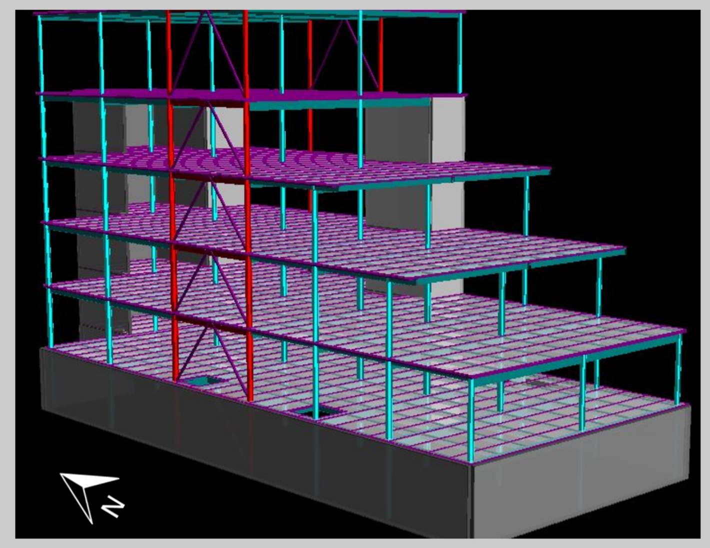
MULTIDISCIPLINARY VERTICAL FARM DESIGN

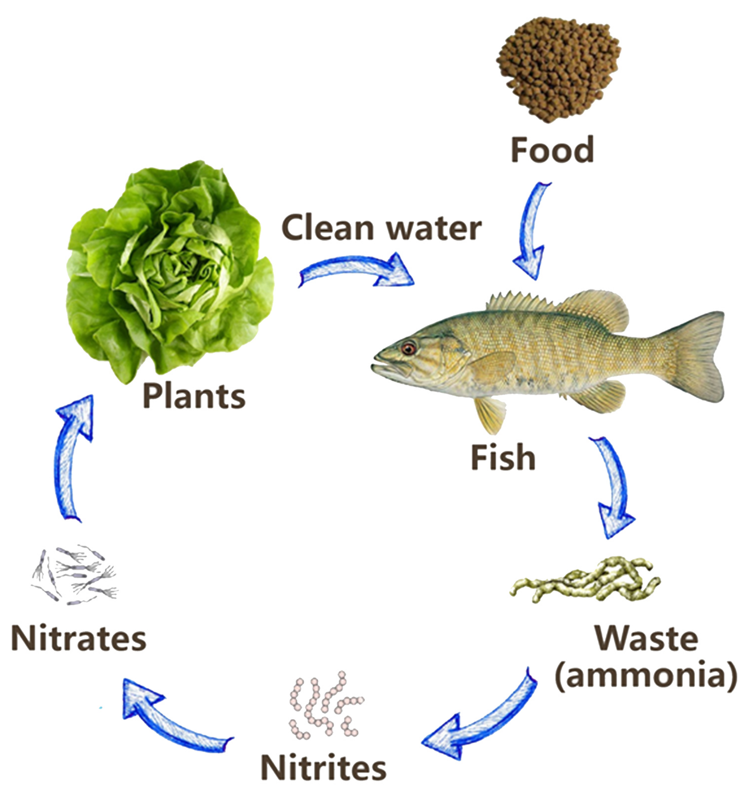
Protection of Health, Safety, and Welfare of the Public

With the primary goal of the building being a means to provide safe and affordable food for the community, the aspects of health, safety and welfare of the public were a major concern for the design team. In order to accomplish this goal, applicable codes and standards were used to ensure a safe operating building. In addition to considering standard building codes, many of the industry professionals pushed the team to consider other aspects of occupant safety. One of these aspects included a condensation analysis to prevent harmful mold development from the greenhouses. Another consideration was a way of growing plants using an aquaponics systems that relies on a natural, symbiotic relationship between plants and fish in order to provide organic nutrients for plant growth.



Collaboration of Faculty, Students, and Licensed Professionals

The design of the vertical farm started at the university level as the design team reached out to several of its licensed engineering faculty for their involvement with the project. Throughout the design, the team also met weekly with over 30 licensed professional engineers and architects for input and guidance. These professionals provided input and advice on all aspects of the design including system selections, materials, system integration, layout, sizing, and legibility of construction drawings. Due to the complex nature of the greenhouse systems, the team turned to greenhouse specialists in order to fully understand the needs and functions of an urban greenhouse. The feedback and support from the licensed faculty and industry professionals proved to be invaluable.



Mechanical System Design

Geothermal system
Air distribution system
Plumbing system
Aquaponics system
Fire protection system

Construction Process

Task scheduling
Time management
Cost estimation
Site development and coordination

Successful Project

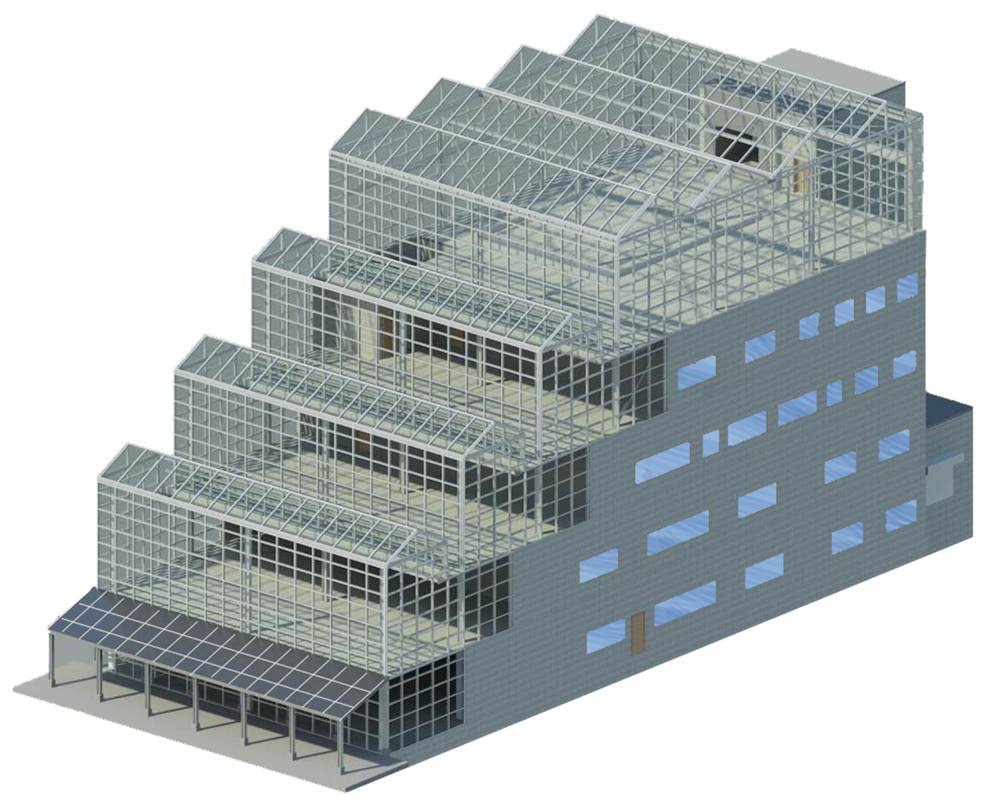
Developed overall project goals
Collaboration with licensed professionals
Allied professional participation
Protection of public health, safety, and welfare
Knowledge and skills in the design industry

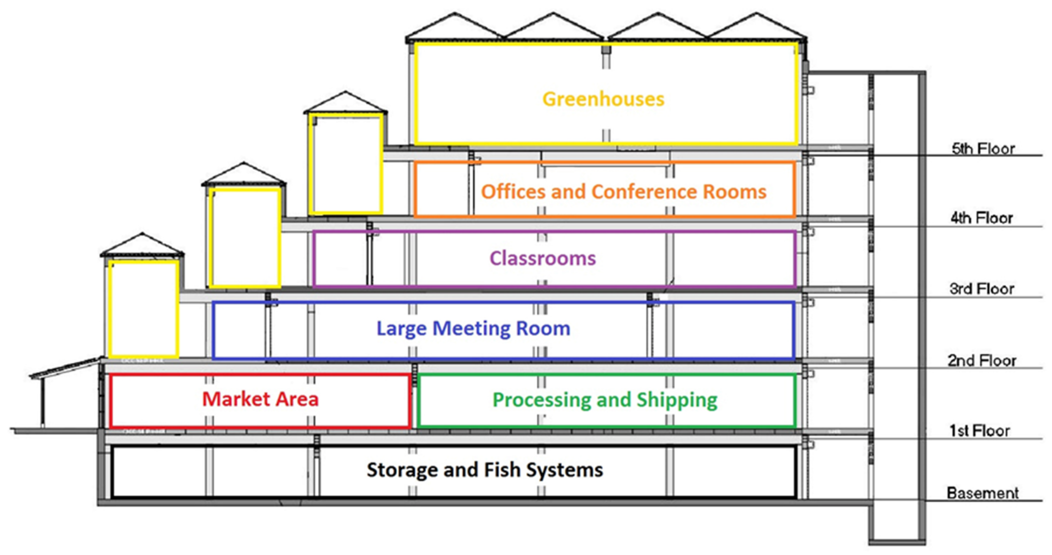
Structural System Design

Gravity framing system
Lateral force resisting system
Building foundation system
Building integrated design

Electrical System Design

Power distribution system
Building and greenhouse lighting system
IT and security system
Power monitoring system





PROJECT GOALS

- INTEGRATION
- BUILDING PURPOSE
- SUSTAINABILITY
- COST

Knowledge and Skills Gained

The involvement of industry professionals gave the student team a chance to see the many facets of the building design process. Not only did the team learn how to collaborate and compromise, but each member learned how to resolve common conflicts that may arise during design. Members of each discipline gained specific knowledge and skills in their own field as well as experience in a real world design project along side licensed professionals. This project gave each member of the team a new perspective on the duties and responsibilities of licensed engineers. The team gained a deeper understanding regarding the importance of communication and coordination on a multidisciplinary design team. This experience also taught the team to provide solutions that are innovative as well as practical.

Successful Project

This project was an entry for an international design competition that focuses on educating and involving students in the engineering and construction process. The proposed building for this project was a five-story vertical farm building that would be used to grow crops, raise fish, and educate the community. The goal of the project was to design and integrate engineered systems into this complex building with an end goal of producing safe, affordable, and healthy foods to the local urban communities. The building consists of several dedicated greenhouse spaces that tier back on top of a mixed-use building for the company and its operations. Due to the complexity of the both the mixed-use building and the greenhouses, it was determined that professional and industry involvement was key to understanding how innovative systems could be integrated into such a unique building. Our team consisted of architectural and construction engineering students who designed the structural, construction, mechanical, fire protection, plumbing, lighting, and electrical systems for the building. While each discipline focused on providing the best design for their system, a large part of the project was working with both student and professionals in all other disciplines in order to provide a unique and integrated overall design.

Multidiscipline and Allied Profession Participation

In an effort to provide the highest level of design for the project, it was decided that additional assistance from professionals outside of the licensed engineers was needed. The team worked along side many different professionals that were experienced in various greenhouse and aquaponic systems. A local urban farming organization with goals similar to the owner's was contacted in order to understand the many details that must be considered when designed for non-profit organizations. Additionally, an aquaculture system designer was contacted to aid in the selection of grow beds and design of the aquaponics system. In order to understand the procedures and costs of the selected geothermal system, a local well-drilling company was also contacted to ensure that this system was feasible.

ABSTRACT

An interdisciplinary team of seven graduate students preparing to be Construction, Electrical, Structural, and Mechanical engineers was challenged to design a high performance building for an international team design competition. The building was to be an urban "vertical farm" for a non-profit organization that desires to educate the community about urban farming. The main objectives of the competition were the development and integration of innovative and original design solutions. These criteria, along with the goals of the company, lead to team mantra of "Innovation through Integration" by using the goals of Integration, Building Purpose, Sustainability, and Cost. Based on these goals, the team was able to develop a design that expanded on the existing urban farming and sustainability practices already used by the client. This is seen in the continued use of solar power and aquaponic systems, and it also in the new solid-oxide fuel cell and geothermal systems that serve the building.

Over the course of this project, 35 licensed professional engineers and architects from industry, licensed professors from the university, and other allied professionals met with students to review design narratives, construction-type documents and listen to oral presentations reviewing the design and major considerations in the project. Licensed professionals met with the students outside of the scheduled class times to mentor students in practical and safe design methods for the chosen systems. All students involved in the project have taken the Fundamentals of Engineering exam, will be completing an ABET EAC accredited degree, will work under licensed engineers following graduation, and plan to pursue professional licensure for themselves.

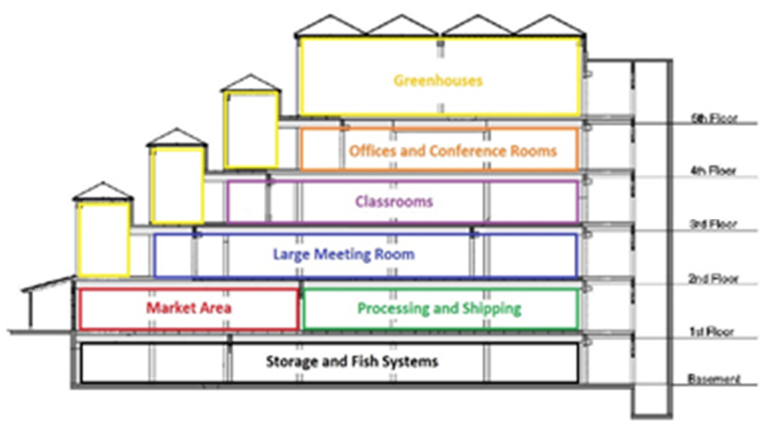
The sustainable, vertical farm systems were designed to meet current building standard codes, LEED requirements, and state and city specific codes. This was in keeping with the project goals and with the knowledge that poorly designed buildings could result in harm to the client and community. It also provided the opportunity to experience the process of researching and understanding location-specific legislation that would affect the design and construction of a real life facility.

This project offered many learning opportunities for the students. Due to the unique spaces of this building, the team gained knowledge on a wide variety of topics on not only the building system design process, but also the interactions between building systems and the design of unique systems such as the aquaponics and greenhouse systems. In addition to system design, the students were also able to see first-hand the way licensed engineers approach and think through unique design challenges, experience the necessary collaboration between disciplines in building design, and communicate their design both verbally and through written documents.

PROJECT DESCRIPTION

INTRODUCTION: This project was part of an annual international student design competition. The multidisciplinary design team consisted of seven (7) Masters of Architectural Engineering students and was completed over the course of six (6) months. The competition focuses on integration within the building engineered systems in order to challenge students to learn to design high performance, sustainable buildings. Students design structural, mechanical, plumbing, fire protection, lighting and electrical systems for the given building and submit a written document with supporting documents and construction drawings. The building chosen by the competition was a five story vertical farm building that utilizes urban farming techniques.

THE BUILDING AND THE CHALLENGE: The five-story vertical farm building can be seen as two purpose types: a mixed used space and greenhouse space. The mixed-use spaces include a market for selling produce, classrooms for educational programs, employee offices and a large gathering space. The greenhouse areas are located on the southern facing, tiered roofs to allow for maximum sunlight. The challenge was to integrate the design of all of the building engineered systems to create a building that was sustainable and simple enough to be operated by volunteers or limited maintenance staff.



DESIGN SUMMARY: The mechanical team was responsible for the HVAC, plumbing, fire protection and aquaponics system design. System design highlights include the use of a geothermal well field, waste heat recovery off walk-in freezers and coolers for the mixed-use building portion. Additionally, the greenhouse design featured separately controlled growing spaces, allowing for more plant variety throughout the facility.

The electrical and lighting team was responsible for the design of the power distribution and emergency systems, lighting, daylighting, and greenhouse lighting systems, telecommunication system, fire alarm system, energy monitoring system, and security system. System highlights include the use of solid-oxide fuel cells to provide the main building power along with a photovoltaic panel array. For the greenhouses, LED luminaires that target the spectrum of light most important for plant growth and photosynthesis were used along with an astronomical time clock and blackout shades.

The structural team was responsible for the design of the gravity framing, lateral load framing, and foundation systems. System highlights include the use of structural steel and reinforced concrete for the gravity and lateral systems, respectively. After collaboration with industry professionals, the allowable bearing capacity was increased to account for the weight of soil that would be removed for the basement level. This increase allowed the structural team to design viable spread footing for the columns and strip footings for the reinforced concrete basement wall. The structural team did account for the structural load of the greenhouse structures; however, a full framing design was not done.

COLLABORATION OF FACULTY, STUDENTS, & LICENSED ENGINEERS

Through the duration of this design project, the interdisciplinary team benefitted tremendously from the interaction with industry professionals. A professor at the university, who is also a licensed electrical engineer, facilitated class periods where the team was able to discuss design with professors who had obtained professional licensing in their respective disciplines and with industry professionals through design presentations. Through this, the team was exposed to more than 30 local licensed professional engineers and licensed architects. In addition to these facilitated sessions, the team contacted specialized professionals for design questions and feedback.

LICENSED FACULTY: Collaboration began early, with the suggestion from a licensed structural faculty member that the team come up with a common set of goals to be used as design criteria for the rest of the project. This engineer explained how setting common goals unites the team's efforts, keeps the owner's needs at the forefront of decisions and allows the team's success to be measured along the way. The team took that advice and considered the nature and needs of all of the disciplines present on the team and the owner and architects goals for the building. The resulting team goals are listed in **Figure 1** in order of importance.

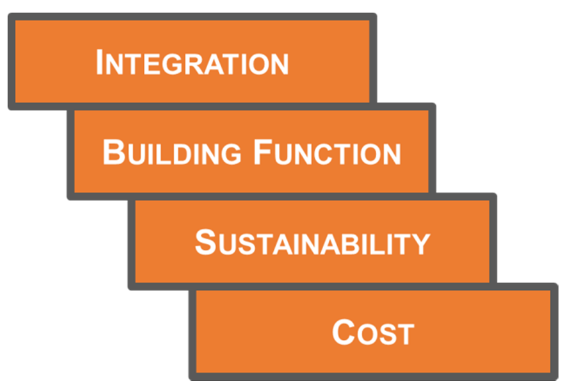


Figure 1: Team Goals

LICENSED PROFESSIONAL ENGINEERS: The mechanical team had many good examples of interaction with industry. Team members met weekly with licensed engineers outside of class for general design guidance as well as additional meetings to discuss systems that are more specialized. Topics covered at these meetings often had to do with system component interactions, equipment selection and sizing procedures, and legibility in design drawings and system layouts within the building. This was especially useful to learn what is commonly seen in real projects and gave students an inside perspective on constructability concerns that are typically seen in industry.

The structural team received guidance from many structural licensed engineers throughout the design process as well. The structural team met with local licensed structural engineers on a weekly basis to discuss the material selection for the gravity and lateral force resisting systems, design of the basement slab supporting large aquaponic fish tanks, support of the greenhouse systems located at the top of each level, and the design/selection of architectural precast cladding. In addition to the weekly meetings, the industry and faculty advisors answered design questions via email.

The electrical team met with many design engineers and licensed professionals throughout the design process. Through the process of weekly meetings, phone calls, and email conversations, the electrical team utilized the expertise of professionals to design a primary and backup power system that utilizes two solid-oxide fuel cells as a renewable power source. The professionals gave the team direction on what equipment was needed, how this equipment interacted with other systems, and what needed to be done to keep vital equipment like the elevator and egress lighting operational in the case of a power outage. The design professionals also gave direction on how these systems are properly coordinated on plans so that the design would be constructed properly, ensuring safety for the end user.

MULTIDISCIPLINE STUDENT DESIGN TEAM: The design team met regularly to ensure the project was on track and created a Google Drive spreadsheet that acted as a real-time request for information (RFI) form. Each discipline had a separate sheet on which members of other disciplines could submit questions, which could then be answered by the specified deadline noted. In addition to communication efforts, the team utilized a common model that allowed all the systems (structural, mechanical, electrical, etc.) to be seen by all disciplines to help avoid clashes and ensure the any interactions between disciplines could be easily seen.

Two of the most notable aspects of the design that required collaboration between all members of the team were the design of the greenhouses as well as the aquaponics design. The greenhouses required input from all members of the team in the selection of the glazing system as well as the grow beds. Different glazing materials were considered based on light transmittance, thermal transmittance, weight of the glazing panels and the fragility of the system in terms of constructability as well as durability.

The aquaponics design also required collaboration between the mechanical, structural and construction teams for the selection of grow bed arrangements. With three different options of grow beds, many considerations were involved in the final selection. **Table 1** shows some of the main considerations for the selection process.

Grow Bed Type	Production Rate	Variety of Plants	Sensitivity to Power Outage	Structural Weight	Mechanical Load
Deep Water Raft	High	Limited	Low	Large	Large
Media Beds	Medium	Unlimited	Medium	Medium	Medium
NFT	Medium-High	Limited	High	Small	Small

Table 1: Aquaponics Collaboration Points

PROTECTION OF PUBLIC HEALTH, SAFETY, & WELFARE

When designing a building project, the public health, safety, and welfare is of the utmost importance. Since employees, volunteers, and the public will occupy the non-profit organization's building, an important aspect of the project was making sure that it would be safe for those inhabitants. In order to accomplish this goal, the team relied on building codes that are established to ensure safe buildings are designed. **Table 2** shows a list of some of the applicable standards used in this project. It was also vital for the public operation of a non-profit organization to carefully manage resources and funding involved with the design. Through cost analysis, a hybrid heating system was designed for the greenhouses that saved 40% on initial project cost when compared to a baseline greenhouse heating system. Payment options and purchasing plans were also investigated for the solid-oxide fuel cells, to minimize the financial impact of expensive on-site power generation equipment on the small non-profit operation.

In addition to these codes, the team considered other aspects of occupant safety. One instance of this was the team's consideration of condensation in the building, which can cause mold growth and material damage, but is not specifically addressed in any of the building codes. A condensation analysis was completed and insulation solutions evaluated for the greenhouse floor system to ensure the mixed-use spaces below would not experience condensation on the structural ceiling, which would result in dripping ceilings, and mold, which can be harmful to occupants.

In addition to ensuring public safety, the project aims to benefit the public health by teaching the public about urban farming practices. The building being designed will produce healthy food and enable others within the community to do the same in order to make eating healthy more accessible to all. The team expanded on the emphasis on education that the client has by designing the aquaponics system with two grow bed types to allow for a first-hand look at how different systems operate. Additionally, an energy monitoring system was implemented in the building that allows the occupants to see the energy consumption of the building, which can be used to educate the public about power use in buildings and in food production.

Structural	Mechanical	Fire Protection	Electrical
2009 International Building Code			
ASCE 7-05	ASHRAE Standard 62.1 - 2013	NFPA 101 - 2012	NFPA 70 - 2011 National Electrical Code
AISC 360-05	ASHRAE Standard 90.1-2007	NFPA 13 (2012)	IECC 2009 - with Wisconsin Commercial Building Code Inserts
ACI 318-08	International Plumbing Code 2012	NFPA 14 (2013)	NFPA 101 - 2012
ASTM Material Standards	ASHRAE Handbooks	NFPA 24 (2013)	NFPA 110 - 2010
Vulcraft Steel Roof and Floor Deck Specification and Load Tables	NGMA - 2010 Standards for Ventilation and Cooling Greenhouse Structures		ASHRAE 90.1 - 2010
PCI Design Handbook			

Table 2: Applicable Codes

MULTIDISCIPLINE & ALLIED PROFESSION PARTICIPATION

In order to deliver the highest level of design for the project, the team needed to contact other professionals outside of the professional engineers that assisted with the project in various areas. The team had a video conference with the licensed architect who designed the initial schematic architectural design. Some aspects of the building, such as the aquaponics and greenhouse systems, were unfamiliar to many of the licensed professional mentors. To help supplement their knowledge on these systems additional professionals were contacted including a local non-profit urban farmer, aquaponics experts, greenhouse manufacturers, and a local well-drilling company.

There was limited interaction with the actual owner of the proposed building, so in order to better understand the owner's needs and intentions for the project, the team contacted a local organization with similar goals and processes. From interactions with the owner of this organization, the team was able to provide some insight into the balance between education and production in the facility, which allowed the design to better fit the needs of this type of organization.

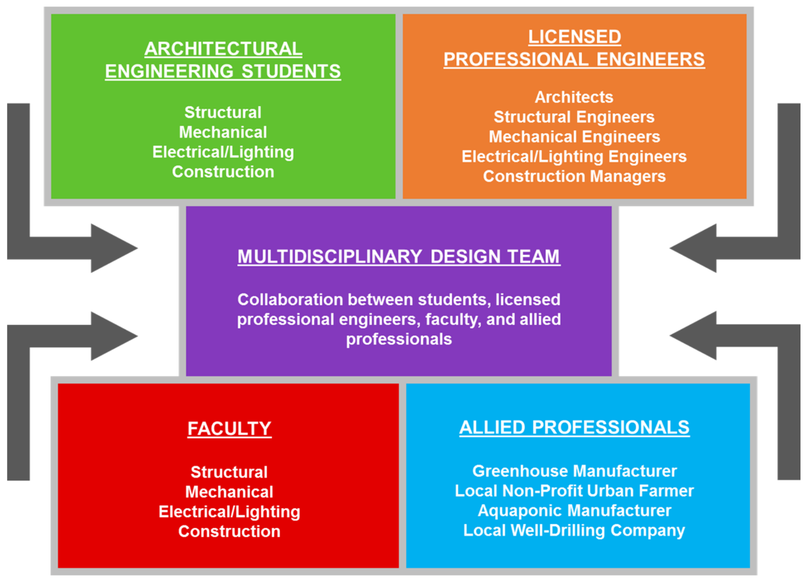


Figure 2: Components of Design Team

An aquaculture system designer was contacted for more information about the design of aquaponics systems and different advantages and disadvantages to the grow bed configurations. This allowed the team to design a simpler, easily maintainable system. For the greenhouse design, a greenhouse manufacturer was consulted to estimate structural loads, appropriate glazing panel selection and acceptable thermal and humidity conditions in such a space.

Finally, to ensure that the geothermal system would be feasible and to better understand costs associated with this system, a local well-drilling company was contacted. This also allowed the team to ensure that the use of the geothermal well field was a plausible option even given the fact that the bores would go through bedrock, which increases the drilling costs significantly.

KNOWLEDGE & SKILLS GAINED

This project allowed the students to experience the compromise, collaboration, and time that is necessary to design a fully functioning building. The students were able to see how each system affected the other disciplines--a concept that is difficult to teach in class. Through discussions and trade-offs resulting from interdisciplinary conflict, the team learned about the compromise and prioritization common in building industry. The use of design goals was vital in resolving these conflicts and ensuring that the design was able to meet the needs of the owner and the public by establishing a hierarchy for the design criteria by which each conflict could be analyzed.

Area of Expertise	What was done?	Knowledge and skills gained
Structural	▪ Gravity framing system design ▪ Lateral force resisting system design ▪ Integrated design	▪ Structural engineering experience with guidance from professional engineers ▪ Revit drafting ▪ Technical writing & communications skills
Mechanical	▪ Load calculation ▪ System selection ▪ System design ▪ Energy modeling	▪ Load calculation methods ▪ Benefits/disadvantages of different systems/materials ▪ System component interaction ▪ LEED baseline standards
Electrical	▪ Distribution & emergency power design ▪ On-site energy generation design ▪ Building & greenhouse lighting design	▪ Understanding of emergency power system requirements ▪ System cost analysis ▪ Special requirements for plant lighting ▪ Energy efficient lighting system controls
Construction	▪ Task scheduling ▪ Time management ▪ Cost estimation	▪ Construction process sequence ▪ Integration & communication with other disciplines ▪ Cost estimation strategies

Table 3: Project Tasks and Skills Gained

As a result of this project, the team has also gained a new perspective of the role of a licensed engineer in our society. Engineers are not only responsible for the technical knowledge necessary to design the structure, but also to provide a practical and sustainable solution. Additionally, it is important for the engineer to practice good communication skills amongst the multidisciplinary team, other professionals, and the client to ensure that the design is implemented effectively.