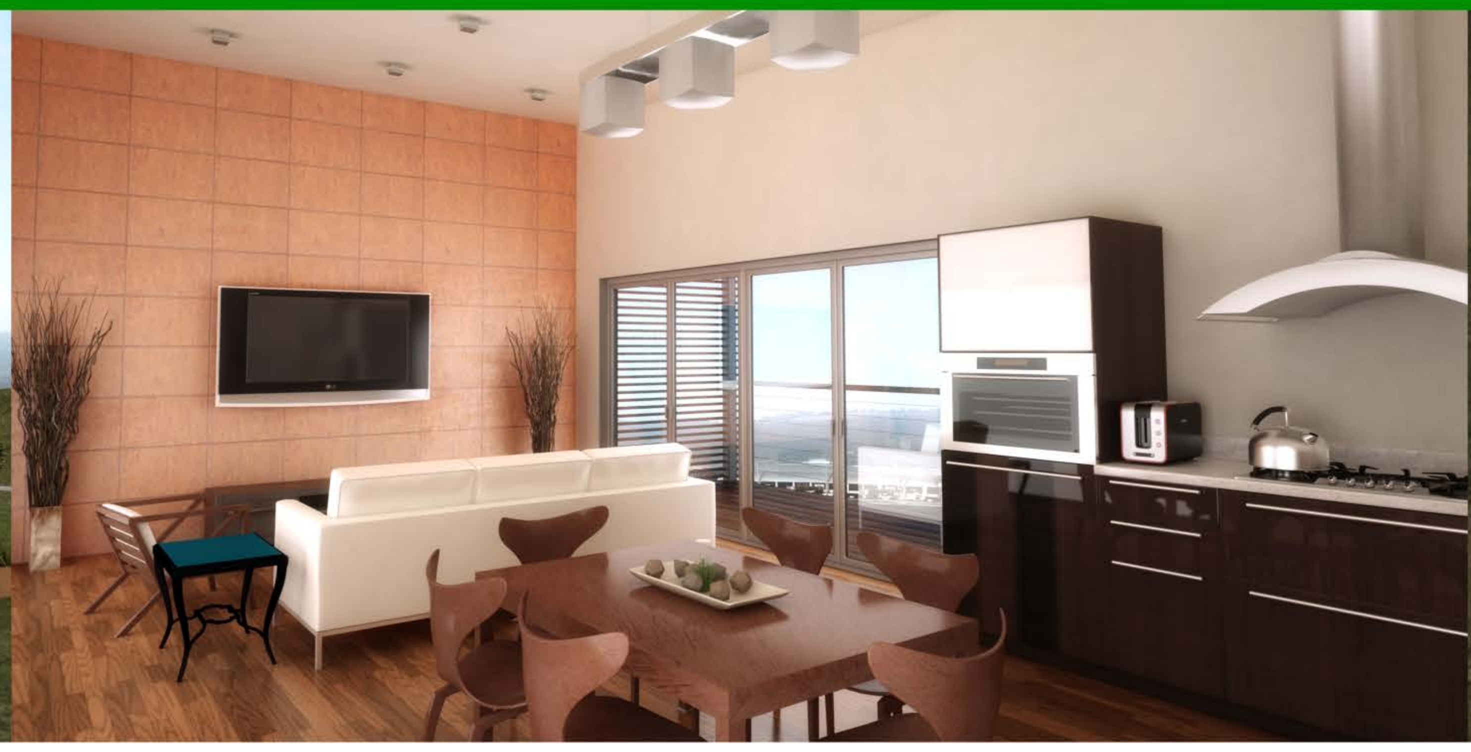
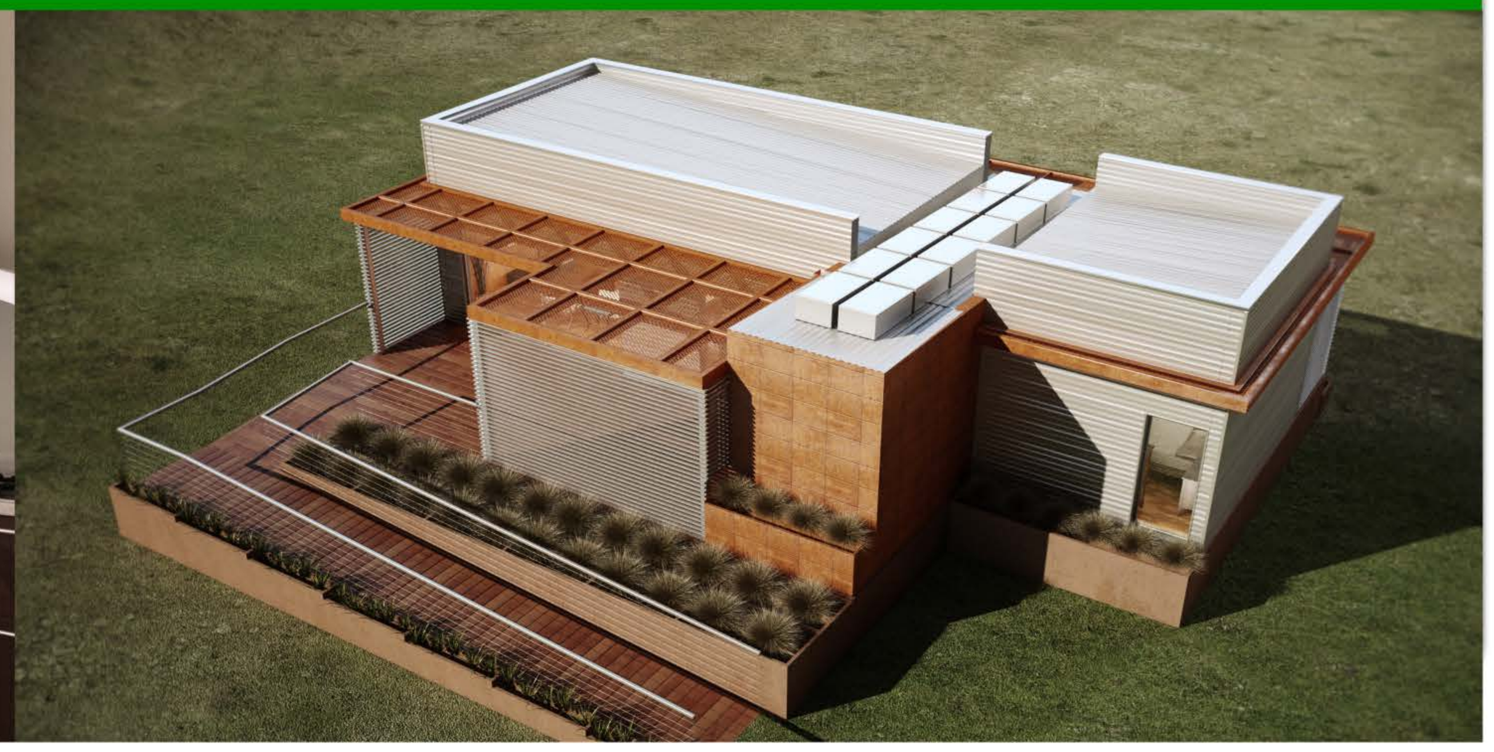
Multidisciplinary Design of a Sustainable, Environmental-Friendly, and Affordable House





Abstract

A multidisciplinary team of over forty graduate and undergraduate students from Civil, Electrical, and Mechanical Engineering was challenged to design a sustainable house with three major objectives: sustainability based on energy efficiency, environmentally friendly, and affordability. In partnership with professional engineers from industry, professors from the University and a Community College, the multidisciplinary team developed a sustainable house able to function with sunlight and water as unique energy sources. Engineering teams were complemented with a communications team with students from the College of Liberal Arts and the College of Business. They were responsible for increasing the public awareness of the project benefits, and for inviting funding sponsors. Websites, videos, presentations, and education descriptions have been developed to promote the project.

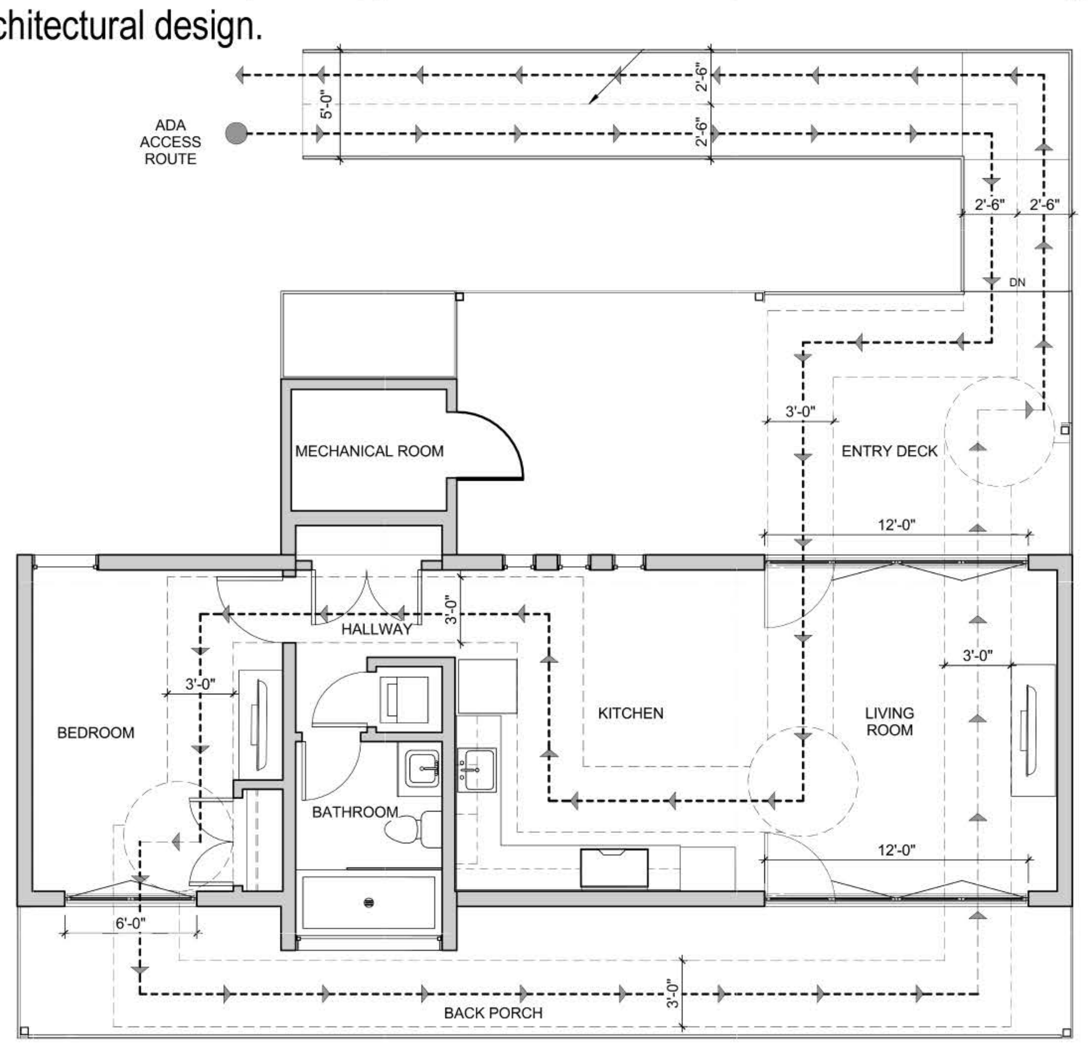
The sustainable house design meets current building standard codes, LEED requirements, and City regulations but also incorporates innovative technologies to address future energy threads. The sustainable house design is also "adaptable" to different climatic regions, and transportable to other locations for reassembling.

Project Description

Our team setup the development of a "net zero" energy consumption house as a primary goal, raising the bar for the challenge. This means that the house must produce at least as much energy as it creates.

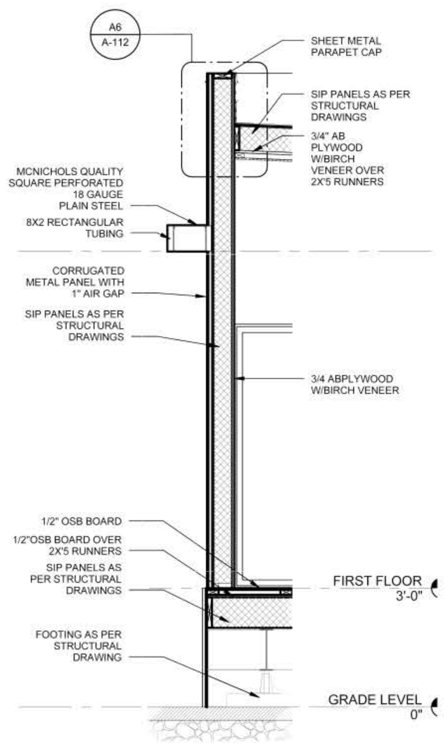
Architectural

The architectural team designed an 800 square foot house with comfortable living space. The conceptual approach needs to incorporate solar technologies in the architectural design.

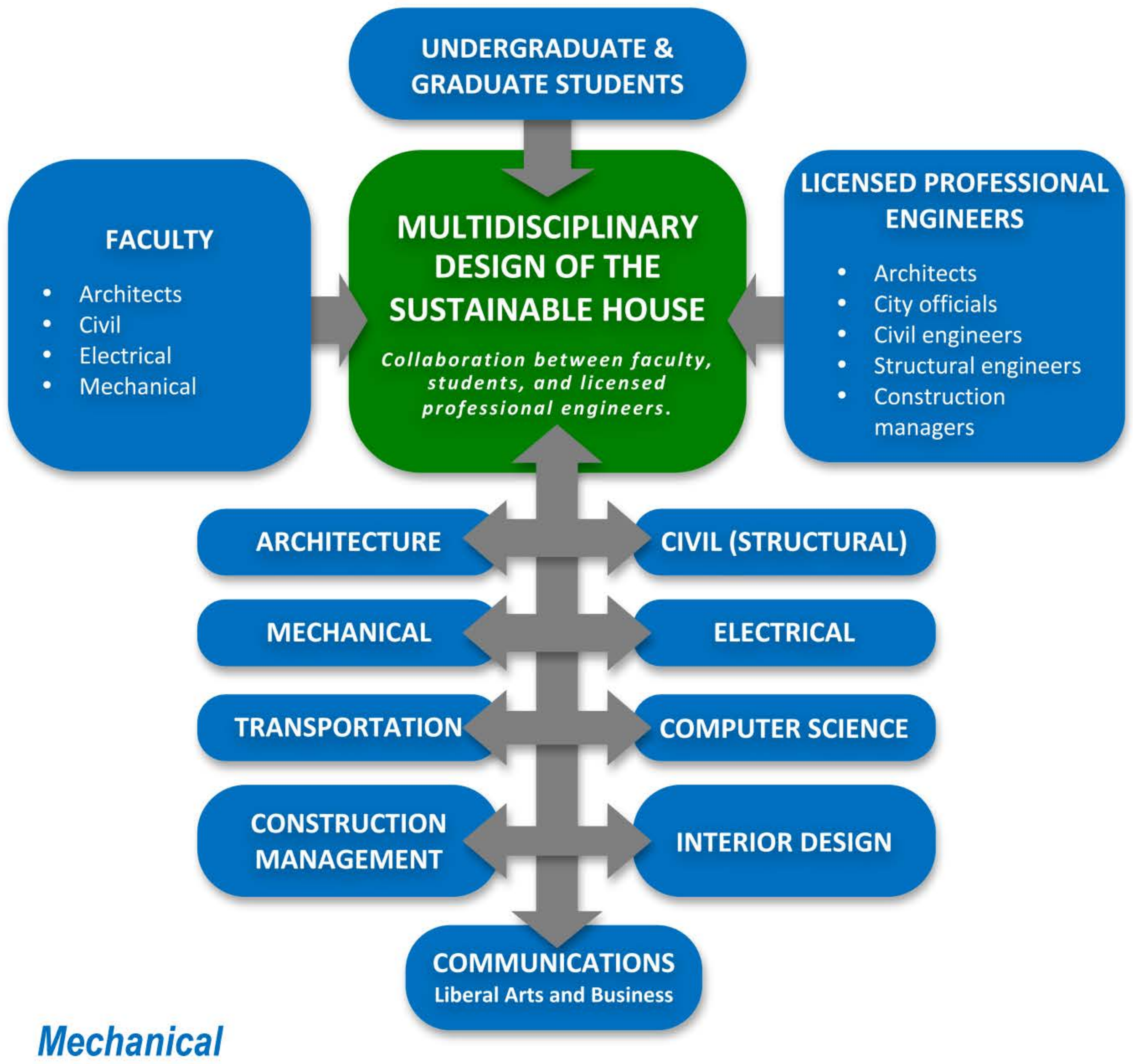


Structural

The house layout consists of three main systems: 1) The foundation, 2) The main house structure, and 3) an exterior canopy and deck. The foundation system has an adjustable height from 11 to 18 inches. There are two longitudinal and four transverse W12X22 A992 steel beams supported by adjustable piers resting on a concrete footing. The piers are braced to the ground with two 40-inch long steel stakes to resist wind uplift, and seismic and wind generated potential overturning and sliding. The walls rest on an 8-inch deep wooden frame sub-flooring system with polyurethane spray foam for insulation and serve as load-bearing wall.



Multidisciplinary and/or Allied Professional Participation



Mechanical

The sustainable house integrates a new heating and cooling system known as radiant heating. This system uses hot and cold water running through the floor and ceiling respectively to create a comfortable living zone for the residents.

Electrical

The electrical engineering team developed the net zero energy balance system required for the house. To remain net zero, the energy consumption in the house due to the different appliances needs to be in equilibrium with the energy produced by the solar panels absorbing sunlight.

Construction Management

This team was responsible of delivering a coherent final design for the sustainable house, and preparing the budget for construction.

Interior Design

The final design connects the conceptual approach with eco-minded people standards of living as well as personal values, inviting them to call the sustainable house as their home.

Communications

The communications team developed websites, videos, and education material to increase awareness of the project to the public. They also delivered jointed presentations with the engineering teams to promote the project looking for potential sponsors to raise additional funds to build the house prototype.

Computer Science

The computer science team developed a network communication system to connect owners' personal devices, such as phones and computers, to the house integrated information system. Through this system the energy efficiency of the sustainable house is checked.

Transportation

The house components were designed in such a manner that when the sustainable house is moved from one location to another, it does not compromise its structural integrity. The transportation of the house, including the loading, was designed to have no disruption in the current flow of traffic.

Benefit to Public Health, Safety, and Welfare: A "Greener" Environment

The emphasis of the design is "clean energy" to be environmentally friendly. The ended sustainable house "green" design relies 100% in solar energy and does not pollute the environment with carbon footprints.

The sustainable house is also a safer place to live when compared to traditional designs. The house is full of safety visible and invisible features. For example, the walls are made of a new composite material that provides outstanding insulation to keep the occupants comfortable, but they are also extremely flame retardant. In addition, with the new heating and cooling system based on water running through the ceiling, the need for air flow via duct work was eliminated, reducing the risk of airborne allergens, and preserving a healthier living environment for the residents.

In the long term, the sustainable house project will have large long lasting impacts. Building and living sustainable houses based on solar energy will help to reduce pollution improving air quality for the entire community. Sustainable houses will contribute to preserve a greener environment while at the same time saving conventional sources of energy for other purposes.

Collaboration of Faculty, Students, & Licensed Professional Engineers

Over forty graduate and undergraduate students from Civil, Electrical, and Mechanical Engineering participated in this project.. Students from the College of Liberal Art and the College of Business provided additional support to promote the project. The whole project was spanned about a year and half over three semesters. The design was carried out by the students of our University and a local Community College. The students were mentored by professors and worked in multidisciplinary teams in collaboration with licensed professional engineers from private and public organizations.

Knowledge or Skills Gained

In addition to the technical and communication skills gained during the project, the students learned that "21st Century Licensed Professional Engineers" have a broader role than just addressing technical problems. In a world that is constantly evolving, licensed professional engineers need to merge current knowledge with innovative ideas in order to provide practical adaptable solutions in response to on-going economic, social, and environmental changes. Engineers are called to become leaders, serving as stewards of our resources in order to preserve a healthy living community, and contributing to a better quality of life.

AREA OF EXPERTISE	*WHAT WAS DONE?*	*KNOWLEDGE AND SKILLS GAINED*
Architecture	• Design a house layout that meets building codes and standard regulations from the City and the Government.	• How to apply building codes and regulations. • Design process sequence from beginning to end. • LEED certification.
Civil (Structural)	• Design of beams and columns and special structural framework to support the solar panels. • Make a structural system to withstand seismic activities. • Make the structure able to be transportable.	• Practical experience in structural design through interaction with professional engineers and architects. • Develop technical reports and write specifications to build the house. • Develop construction drawings using AUTOCAD.
Mechanical	• Design a self-sustainable energy house system using sunlight and water as sources of energy.	• How to design a "net-zero" energy consumption house system.
Electrical	• Calculate energy created by house features. • Distribute solar energy to the entire house.	• Use of solar panels. • Apply energy saving methods in house designs.
Computer Science	• Create a network communication system to monitor energy efficiency.	• How to apply computer science knowledge to energy design concepts.
Transportation	• Traffic flow analysis • Transportation logistics	• How to identify the best routes to transport the house • Rules and regulations on how to transport heavy loads across States
Construction Management	• Time management • Task scheduling • Health safety plan • Assembly/disassembly logistics • Cost Estimation	• Construction process sequence • How to estimate costs • How to communicate across multiple engineering disciples • Work under OSHA/federal safety standards
Interior Design	• Incorporate eco-friendly materials in the design. • Adapt the design to local culture and resident's values	• Work with engineers to maximize energy usage in the interior design.
Communications	• Websites, videos, presentations, and education material to increase public awareness of the project.	• Be able to communicate the project benefits in a non-technical language. • Integrate ideas from different disciplines.

Multidisciplinary Design of a Sustainable, Environmental-Friendly, and Affordable House

Abstract

A multidisciplinary team of over forty graduate and undergraduate students from Civil, Electrical, and Mechanical Engineering was challenged to design a sustainable house with three major objectives: sustainability based on energy efficiency, environmentally friendly, and affordability. In partnership with professional engineers from industry, professors from the University and a Community College, the multidisciplinary team developed a sustainable house able to function with sunlight and water as unique energy sources. Engineering teams were complemented with a communications team with students from the College of Liberal Arts and the College of Business responsible for increasing the public awareness of the project benefits, and inviting sponsors for additional funding. Websites, videos, presentations, and education descriptions have been developed to promote the project.

The sustainable house design meets current building standard codes, LEED requirements, and City regulations and incorporates innovative technologies to address future energy threads. The sustainable house design is also “adaptable” to different climatic regions, and transportable to other locations for reassembling.

Figure 1.*View of the Sustainable, Environmental-Friendly, and Affordable House*

While working in this project, the students learned that 21st Century Professional Engineers have a broader role than just addressing conventional technical problems. In a world that is constantly evolving, professional engineers need to merge current knowledge with innovative ideas to provide practical solutions, which are adaptable to on-going economic, social, and environmental changes. Engineers are called to become leaders and serve as stewards of our resources in order to preserve a healthy living community, and contribute to a better quality of life.

Multidisciplinary Design of a Sustainable, *Environmental-Friendly, and Affordable House*

I: Project Description

Introduction

For many years, the challenge of designing and building sustainable houses which are more energy efficient and affordable has not been overcome. Raising the bar for this challenge, our team setup the development of a "net zero" energy consumption house as a primary goal. This means that the house must produce at least as much energy as it creates. This “net zero” energy consumption target is aligned with the U.S. government criteria for energy efficiency. As a result, a self-sustainable home was designed using sunlight and water as unique sources of energy. The sustainable house design is not a science fiction project since it has to meet all current building standard codes, LEED requirements, and Federal regulations. The sustainable house design also needs to be affordable keeping the overall cost of construction low without compromising quality standards of living. Without affordability, the house would not be commercially available to the public. The sustainable house should also be adaptable to different climatic regions, and movable to another location for reassembling.

More than forty graduate and undergraduate students from Civil, Electrical, and Mechanical Engineering participated in this project under the supervision of Faculty at the University. Undergraduate and graduate students work closely in multidisciplinary teams with engineering firms being mentored by professional engineers. Partnership with a Community College was an additional benefit in order to address all the areas of expertise required for the successful completion of this project. This project demanded many hours of collaboration, enhancing communication and teamwork skills. Students from the College of Liberal Arts and the College of Business supported the engineering teams to communicate to benefits of the project to the public.

City Requirements

The house design must meet City construction residential regulations but also some commercial requirements since the prototype will be exhibit to the public. Some of these additional requirements include having a fire protection system in place, providing a ramp to permit wheel chairs and mobility scooters access to the house. For the approval of the house design, all drawings and construction documents prepared by students were reviewed and certified by professional engineers.

Multidisciplinary Design Process

Students were organized in teams to cover all the areas of expertise to develop an integrated design of the sustainable house. The areas of expertise include:

- Architectural
- Mechanical
- Transportation
- Construction Management
- Civil (Structural)
- Electrical
- Computer Science
- Interior Design
- Communications

Architectural

The architectural team designed an 800 square foot house with comfortable living space. The conceptual approach needs to incorporate solar technologies in the architectural design. The sustainable house has to comply with all the governmental rules and regulations. A prototype of the sustainable house design will be built in the next phase of the project.

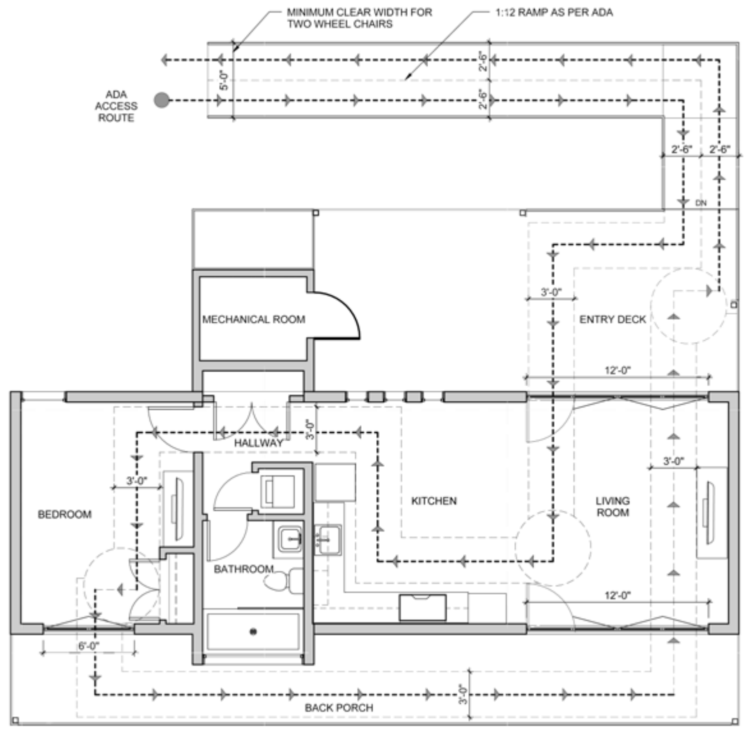


Figure 2. ***Architectural and Civil First Floor***

Structural

The structural engineering team composed by students from Civil Engineering worked closely with the architectural team. The house layout consists of three main systems: 1) The foundation, 2) The main house structure, and 3) An exterior canopy and deck. The foundation System has an adjustable height from 11 to 18 inches.

There are two longitudinal and four transverse W12X22 A992 steel beams supported by adjustable piers resting on a concrete footing. The piers are braced to the ground with two 40-inch long steel stakes to resist wind uplift, seismic and wind generated overturning and sliding. The building codes used to design the foundation system were the AISC-Steel Construction Manual, ACI 318-08, 2009 IBC, and ASCE 7-10. Most of the main house structure is made of structural insulated panels (SIP) with a polyurethane core to provide high-efficiency insulation and speedy construction. The roof consists of 8 ¼-inch thick panels providing an R-value of 54, and the walls consist of 6 ½-inch panels with an R-value of 42. The walls rest on an 8-inch deep wooden frame sub-flooring system with polyurethane spray foam for insulation. They serve as load-bearing walls as well as the lateral-force-resisting-system for wind and seismic loads. The exterior space of this home is made up of a floor deck with a partial canopy overhead.

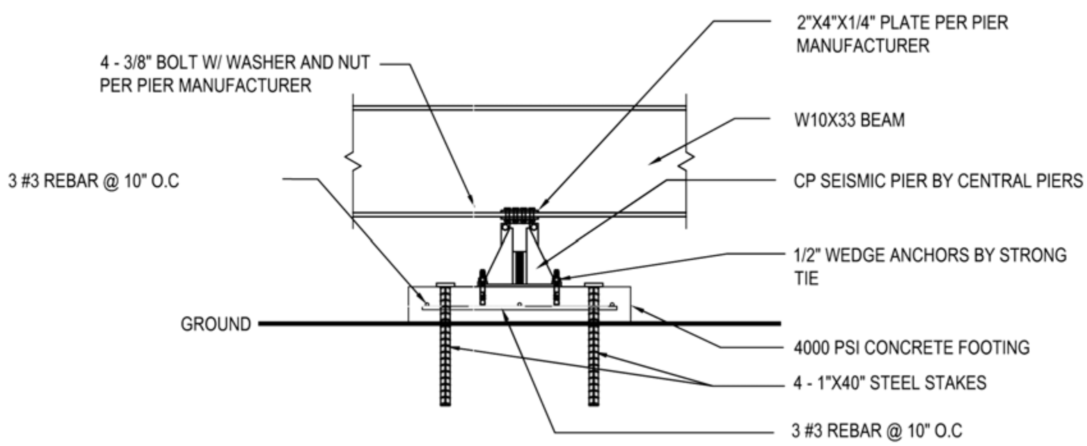


Figure 3. ***Seismic Pier at Footing***

The deck material is made of a high-performance wood-alternative composite material. The framing system for the deck will consist of 8 ¾ inch box beams serving as supporting girders for the joists spanning throughout the whole deck. Wooden 4x4 posts with a 6-inch adjustable base transfer the deck loads to the ground. The structural elements were designed in such manner that the house could be disassembled and reassembled in a different location without compromising its structural integrity.

Mechanical

The sustainable house integrates a new heating and cooling system design called as radiant heating. This system uses hot and cold water running through the floor and ceiling respectively to create a comfortable living zone for the residents. A radiant heating system has no airflow reducing the spread airborne allergens typically associated with ducted air conditioning units. In-depth calculations on heat distribution and water flow analysis were conducted to design the radiant heating system. The mechanical team interacted with the civil and electrical engineering teams to design the water system for the entire house, including the plumbing.

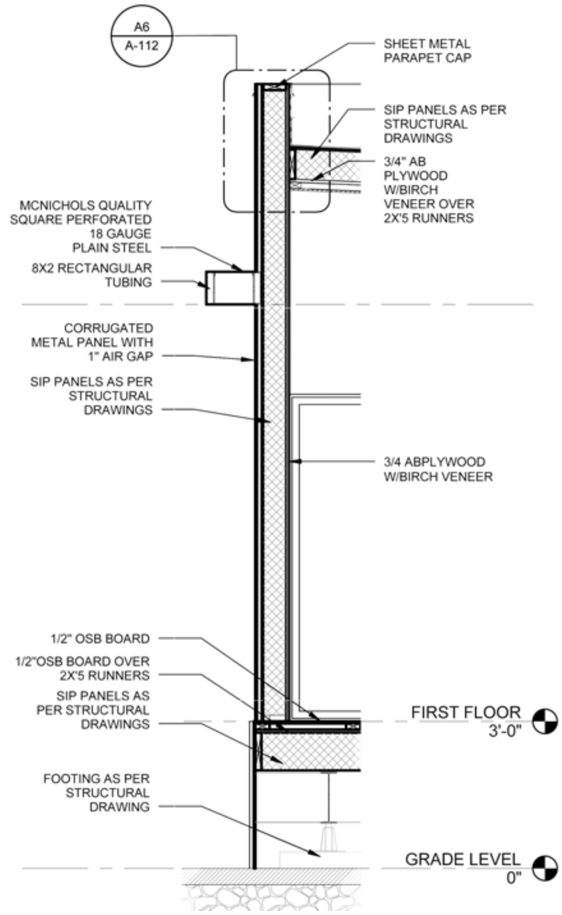


Figure 4. ***Detail of the Wall Section***

Electrical

With the incorporation of solar energy in the house design, the electrical engineering team developed the net zero energy balance system. To remain net zero, the energy consumption in the house due to the different appliances needs to be in equilibrium with the energy produced by the solar panels absorbing sunlight.

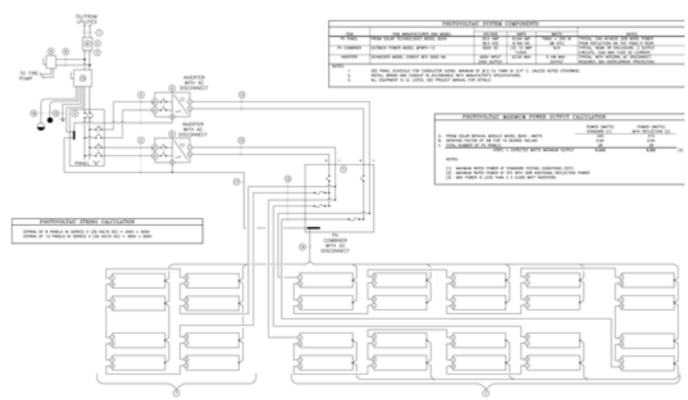


Figure 5. ***Schematics of the Electrical Design***

Computer Science

The computer science team developed a network communication system to connect owners' personal devices, such as phones and computers, to the house integrated information system. Through this system, information about room temperatures, lights, and energy usage is monitored from within or outside the house. Energy efficiency of the sustainable house is checked through this integrated network communication system.

Transportation

The transportation team designed the sustainable house with the capability to be disassembled and reassembled without compromising its structural integrity. The house components were designed in such a manner that when the sustainable house is moved from one location to another, it does not affect the current flow of traffic. This was one of the most challenging tasks faced by the team.

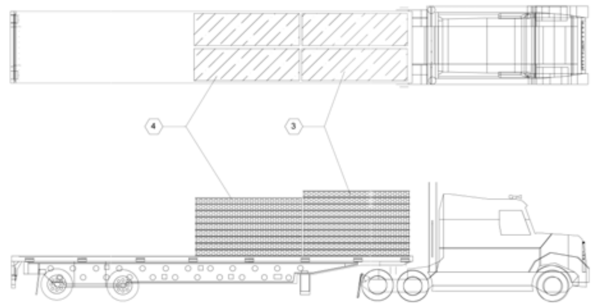


Figure 6. ***Schematics of the Truck Loading***

Construction Management

The construction management team played a key role in the success of this project. With multiple engineering disciplines working together, organization and communication skill were critical for an efficient integration of the designs that were coming from different areas of expertise. This team was responsible of delivering a coherent final design for the sustainable house, and preparing the budget for construction.

Interior Design

The task of the interior design team was to make the house comfortable for the residents and with personality. The overall conception was to provide a house interior design adapted to local culture as well as individual resident needs. For example, an advisory group from a culinary Community College program provided recommendations for the kitchen design. The final design connects an environmental friendly conceptual approach with eco-minded people standards of living as well as personal values to invite them call the sustainable house as their home.

Communications

The communications team developed websites, videos, and education material to increase the awareness of the project to the public. They also delivered jointed presentations with the engineering teams to promote the project to potential sponsors in order to raise additional funds to build the house prototype.

II. Collaboration of Faculty, Students, and Licensed Professional Engineers

Over forty graduate and undergraduate students from Civil, Electrical, and Mechanical Engineering participated in this project. The students were mentored by professors and worked in multidisciplinary teams in collaboration with professional engineers from private and public organizations. This project gave the students a unique opportunity to interact with other disciplines outside their field of expertise.

The whole project was spanned about a year and half over three semesters. The initial design phase was carried out by the students of our University and a local Community College. The designs were reviewed by professional engineers and several changes were recommended. A revised design was developed in interaction with Faculty and Licensed Professional Engineers. With feedback continuously streaming through the students, faculty, and professional engineers, the final design was finally approved for construction. Some of the students that participated in the design phase have been hired by consulting firms involved in this project.

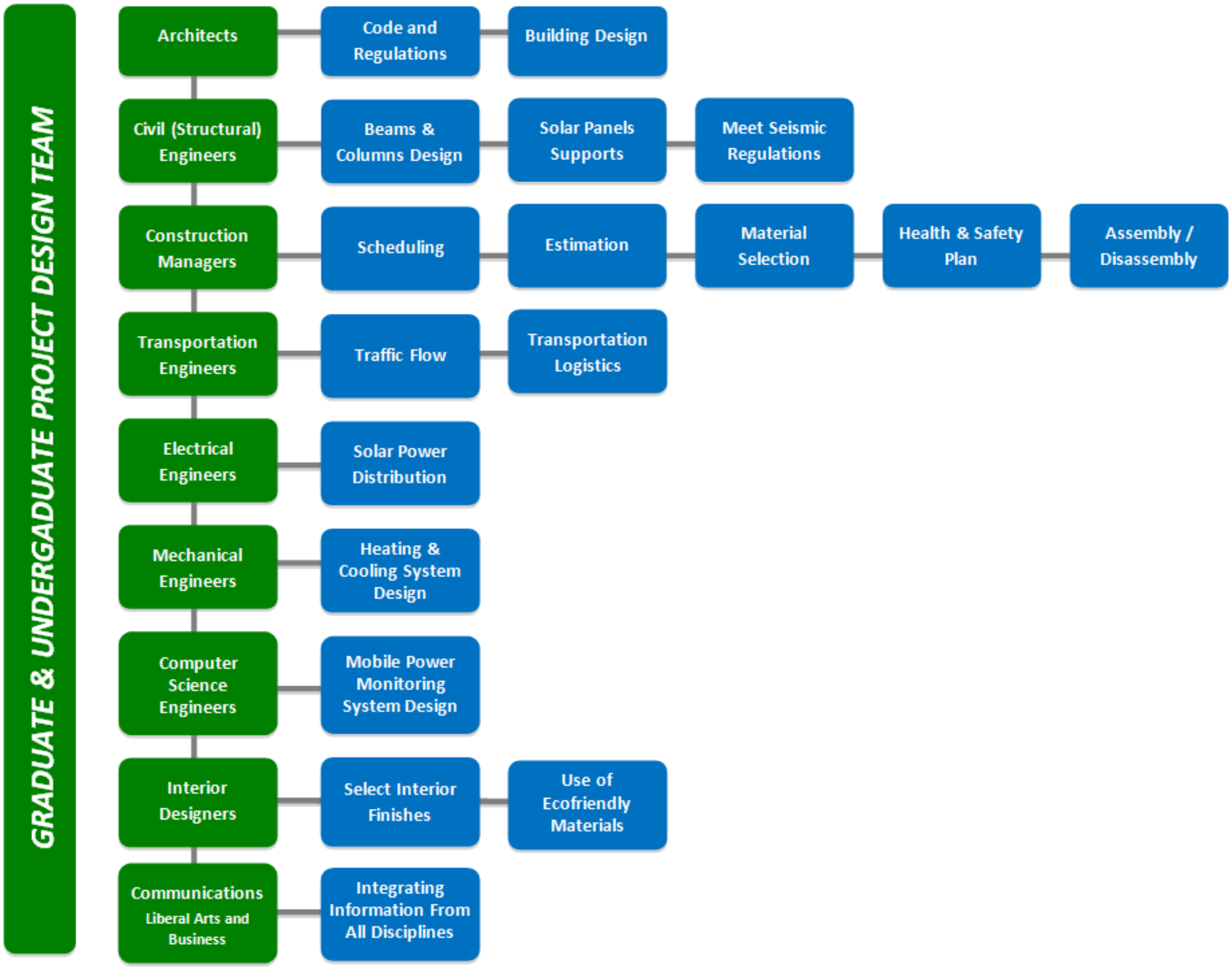


Figure 7.*Collaboration of Faculty, Students, and Licensed Professionals Engineers*

III. Benefit to Public Health, Safety, and Welfare: A "Greener" Environment

With today's society so focused on alternative sources of energy, the sustainable house was developed from the ground up of current practices to become the wave of the future by integrating innovative technologies. The emphasis of the design is "clean energy" to be environmentally friendly. The ended sustainable house "green" design relies 100% in solar energy and does not pollute the environment with carbon footprints.

The sustainable house is also a safer place to live when compared to traditional designs. The house is full of safety visible and invisible features. For example, the walls are made of a new composite material that provides outstanding insulation to keep the occupants comfortable, but they are also extremely flame retardant. In addition, with the new heating and cooling system based on water running through the ceiling, the need for air flow via duct work was eliminated, reducing the risk of airborne allergens, and preserving a healthier living environment for the residents. In the long term, the sustainable house project will have large long lasting impacts. Building and living sustainable houses based on solar energy will help to reduce pollution improving air quality for the entire community. Sustainable houses will contribute to preserve a greener environment while at the same time saving conventional sources of energy for other purposes.

IV. Multidiscipline and/or Allied Profession Participation

The sustainable house design required the participation of multiple engineering disciplines: Civil, Mechanical, and Electrical. There was also a team from the College of Liberal Arts and the College of Business who joined the engineering group to develop material to communicate the benefits of the project to the public, and invite potential sponsors to contribute with additional funds to build the house.

Licensed professional engineers, faculty professors from the University, and instructors from a Community College mentored the students' teams to successfully address the architecture, structural, mechanical, and electrical aspects of the sustainable house design. This project gave the students an opportunity to work closely with Licensed Professional Engineers resulting in an unforgettable learning experience not possible with traditional education methods. Requirements to meet current building codes, LEED requirements, and City regulations demanded a close review of the designs prepared by students, applying knowledge that could be only acquired through years of engineering practice.

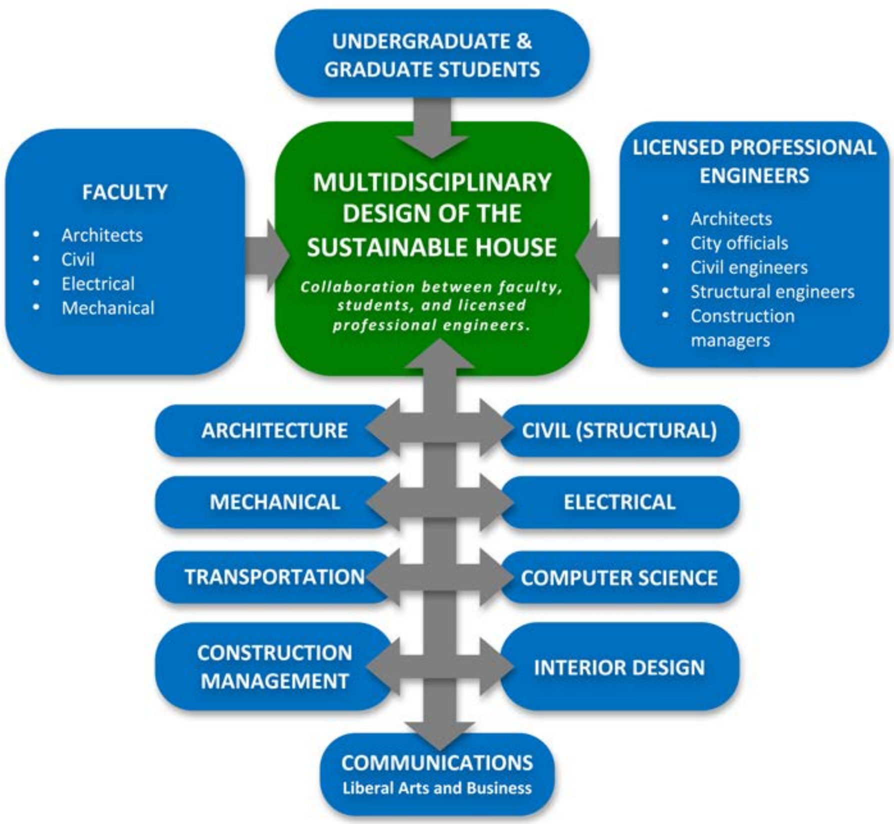


Figure 8. ***Multidiscipline and/or Allied Profession Participation***

V. Knowledge or Skills Gained

Connecting professional practice with academic education was one of the most rewarding learning experiences for the students. Students worked closely with Licensed Professional Engineers learning directly from their professional practical experience. This project allowed students to gain knowledge and skills, which are very difficult to acquire through traditional education. From the beginning, the sustainable house design forced the students to think outside of the box demanding for innovative engineering practical solutions. Students need to be aware of current building codes, LEED requirements, and City regulations while at the same time integrate innovative technologies. Very few students have had the opportunity to work on a project of this large before. Even fewer had worked on a project that required multiple disciplines to interact. Learning to function as an effective multidisciplinary team toward a common objective was one of the major challenges to overcome by the students.

The interaction among Civil, Electrical, and Mechanical engineers enhanced their oral and written communication skills. The integration of a communication team to the project provided a broader vision to engineering students. They learned how to promote a project using communication tools. Websites, videos, and target-user oriented documentation were developed to gain support from the public, and to invite potential sponsors in order to obtain additional funding for building the house prototype.

As a result of this project, one of the major lessons learned by the students is the shift of perspective about the role of engineers in our society. Students learned that 21st Century Professional Engineers do not just address technical problems, but they need to foster a sustainable healthy living community. Using engineering knowledge to provide practical solutions in response to on-going economic, social, and environmental changes is a major challenge for engineers. This challenge requires an active leadership role in which engineers are called to serve as stewards of our resources, paving the way to higher standards of living for the overall society.

Table 1. ***Specific Knowledge and Skills Gained by the Students***

AREA OF EXPERTISE	*WHAT WAS DONE?*	*KNOWLEDGE AND SKILLS GAINED*
Architecture	• Design a house layout that meets building codes and standard regulations from the City and the Government.	• How to apply building codes and regulations. • Design process sequence from beginning to end. • LEED certification.
Civil (Structural)	• Design of beams and columns and special structural framework to support the solar panels. • Make a structural system to withstand seismic activities. • Make the structure able to be transportable.	• Practical experience in structural design through interaction with professional engineers and architects. • Develop technical reports and write specifications to build the house. • Develop construction drawings using AUTOCAD.
Mechanical	• Design a self-sustainable energy house system using sunlight and water as sources of energy.	• How to design a “net-zero” energy consumption house system.
Electrical	• Calculate energy created by house features. • Distribute solar energy to the entire house.	• Use of solar panels. • Apply energy saving methods in house designs.
Computer Science	• Create a network communication system to monitor energy efficiency.	• How to apply computer science knowledge to energy design concepts.
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Interior Design	• Incorporate eco-friendly materials in the design. • Adapt the design to local culture and resident’s values	• Work with engineers to maximize energy usage in the interior design.
Communications	• Websites, videos, presentations, and education material to increase public awareness of the project.	• Be able to communicate the project benefits in a non-technical language. • Integrate ideas from different disciplines.