), BREEAM (Building Research Establishment Environmental Assessment Method), DGNB (German Sustainable Building Council) and CASBEE (Comprehensive Assessment System for Built Environment Efficiency) [10]. However, since the project's green building was made with LEED in mind, all discussion will refer to it.

Developed by the USGBC, created in 1993 to promote construction sustainability [11], the LEED rating system was initially released in 2000 and has been updated since the current version, LEED v4.1. There are multiple rating systems within LEED with

scorecards for construction, retail, hospitality and healthcare. For this green building, the building design and construction scorecard was used with eight categories for a total of 110 credits that can be earned. There are multiple credits that can be earned in each for certain requirements. Depending on the amount of credits, four certification levels can be reached: 40-49 for Certified, 50-59 for Silver, 60-79 for Gold, and 80-110 for Platinum. Fig. 3 shows the LEED v4.1 scorecard where each category is broken down into requirements that are assigned with a certain number of credits, all adding up to 110.

For this project's residential building, the level of certification achieved was Gold with a total of 60 points. For location and transportation, bicycle facilities and an electric vehicle charging station were added as well as the location of the building being near bus stops. A RainFlo 5100-PRO rainwater collection system was installed along vegetated roof

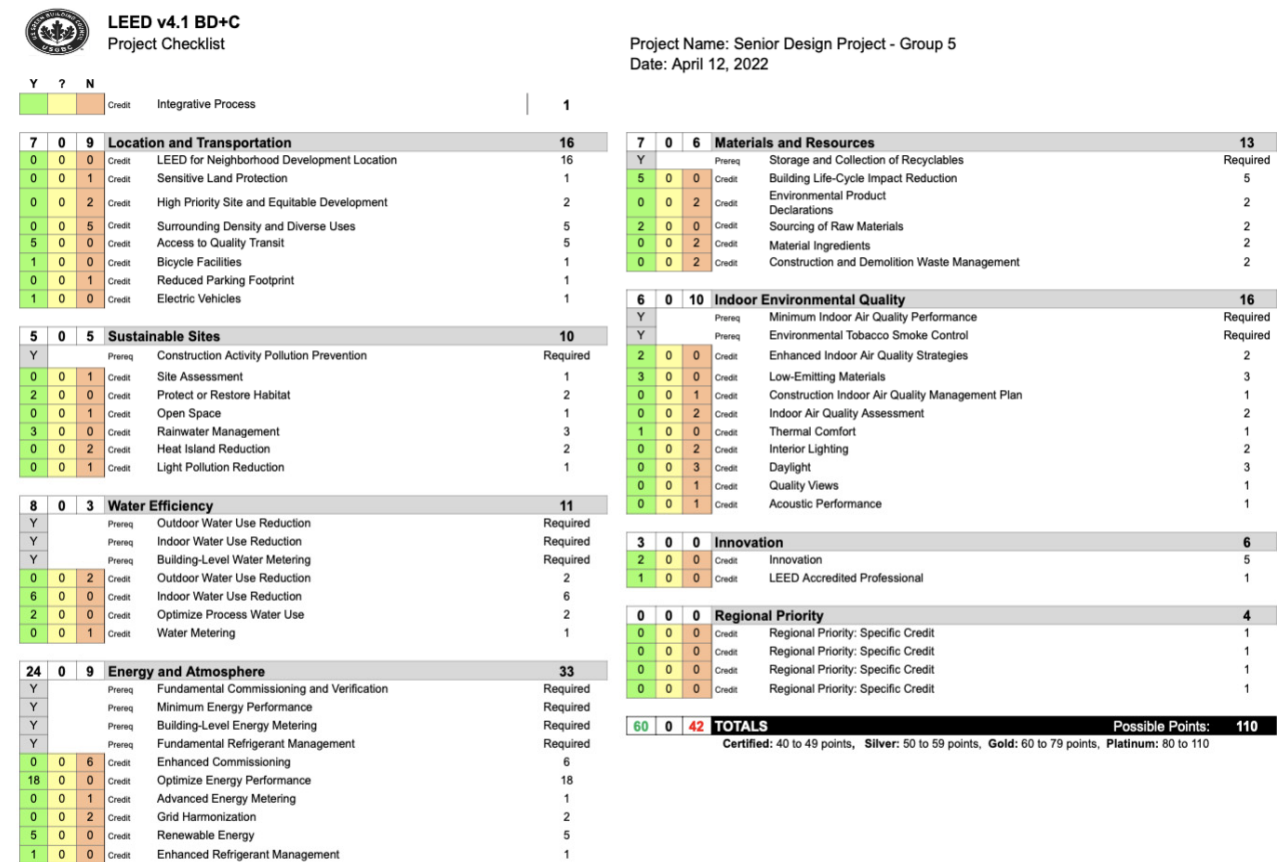


Fig. 3 LEED scorecard.

**Table 1 LEED features cost analysis.**

LEED features	Cost	Points	
Location and Transportation			
Bicycle Facilities	\$900	1	
Electric Vehicle	\$4000	1	
Access to Quality Transport		5	
Sustainable Sites			
Rainwater Management	\$5,075.00	3	
Protect or Restore Habit		2	
Water Efficiency			
Indoor Water Use Reduction	\$1,650	6	
Optimize Water Use	\$3,882.00	2	
Energy and Atmosphere			
Optimize Energy Performance	\$5,300	18	
Renewable Energy	\$10,684	5	
Enhanced Refrigerant Management	\$1,000	1	
Materials and Resources			
Sourcing of Raw Materials	\$10,000	2	
Building Life-Cycle Impact Reduction		5	
Indoor Environmental Quality			
Thermal Comfort	\$5,000	1	
Low-Emitting Materials	\$2,513	3	
Enhanced Indoor Air Quality	\$2,240	2	
Innovation			
Innovation	\$150	2	
LEED Accredited Professional		1	
	\$52,394	60	LEED gold

surfaces for sustainable sites. For water efficiency, indoor water use was reduced with the use of an Energy Star dishwasher and washing machine, a cooling tower to optimize water use and water meters for irrigation. Water efficiency and sustainability have become more important than ever with climate change causing historical climate data to change rapidly causing larger chances of floods, droughts and storms [11]. Energy efficient interior lighting, daylight responsive lighting, solar panels, an efficient refrigerant and an efficient HVAC (Heating, Ventilation, and Air Conditioning) system were added for energy and atmosphere. Adding energy efficient systems to the building helps promote green power and carbon offsets by supplying renewable energy and reducing greenhouse gas emissions using heating, ventilation, cooling and lighting appliances [11]. By reducing the building's negative environmental impact,

the Life Cycle Assessment increases. Energy is also saved by sourcing raw materials, installing an ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) engineered natural ventilation system, rollout mats, low-emitting paints, flooring and insulation. With all these LEED features added, occupant satisfaction will increase [12] as well as promote pro-environmental behavior in occupants such as recycling more often, using natural light over artificial and saving water [9]. Finally, having a LEED accredited professional on the project can help plan and organize during LEED specific meetings as seen when Scott [13] studied the process of developing a LEED military facility.

## 5. Cost Analysis

Greenification does result in a slightly higher end cost for an average building but the features added to

the building can also have a quick financial return. For an average 3-story residential building the costs for all materials resulted in a total of \$1,025,223.63. When considering LEED features the building only increases by 5% which adds only \$52,394 to the ending costs of the gold LEED certified building. Only a 2% difference from the usual 2%-3% cost increase was seen in LEED buildings [14]. LEED features like solar panels and HVAC systems can also pay off those additional costs in just about a couple years after installation making the additions even more desirable. The solar panels for example can take anywhere from 5-9 years to pay off depending on the abundance of sunlight in the area. HVAC systems immediately after installation can contribute to paying off the LEED features. Considering the LEED features in Table 1 it would take about 8 years to begin paying off the features and about 25 total years to have the features completely paid off without any government assistance. For this reason, many owners and investors are looking into developing and innovating green buildings [15].

## 6. Educational Objectives

The LEED research project introduces the student-scholar model and exposes students to a variety of avenues civil engineering offers such as, project management, structural engineering, and environmental engineering. The project exposes students to valuable skills that are needed in the field of engineering. Being a part of a group that encourages creativity, teamwork, and innovation, it teaches skills that transfer seamlessly to the field. The project encourages diversity within minority groups in engineering such as women, to take leadership roles and be role models for future generations to follow their footsteps in the STEM (Science, Technology, Engineering, and Mathematics) field. Understanding LEED gives young engineers an understanding of ethics and how to apply the ecological concept into the field of construction. The world is heading to a point where engineers must

understand how to follow environmentally friendly procedures to combat pollution and climate change. Using the student-scholar model, students are well equipped to tackle the field of engineering and gain skills needed for the real world.

Civil engineering as a major is a broad discipline. Upon getting a baccalaureate degree in CE, graduates are able to go into various engineering fields such as, geotechnical, structural, environmental, etc. California State University, Northridge's civil engineering program introduces the student-scholar model to prepare students for the master's program offered at their university. However, the LEED research projects give young engineers a broader perspective of what fields the students would be interested in. The project gathers pieces of content that is learned throughout the four-year program to show young engineers the practical application of their curriculum.

Diversity within the field of engineering as a whole has progressed at a steady rate when compared to the 20th century. The LEED research projects enhance diversity within young engineers by encouraging leadership and teamwork. The project mimics real life scenarios where engineers must cooperate with a variety of team members no matter the gender or ethnicity. In team environments all members have a saying: it was up to the leader to gather the ideas and incorporate them into the project. Under the LEED research projects, everyone is encouraged to take ownership and be a leader, all culminating into a group of young engineers ready to transition into the field.

With the earth's health rapidly declining, understanding LEED will aid in the fight against climate change. The construction industry plays a crucial role in creating pollution through the use of natural resources, production of waste, and high energy consumption. The LEED research project enhances students' understanding of pollution that is caused from construction, thus, provoking young engineers to innovate new technologies and modern concepts to combat pollution. With updated

technologies, communities will be able to thrive with a healthier surrounding.

Throughout the civil engineering curriculum, students are taught the theoretical practices of engineering using math and science. However, the LEED research projects show young engineers a glimpse of how to transfer theoretical knowledge to practical knowledge in the field. The project gives students skills such as leadership, creativity, and an understanding of community, all skills which cannot be taught in the classroom. The research project encourages a seamless transition from university to the field of engineering.

## 7. Conclusion

The purpose of this research project was to take a fundamental step into the future of building construction by designing a building that was LEED certified while upholding the integral code parameters found in structural design standards. With a LEED Gold Certification, the building design contributes to reducing the building's negative environmental impact by adding features such as electric vehicle charging stations, a rainwater collection system, or Energy star rated appliances like dishwashers, washing machines, refrigerators, and interior lighting. Although the addition of these features resulted in a 5% increase in overall cost, it is a small price to pay when considering how much environmental damage climate change has done thus far and will continue to do. The reported research was conducted by a diverse group of undergraduate civil engineering students at California State University, Northridge through the implementation of a student-scholar model. Engineering education needs to properly address today's challenges through inclusion of modern techniques and approaches, e.g. LEED, and this project intends to take a significant step in this regard.

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