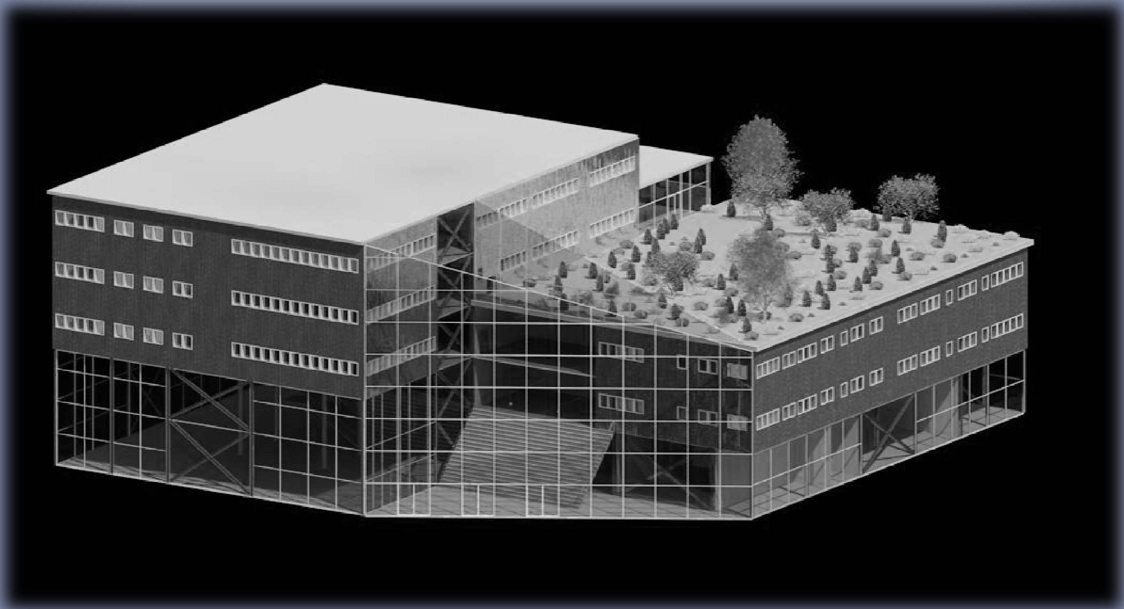

Design of a Building for the College of Engineering, Technology, and Computer Science at the IPFW Campus

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Table of Contents

List of Tables

List of Figures

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Abstract

The existing Engineering, Technology, and Computer Science building (ET building) built in 1992 is a three-story building that currently accommodates four departments: Engineering, Manufacturing & Construction Engineering Technology and Interior Design, Computer and Electrical Engineering Technology & Information Systems and Technology, and Computer Science. During these 20 years, many programs have been added to each department. Furthermore, in the last ten years, the Engineering, Technology, and Computer Science (ETCS) College enrollment has grown at an average annual rate of 4% and has now almost 2,000 students.

From this, it can be seen that the ETCS College is outgrowing the ET building, which seems to be ineffective for providing excellent teaching, state-of-the-art laboratories, centers of excellence, and many other facilities. Without such, the ETCS mission and objective of being the leading regional engineering institution will be a challenge.

Accordingly, a new space is needed that can accommodate all programs, faculty, laboratories, and research facilities. The best solution to this growing problem is to build an aesthetically pleasing building that can be a statement piece for the IPFW campus and be completely functional as a facility for the College of Engineering, Technology, and Computer Science.

By designing a new building for the ETCS College the group was able to accommodate the future growth of the college. The building met the group's goals by providing a total building area of 133,900 sq. ft. This new building included areas such as: student study rooms, individual offices for professors, laboratory spaces within the building, student organization spaces, centers of excellence, large meeting rooms, a large lecture hall, and additional, adequate classroom space. The group's new design also provided better aesthetics with more than 60% of the building's exterior covering being windows and proposed that a roof garden be implemented on the roof of the third story. The group was also able to meet the reasonable budget requirement of staying under $55 million, with a total cost estimated at $36 million. By comparing design criteria against the group's four alternative designs, it was determined that an all steel building was the best design. This also allowed the group to achieve the "green engineering" design goal, because steel has a minimal environmental impact compared with the other alternative designs.

I. Section I: Problem Statement

I.1. Problem Statement

The existing Engineering, Technology, and Computer Science building (ET building) built in 1992 is a three-story building that currently accommodates four departments: Engineering (ENGR), Manufacturing & Construction Engineering Technology and Interior Design (MCET), Computer and Electrical Engineering Technology & Information Systems and Technology (CEIT), and Computer Science (CS). During these 20 years, many programs have been added to each department. Furthermore, in the last ten years, the Engineering, Technology, and Computer Science (ETCS) College enrollment has grown at an average annual rate of 4% and has now over 50 faculty, limited time lecturers, and staff members, and almost 2,000 students.

From this, it can be seen that the ETCS College is outgrowing the ET building, which seems to be ineffective for providing excellent teaching, state-of-the-art laboratories, centers of excellence, spacious classrooms, faculty and staff members' offices, student organizations rooms, departmental libraries, and lecture halls for senior design presentations and hosting guest speakers.

Without such facilities, the ETCS mission and objective of being the leading regional engineering institution will be a challenge. The current practices of lecturing 30% of the courses in other buildings, combining limited time lecturers' offices, holding faculty meeting and senior design presentations in other buildings, sharing labs among different departments, and using some labs as storage space, are not considered a sustainable solution. It is noteworthy to mention that besides the rising enrollment, full majors have been added to the ETCS College, which were not considered in the plan of the current building.

Accordingly, a new space is needed that can accommodate all programs, faculty, laboratories, and research facilities. The best solution to this growing problem is to build an aesthetically pleasing building that can be a statement piece for the IPFW campus and be completely functional as a facility for the College of Engineering, Technology, and Computer Science. Considering the ecologic movement of the recent years, this solution should also strive to uphold high environmental and efficiency standards.

I.2. Scope of Project

As professionals designing this building, the senior design team would be part of a much larger team of professionals including architects and other engineers. Thus, the group's responsibilities include only the structural design of the building and some main architectural characteristics.

I.3. Background

I.3.1. IPFW and ETCS growth

Indiana University - Purdue University combined campus in Fort Wayne was inaugurated in 1964 after having offered courses at different Fort Wayne locations for many years. The next decade was a time of rapid growth leading to the formal merger of the campus administration in 1975. Student enrollment grew significantly throughout the years reaching over 10,500 by 2000, and that has reflected on its facilities. In the 1990s, the Visual Arts Building, Williams Theatre, the Engineering, Technology, and Computer Science Building, and the Science Building were added to the campus. In 2004, Student Housing was opened on the Waterfield Campus across Crescent Avenue, which was connected to the main campus by the Willis Family Bridge the previous year. In the late 2000s, the additions of the John and Ruth Rhinehart Music Center, the Holiday Inn at IPFW, the Coliseum, the Medical Education Building, and the Ron Venderly Family Bridge helped IPFW accommodate its rapid student growth (see Table I-1). Phase 3 of Student Housing, the Keith Busse Steel Dynamics Alumni Center, and the Student Services Complex were added in the last two years completing the current 40 buildings and structures that the 682 acres IPFW campus has.

Table I-1. IPFW Enrollment Statistics 2000-2010.

Year	Undergraduate	Graduate	Total
2000	9,773	759	10,532
2001	10,282	847	11,129
2002	10,880	877	11,757
2003	11,068	738	11,806
2004	11,089	721	11,810
2005	11,028	767	11,795
2006	10,890	782	11,672
2007	11,110	833	11,943
2008	11,578	760	12,338
2009	12,876	799	13,675
2010	13,402	790	14,192

With over 14,000 students, the school is now academically composed of four colleges, two schools, and three divisions. The College of Engineering, Technology, and Computer Science (ETCS) is accommodated in the Engineering Technology (ET) building. This structure was constructed in 1992 to accommodate the four departments that composed the ETCS College. : Manufacturing Engineering Technology (MET), Civil & Architecture Engineering Technology (ARET), and Electrical Engineering Technology (EET). Since then, other departments have been added and many new programs are now offered. Thus, the programs and departments have been rearranged as follows:

- Department of Computer and Electrical Engineering Technology & Information Systems and Technology (CEIT): Electrical Engineering Technology, Computer Engineering Technology, and Information Technology.
- Department of Computer Science (CS): Computer Science and Information Systems.
- Department of Engineering (ENGR): Civil Engineering, Computer Engineering, Electrical Engineering, and Mechanical Engineering.
- Department of Manufacturing & Construction Engineering Technology and Interior Design (MCET): Architectural Engineering Technology, Civil Engineering Technology,

Construction Engineering Technology, Industrial Engineering Technology, Interior Design, and Mechanical Engineering Technology.

- Department of Military Science & Leadership: Military Science.
- Department of Organizational Leadership and Supervision (OLS): Organizational Leadership and Supervision.

The CEIT, CS, ENGR, and MCET departments are located in the ET building, while the OLS and the Military Science departments had be to be located in Neff and Dolnick respectively due to lack of space in the ET building. The increasing amount of programs is a reflection of the growing student enrollment of the ETCS College. As shown in Figure I-1, the student enrollment has increased dramatically in the last five years from 1,240 to 1,918.

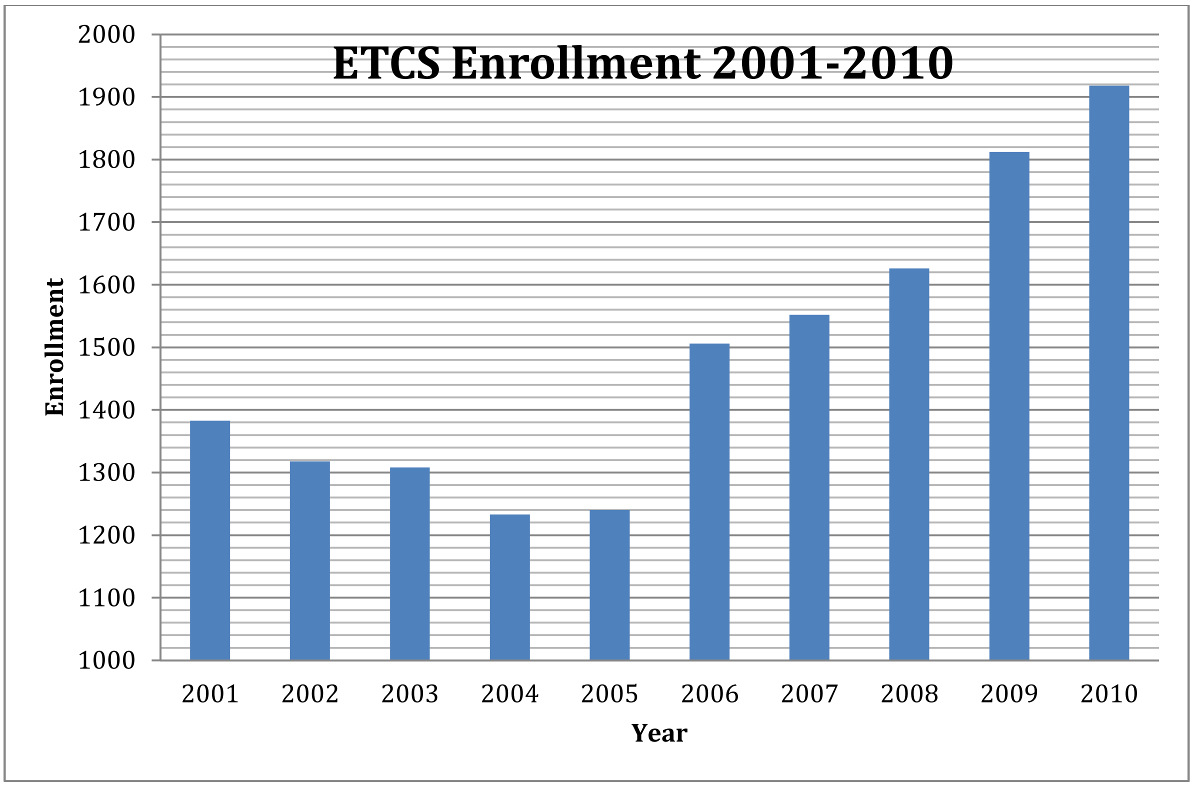

Figure I-1. ETCS Enrollment 2001-2010.

I.3.2. Green Engineering

In engineering, design solutions to technical problems should always consider the product's harm to the environment – from its production through its operating live to its final disposal. The solution to the problem presented here is the construction of a new building on the IPFW campus. This building is to be designed considering the contemporary environmental issues by minimizing pollution and integrating the building with the natural environment as much as possible.

In 1998, the U.S. Green Building Council (USGBC) established the Leadership in Energy and Environmental Design (LEED) certification program. LEED consists of a suite of nine rating systems for the design, construction and operation of buildings, homes and neighborhoods. For this project, the system to be considered is the LEED for New Construction and Major Renovations. This rating system for buildings was designed to guide and distinguish high performance buildings that have less of an impact on the environment, are healthier for those who work and/or live in the building, and are more profitable than their conventional counterparts. LEED for New Construction offers many benefits including environmental, economic, and occupant-oriented performance and health advantages. LEED certified projects cost less to operate and maintain, are energy- and water-efficient, have higher lease-up rates than conventional buildings in their markets, and contribute to occupant health and productivity.

LEED for New Construction is a performance-oriented rating system where building projects earn points for satisfying criterion designed to address specific environmental impacts inherent in the design, construction, operations and management of a building. The LEED certification system is organized into five environmental categories: Sustainable Sites (SS), Water Efficiency (WE), Energy and Atmosphere (EA), Materials and Resources (MR) and Indoor Environmental Quality (IEQ). An additional category, Innovation in Design (ID), addresses sustainable building expertise as well as design measures not covered under the five environmental categories. There are 100 base points; 6 possible Innovation in Design and 4 Regional Priority points. The number of points the project earns determines the level of LEED Certification the project receives. LEED certification is available in four progressive levels according to the following scale:

- Certified 40–49 points
- Silver 50–59 points
- Gold 60–79 points
- Platinum 80 points and above

Considering that LEED certification program involves many aspects of the building and not only the structural design of it, ensuring that our building would be LEED certified would be outside of the project scope. Therefore, in order to keep in line with the current global "green movement", the team decided to design this building in line with the LEED for New Construction guidelines. Striving to anticipate and minimize hazards to the environment, when a decision had to be made, the team would first consider the environmental impacts of that decision and choose the option that would potentially obtain the most points in the LEED certification process. This methodology ensured the building to be not only designed to minimize its negative environmental impact, but to enhance the natural environment.

The final goal is that if this building were to be built, the entire project team, which would include other engineers and architects, would strive to achieve at least LEED certification, if not Platinum level.

I.4. Project Goals and Requirements

Before starting on the design aspects of this project, the team decided on some project goals that this building had to meet.

The main goal for this project is to accommodate the ETCS college growth; being able to keep all its departments in one building, including laboratories. Secondly, it is important to consider the contemporary environmental issues that currently present a concern worldwide. Therefore, our building should have minimal environmental impact. Furthermore, the designed building should not only be functional, but also be aesthetically pleasing. Lastly, it is important to keep in mind that this building is part of a College campus and, thus, accessibility is a relevant factor in this project.

Once the goals were set, the project requirements had to be specified.

The most fundamental requirement is naturally safety. Based on the design standards used, it can be ensured that a probability of failure of the structure is of less than 1/100,000.

Taking into account the size of the current building, the number of students and departments it was designed for, and the growth of the ETCS College, the team came up with a minimum surface area of 130,000 square feet required to properly accommodate the current and future needs of the ETCS College.

Based on a preliminary cost estimate done using the RS Means (Table I-2), the group decided the budget had to be under $55 million.

Table I-2. Construction Costs Including labor, equipment, unit, and overhead costs.

Floor	Type	Surface Area (ft^2)	Height (ft)	$/$ft^3$	Price (millions)
Ground	Laboratories	50,000	20	19.5	$15.60
1-3	Classrooms and Administration	150,000	16	17.95	$43.08
	City Reduction Factor			88.3%	$51.81
	Sustainability Factor			2%	$1.04
	TOTAL				**$ 52.85**

*Based on RSMeans 2010

In order to have a maximum amount of natural light coming into the building, the team set the requirement to have at least 60% of the building exterior wall surface to be windows.

I.5. Specifications

The design codes used by the group were the American Concrete Institute (AIC) and the American Institute of Steel Construction (AISC). These codes were used to factor loads, determine design standards and factors of safety, as well as size members and slabs. The group also abided by the American Society of Civil Engineers (ASCE 7-05) and International Building Code (IBC 2006) general building codes. These codes were used to determine uniform loads, wind design loads, and serviceability criteria.

I.6. Design Variables

I.5.1. Initial Cost

Initial cost is one of the most important factors in any construction project. Concepts and designs are useless unless they can be built – and without money, nothing can be built. *RS Means Building Construction Cost Data, 2011* uses data for more than 120,000 projects in North

America, reported from contractors, designers, and owners, to allow for early and detailed cost estimates [1].

Early cost estimates are generally prepared very early in projects to allow the client to decide whether they are committed to the project and to decide the feasibility, location, and scope of the project as a whole. These estimates rely mainly on historical data, sketches, and brief descriptions about the project. It is generally prepared for budgeting and for selection of the best alternative and can take less than a day to prepare, although the accuracy is less than 80%.

Detailed cost estimates are based off many components. The first of which is the project's direct costs which are directly associated with the project's activities, including material, labor, and equipment costs. Direct costs generally account for approximately 70% of the total cost [1]. Another component in detailed cost estimates in the indirect costs, which include project and general overhead. Project overhead is distributed on all activities based on the direct cost of each activity and generally accounts for approximately 5 – 30% of the total cost [1]. These costs include variable costs such as wages and salaries of supervisors, engineers, and secretaries as well as fixed costs of site preparation. General overhead also contributes to indirect costs by about 0 – 15% of the total project cost and includes costs that cannot be attributed to any particular job, such as office expenses [1]. The last component of the detailed cost of a project is markup, which includes the profit and risk contingency of the project.

When considering the design variables for this project, an early cost estimate would not be enough to evaluate the alternatives. The size, location, and general components of all alternatives remain the same throughout all alternatives. Also, the indirect costs and markup components of a detailed cost estimate stay relatively consistent through all alternatives, since it is only the main structural components that vary. Therefore, only the direct costs associated with the project are considered a design variable between the alternatives.

I.5.2. Aesthetics

On any academic campus, aesthetics is an exceedingly important factor that can often be overlooked. It can draw more potential students to choose the campus, gain valuable media attention, have a positive impact on the community, and improve student and faculty satisfaction with the campus. Although overall aesthetics is a project goal, the main architectural features of the building will not be changing with the different alternatives. However, the aesthetics inside of a building are also very important. This side of the aesthetics is what is defined as a design variable for this project. Components such as open space, columns protruding into classrooms, and height of ceilings can vary significantly based on the different structural components used.

I.5.3. Environmental Impact

A current trend in Civil Engineering is moving toward more sustainable structures and decreasing the environmental impact of projects. Given this increased awareness of a project's footprint, the environmental impact during construction and over the life of the structure is a variable which aids in the decision of an alternative. CO_2 emissions, energy consumption, and resource depletion we the areas compared between concrete and steel construction.

In *Comparison of Environmental Impacts of Steel and Concrete as Building Materials Using the Life Cycle Assessment Method*, T. Johnson analyzed several areas of environmental impact of both steel and concrete. Within concrete construction, there is the production of framework, reinforcing bar, and concrete, which includes cement and aggregate production to consider. Construction is broken down into formwork, reinforcing bar, and concrete placement and then formwork removal. Steel construction consists of steel beam production, steel connection production, and steel fabrication, which includes beams, connections, and welding. Fireproofing and concrete production are also considered. The environmental impact of steel construction consists of steel erection, fireproofing application, and concrete placement. Raw material extraction, initial production, material manufacture, and transportation are also factors that were analyzed in the study. The results of the study are shown in Table I-2 below. It can be seen that steel has 25% less total CO_2 emissions and 68% less total resource depletion.

Table I-3. Summary of Environmental Impact of Concrete and Steel

	CO_2 Emissions	Energy Consumption	Resource Depletion
Steel	14.4 kg/SF	102.1 MJ/SF	2.8 Mg/SF
Concrete	16.4 kg/SF	102.5 MJ/SF	8.8 Mg/SF

I.5.4. Durability

The durability of the building is considered to be its ability to resist wear and tear during the life of the structure. Although all of the materials used will be durable for many years, as the life of the structure approaches 50 years and more, the durability of the materials begins to become a factor. Since the structure is designed to stay standing 100 years, how well the materials continue to last with minimal maintenance becomes a factor.

I.5.5. Constructability

Since the location of the new building is in a central location on campus, significant construction would seriously disrupt normal campus life. Construction time and ease of construction can vary significantly when different materials are selected for the structural components. Although some of the aspects of construction will remain the same due to the main architectural features of the building staying constant throughout the different alternatives, the majority of the construction comes from main structural components, leaving constructability as a large and greatly important design variable.

I.7. Limitations and Constraints

I.6.1. Cost

As in most projects, but especially in the current struggling economy, cost is of high relevance when designing and constructing a building. While most of the time initial cost is the primary concern, the life-cycle cost of the building cannot be disregarded, as it includes the cost of owning, operating, maintaining, and disposing of the building. Although money is to be spared, the building must still meet the project goals and, thus, the challenge is to minimize the total project cost while satisfying the requirements. On top of that, as IPFW is a public university, the construction has to be partially funded by the state of Indiana.

I.6.2. Construction Time

Even though the construction process is outside of our senior project scope, construction time is an important factor and should be considered during the design process. Being on a college campus, the construction of this building should be completed in the shortest period of time possible so as to minimize the impact on campus life. Furthermore, the extreme weather conditions of Fort Wayne's winter should be taken into account when scheduling.

I.6.3. Size & Location

The selection of the location of this building is important for several reasons. Firstly, it has to be of easy access for any faculty, staff, students, or visitors of IPFW. Also, it would be wise to locate it close to other buildings with teaching facilities in order to enhance effectiveness on campus, especially knowing that one of the IPFW goals is to have a maximum 10-minute walk between any two buildings on campus. Finally, the location will determine the maximum surface area of the first floor.

I.6.4. Additional Considerations

Apart from the above-mentioned constraints, the following are to be considered for the final design of this building.

a) IPFW Green Space

IPFW is overall quite integrated with its natural environment. It has several green areas such as the science mall or the area behind the music building, it is located along the river, and even has a trail going through campus. Thus the location of the building should be chosen with consideration of the campus green space and natural environment.

b) IPFW Master Plan

The IPFW master plan is designed for 15 years and reviewed every year. When developing any construction project related to the university it is important to ensure it will fit well into the master plan and not disturb previously planned projects.

c) Parking & Bus rerouting

Both Citilink (route 3) and Campuslink bus routes go through campus. When deciding where to locate the building it is important to consider how that will affect those routes and in such case, alternative routes should be developed.

d) Enclosed walkway

This year, IPFW just opened the Student Services Complex, which includes an enclosed walkway between Hilliard Gates Sport Center, Walb Student Union, and the Helmke Library. If the new building were to be located close to any of these structures, it would be interesting to consider extending the walkway to connect the new building to other campus facilities.

II. Section II: Conceptual Design

II.1. Location of Building

The team was informed by the IPFW Physical Plant, that the ETCS building was originally built so that it could be eventually mirrored on the other side of the lobby. Since our project is to design a new building, that option was discarded right away. As alternative locations for a new building considering the IPFW master plan, the Physical Plant proposed the parking lot located between the library and the current ETCS building, the corner parking lot at the Southeast end of campus, or a location on the other side of the river, by the new alumni center. Considering the proximity to the current ETCS building and the goal of having a 10-minute walk between any two buildings set by IPFW, the team decided that the first option was the most adequate. The current parking lot, shown in Figure II-1 by the central blue square, is 265ft x 240ft, which determines the maximum area for our first floor. For construction purposes and considering the total surface area needed for the new building, the team decided to make the building 210ft x 210ft. This would also allow for additional space for sidewalks, delivery and drop-off/pick-up driveways, or additional green space.

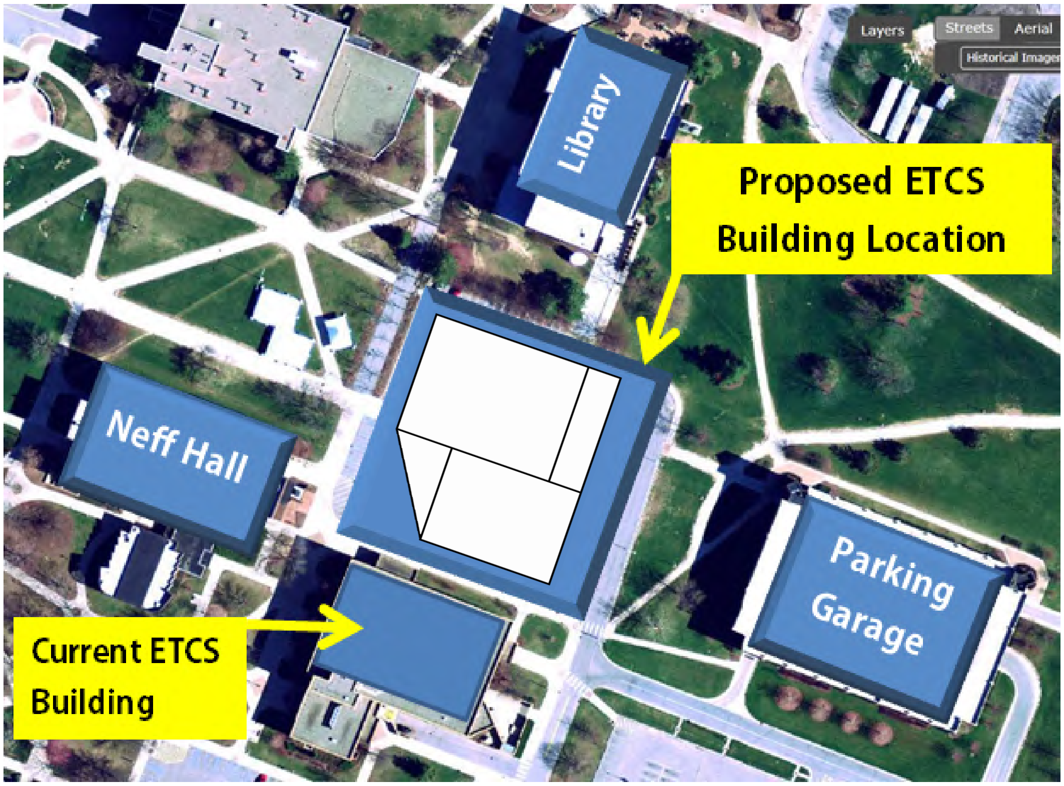

Figure II-1. Aerial view of the proposed building location on the IPFW campus.

II.2. Initial conceptual design

Aesthetics is an important factor for the design of the new building, as it can make the campus as a whole more attractive to current and future students. A building with strong, unique aesthetics will also be a stamp for IFPW engineering as well as a trademark for the city as a whole. It was therefore important to begin with getting inspiration from other sketches and buildings before sitting down and deciding on how the final product would look.

Figure II-2 below shows three different sketches or renderings of other buildings that were used in inspiration for our design. On the left is a rendering of an apartment complex, in which there are many garden areas and plants, but most significantly the structural components of the cross bracing is incorporated as an architectural picture, and is really what makes this building a statement piece. In the middle photo, the entrance is a separate area from the rest of the building. There is not just a large door; instead there is a truly noticeable entrance. In the sketch at the right, inspiration was taken from the multiple levels and sections that seem to form a sort of puzzle.

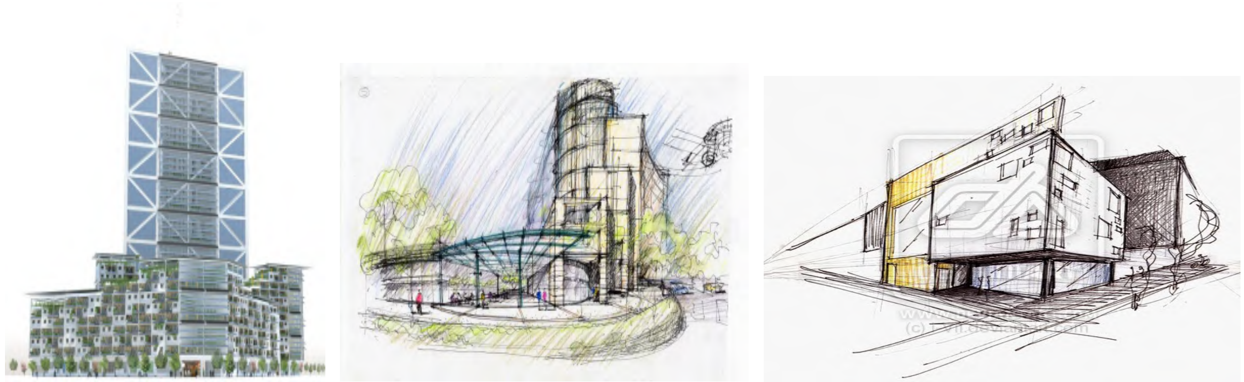

Figure II-2. Initial inspiration from sketches and renderings of other buildings ([4], [5], [6]).

Figure II-3 below shows three photos of other engineering buildings from across the United States. It was important to take inspiration from other building with the same use, as they show a connection between the functionality of the project as well as the aesthetics. In the photo on the far left, this Oregon State incorporated interesting and eco-friendly landscaping into their LEED certified engineering building. In the photo in the center, the University of Michigan combined multiple textures and large amounts of glass to make this engineering building a true statement piece. On the far right, practicality meets aesthetics in a way truly sought after in this project. With high ceilings for the labs on the ground floor and an elevated entrance, as well as a walkway connecting the building to others on campus, this is a building that would definitely be a match for the IPFW Campus.

Figure II-3. Initial inspiration from other engineering buildings ([7], [8], [9]).

Preliminary rough sketches were drawn by one of the group members on this project. One of these sketches can be seen below in Figure II-4. Key structural features were incorporated into the architecture through the cross bracing that stands out along the corners. A strong entrance adds a three dimensional feel and makes a statement for the building, while keeping with the theme of other IPFW buildings, such as the Rhinehart Music Building. Sixteen-foot ceilings with tall windows are shown to increase natural light and sustainability. It can also be seen that the roof is covered in greens and wind turbines, not only to add interest to the building, but also to improve the sustainability of the project.

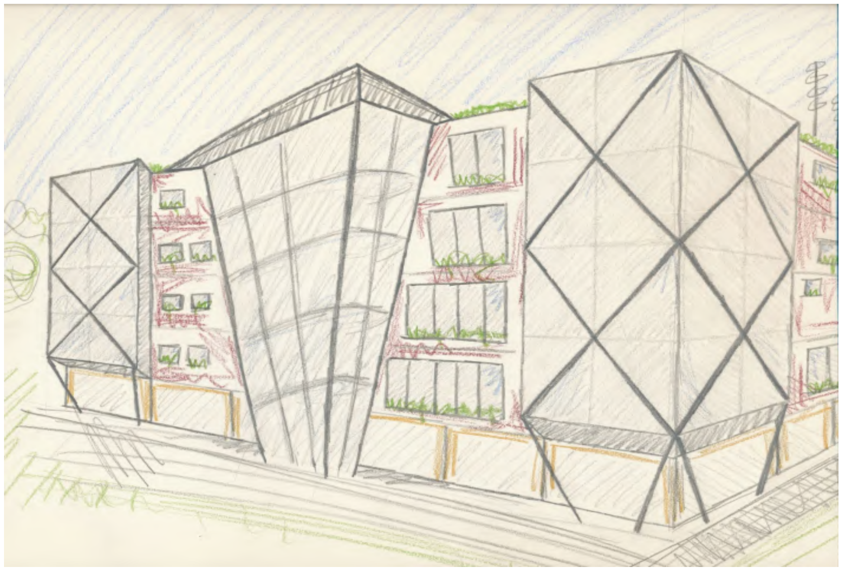

Figure II-4. Preliminary sketch combining different inspirations.

The conceptual design then began to take into account practicalities, such as space and floor plans. Figure II-5 shows a very minimalist CAD sketch of the basic architecture chosen for the building. With multiple levels within the structure, areas were sectioned off for different uses. For example, the area that is only three stories and protrudes out, as seen in the figure, has a garden on its roof. The fourth floor adjacent to it was decided to be a student study area, where they would have access to this roof garden.

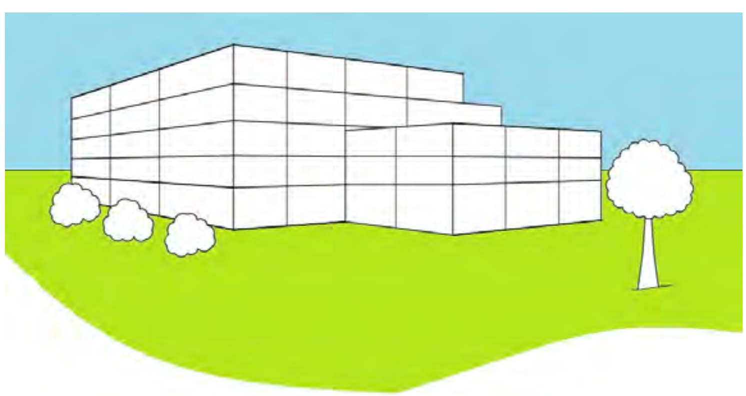

Figure II-5. Basic conceptual design.

II.3. Floor plans

Based on the space provided by the current ETCS building for the different services and considering its inadequacies, the team came up with the amount of surface area needed for each service (Table II-1).

Table II-1. Space assigned for general services provided by the new ETCS building.

Service	Total Area (ft^2)
Main Center of Excellence	2,800
Classroom Space	49,500
Dean's Office	3,500
Laboratory space	15,000
Lobby	17,200
Offices	30,000
Student Study Spaces	15,900
TOTAL	133,900

The first decision made by the team when considering floor plans was the fact that the laboratories had to be on the first floor in order to facilitate access when transporting heavy machinery or large items. Furthermore, in order to change the typical arrangement of an enclosed artificially lighted lab, the team chose to put windows all around this first floor and make it 20ft tall so as to allow more sunlight to come through. As shown in Table II-2, the total surface area found for the laboratory area was 15,000ft^2. From there, we determined that that area of the building would be 100ft x 150ft.

Table II-2. Space assigned for general services provided by the new ETCS building.

Laboratory	Total Area (ft^2)
Environmental	500
Fluid Mechanics	1,500
Machine Shop	2,500
Materials	3,500
Soil Mechanics	2,000
Student Organization storage	1,500
Corridors, bathrooms, stairs, etc	3,500
TOTAL	15,000

Then, the team determined that that area seem to fit well in order to obtain the needed office space to accommodate faculty members in individual offices and provide large meeting rooms as well as a staff/faculty lounge. Thus, that section of the building would be three stories high.

Then, considering the space left based on the parking lot size, the team decided to create a basic squared shape of 210ft x 210ft from which we cut one of the corners to accommodate the main entrance diagonally so it would be more welcoming as it would invite entry to people from various directions. The next two major spaces to be considered were the lobby and the student study area. The lobby had to be welcoming, with lots of natural light going in and appear as a large open space. Thus, it was decided to make all windows around the exterior surface and, in order to catch more natural light and give this great welcoming feeling to visitors, make the lobby be two stories tall, giving it a total height of 36ft. Then, the study area had also to be an area filled with natural light and from which students could feel like they are almost working outside. Thus, as shown in Figure II-6, it was decided to use the opposite corner from the main entrance to locate the study space area. This façade would also be all windows for all four stories. The number of stories was also determined based on the determined necessary space. Finally, the classrooms had then to be located above the lobby. Based on the amount of classrooms needed, the team determined three floors would be necessary, making that section of the building five stories high.

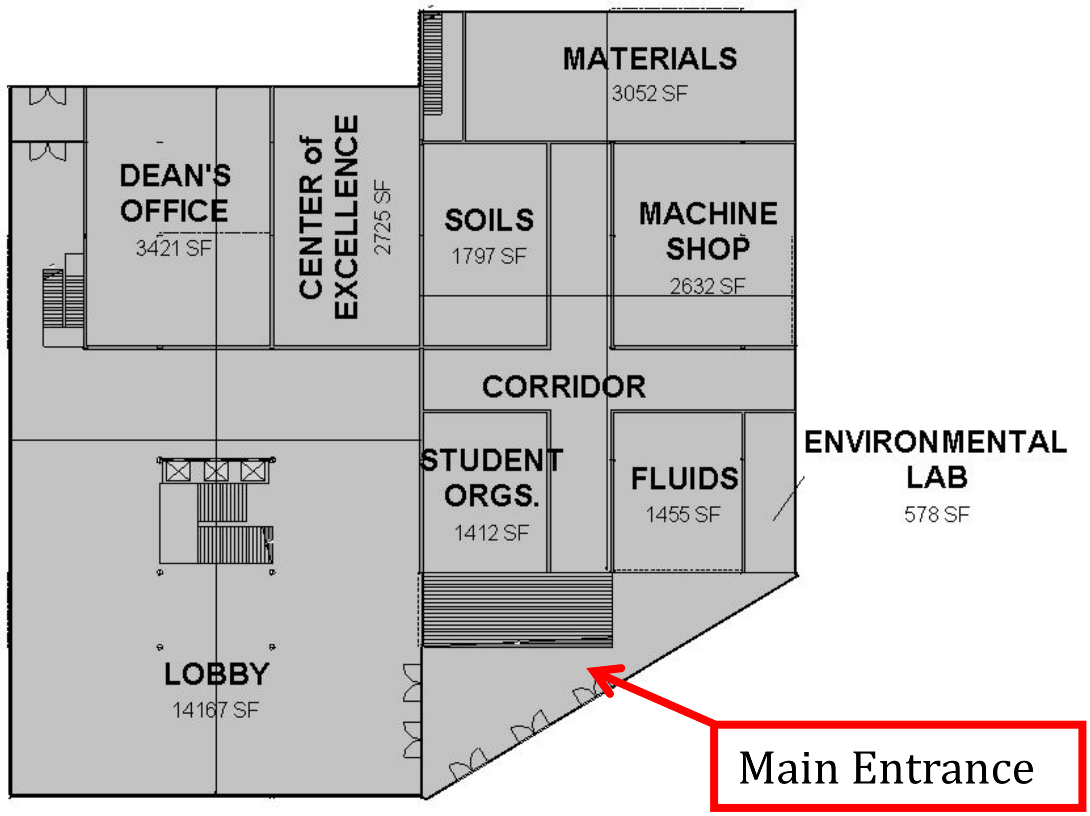

Figure II-6. First floor floor-plan.

As shown in Figure II-6, the main stairs and three glass elevators were finally located at the center of the lobby using the area provided by the structurally-needed columns in the center. This would also reflect the idea of a dynamic space, as people would be seen walking up and down the stairs or across the elevated walkway that connects the central stairs to the second floor above the laboratory space.

Figure II-7 below shows the 3rd floor plan. The office section on the right is the same on floors 2 and 3. For the classroom area, except for the lecture hall that only takes up floors 3 and 4, the space distribution is the same for floors 3 through 5. Finally, in the study space area, the different stories contain the following areas:

- 1st floor: Dean's office and Center of Excellence as shown in Figure II-6.
- 2nd floor: library. There is direct access to the library from the lobby.

- 3rd floor: study rooms distributed as shown in Figure II-7.
- 4th floor: large open silent study area with access to the roof garden located above the office space.

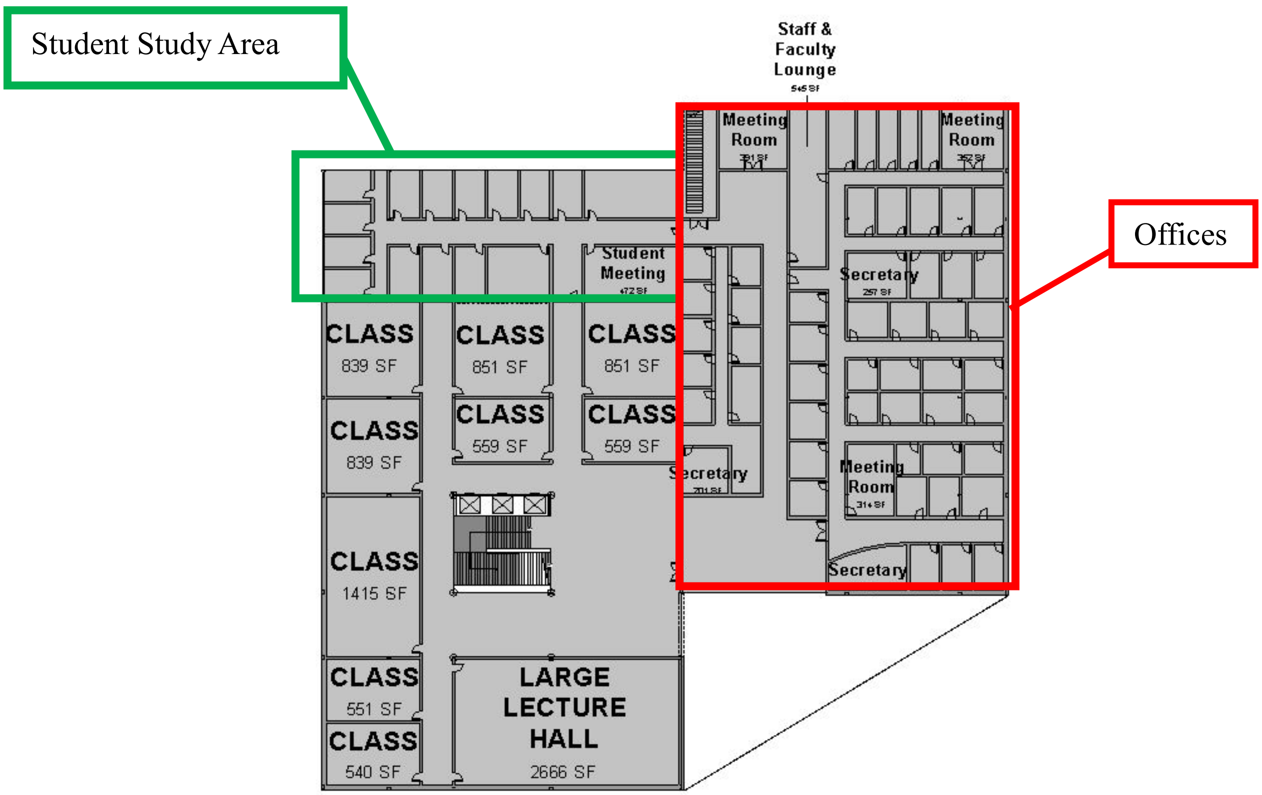

Figure II-7. 3rd floor floor-plan – semi-typical story.

III. Section III: Summary of Evaluation of Different Conceptual Designs

Given the scope of the project, there are three alternative designs on top of the alternative 0, the "do nothing" alternative. The first of which is to build a structure in which the majority of the structural components are steel. In the second alternative, the main structural components are concrete. The final alternative is a combined structure, which uses a combination of steel and concrete structural components. Within all of these alternatives, it is important to note that many components of the buildings stay the same. The main architectural feathers, floor plans, and many components of the cost are all portions that do not change between the alternatives.

III.1. Alternative 0: "Do nothing"

Within the do nothing alternative, the ETCS College would have to make the current building adequate with no new construction. Current practices would have to change to accommodate the over growth of the current college. Currently the majority of the courses are held at similar times, which are not spread throughout the week. By adding more courses to Monday and Wednesday mornings as well as Fridays, there would be less overlap and allow for more courses to be held in the current building. Also, if storage space could be acquired throughout other areas of campus, it could clear up laboratory space allowing more labs to be combined to allow lab courses to be held in the ETCS building.

III.1.1. Advantages

The main advantage of this alternative is that there will be no hassle of new construction on campus. Since the location of the new building is in a central location on campus, construction would seriously disrupt normal campus life.

III.1.2. Disadvantages

Even with altering current practices, the disadvantages of this alternative highly outweigh the advantages. Many of the project goals will not be met, student study areas, individual offices, large conference rooms, student organization space, large lecture hall, and centers of excellence.

III.2. Alternative 1: Steel structure

Alternative 1 is a structure where all main structural components are composed of structural steel. The entire gravity system, which is composed of columns, beams, and girders are designed with wide flange structural steel. The vertical system is composed of HSS structural tubing, and the floor system is a composite concrete and steel metal deck.

III.2.1. Advantages

Steel has a higher strength – to – weight ratio than concrete in both tension and compression, giving this alternative the highest strength to weight ratio of all. In this area of the country, steel is a readily available material, contributing to this alternative having the lowest environmental impact of the three.

III.2.2. Disadvantages

Steel is a more expensive material than concrete, and the price fluctuates significantly with time. This results in problems with bidding, since the bid price could be significantly different than the actual cost. Since IPFW is a public, state funded university, this could pose a large problem with the funding of the project. Steel also has slower construction time than concrete. Since the location of the new building is in a central location on campus, long construction times can significantly disrupt day to day activities. Steel structures also require significant fireproofing that is avoided when using concrete for structural components.

III.3. Alternative 2: High-Strength Concrete Structure

Alternative 2 is a structure where all main structural components are composed of high strength reinforced concrete. The entire gravity system, which is composed of columns, beams, and girders are designed with high strength reinforced concrete, where the compressive strength is 8000 psi versus normal weight concrete which is generally 4000 psi. The vertical system is still composed of HSS structural tubing, as concrete shear walls would have severe negative effects on the aesthetics of the building. The floor system is a composite concrete and steel metal deck, where the concrete is 3000 psi concrete. High strength concrete is not used for the floor system, as strength is not the limiting factor – deflection is. Therefore, using high strength concrete would be a pointless added cost.

III.3.1. Advantages

The price of concrete stays relatively stable, and is cheaper than steel. It has a high strength – to – weight ratio in compression, and additional fireproofing is not needed. At lower elevations, construction occurs at a much more rapid pace than steel structures.

III.3.2. Disadvantages

Although the strength – to – weight ratio is high in compression, overall the concrete structure does have the lowest strength – to – weight ratio of all three alternatives. Constructability does become more difficult, lengthy, and expensive at high levels due to the need for pumping of the concrete up to the high floors. As shown in Section I.5.3, the environmental impact of concrete is more significant, especially in terms of CO_2 emissions and depletion of natural resources, making this alternative have the highest environmental footprint. Also, it was found through the design that in general the column sizes in this structure are larger and extra columns are necessary through some of the open spaces that are vital to the aesthetics of the design.

III.4. Alternative 3: High-Strength Concrete & Steel Combined

Alternative 3 is a structure where all main structural components on the bottom two stories are composed of high strength reinforced concrete. The top three stories then have structural components that are structural steel. The vertical system is still composed of HSS structural tubing, the same as it is for the other two alternatives. The floor system on all stories is a composite concrete and steel metal deck, where the concrete is 3000 psi concrete. High strength concrete is not used for the floor system, as strength is not the limiting factor – deflection is. Therefore, using high strength concrete would be a pointless added cost. Figure III-1 below shows the different materials within the structure. The teal color represents the structural components that are concrete and the green represents those that are steel.

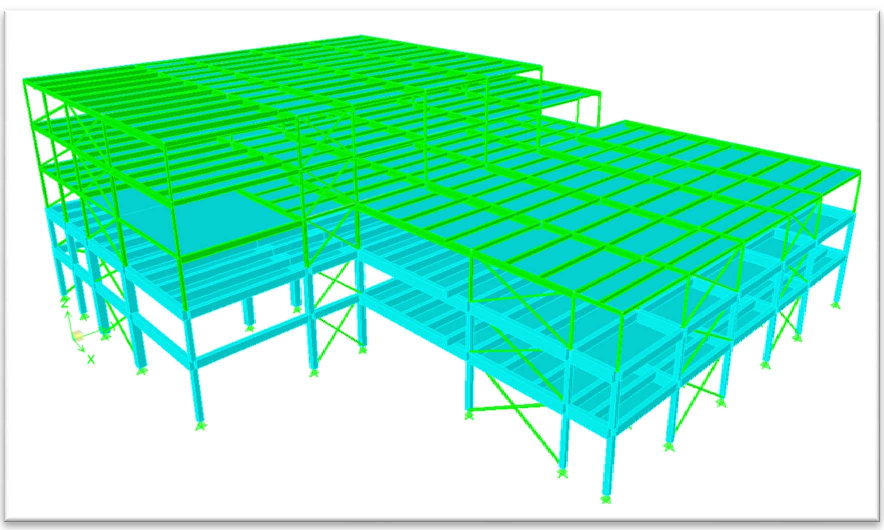

Figure III-1. Snapshot of Alternative 3 structure showing different materials used.

III.4.1. Advantages

This alternative provides the best of both worlds with constructability. The quick construction of concrete is taken advantage of at the lower levels, which dealing with expensive and lengthy pump trucks at the upper levels is avoided. Also, fireproofing is only necessary through approximately 60% of the structure.

III.4.2. Disadvantages

Within this alternative, it was found through the design that, in general, the concrete columns' sizes in this structure are still larger and extra columns will still be necessary through some of the open spaces that are vital to the aesthetics of the design. Also, many parts of this design fall in between the other two alternatives. The cost is more than concrete but less than steel. The strength-to-weight ratio is lower than steel but higher than concrete.

III.5. Decision Matrix

Before the alternatives can be compared to one another, it must be decided which design criteria are the most important. A systematic approach to doing this is by comparing each criterion against one another, one at a time. It has been shown that humans can compare two things much more efficiently than they can compare even three or four [3]. A systematic approach is then used, as outline in *Engineering by Design*, called a Design Criteria Weighting Matrix, as shown in Figure III.5.1 below. The criterion in each column is compared to each of the criteria in the rows to the right. If the criterion in the column is decided to be more important, it gets a 1. If it is found to be less important, it is assigned a 0; and if the two criteria are found to be of equal value, it is assigned a 0.5. This simplified system of comparing all criteria is then performed throughout the entire chart. The values in the each of the columns are then summed, and the criterion with the highest sum is then the most valuable design variable. This sum is then divided by the total of all criteria, and this is the weight of the design variable when used in the decision matrix, shown in Table III-1. It can be seen that initial cost was determined to be the most important criteria, followed by constructability, aesthetics, and environmental impact and durability, respectively.

Table III-1. Design criteria weighting matrix.

Design Criteria	Initial Cost	Aesthetics	Environmental Impact	Durability	Constructability
Initial Cost	–	0	0	0.5	0
Aesthetics	1	–	0	0.5	0.5
Functionality	1	1	1	1	1
Environmental	1	1	–	0	1
Durability	0.5	0.5	1	–	1
Construction	1	0.5	0	0	–
Total	**4.5**	**3**	**2**	**2**	**3.5**
Weight Factor	**30%**	**20%**	**13%**	**13%**	**23%**

In order to make an unbiased decision as to which of the alternatives would be chosen for the detailed design, a decision matrix was used as seen in Table III-2 below, following the guidelines found in *Engineering by Design* [3]. Each of the alternatives was rated against each of the design variables according to the following rating scale:

- 5 – Excellent
- 4 – Very Good
- 3 – Good
- 2 – Poor
- 1 – Very Poor

That value was then multiplied by the weight factor of each of the variables, so that the more important variables would have more of a factor in deciding which alternative to use in the design. These values were then summed, as seen in the second to last column. Whichever alternative had the highest total values was determined to be the best design. Complete rankings can be seen in the last column of Table III-2 below.

Alternative 1, the steel structure, was found to be the best alternative design. Although it did not receive the highest rankings in the two most important criteria of initial cost and constructability, its benefits were shown in aesthetics, environmental impact, and durability, where it received the highest rankings in all categories.

Table III-2. Design alternatives decision matrix.

Design Criteria / Requirement Weighting / Design Alternatives	Initial Cost	Aesthetics	Environmental Impact	Durability	Constructability	Total Weighted Factor	Ranking
	30%	20%	13%	13%	23%	100%	
Alternative 0	5 / 1.5	1 / 0.2	4 / 0.53	1 / 0.13	-- / --	2.37	4
Alternative 1	2 / 0.6	5 / 1.0	4 / 0.53	5 / 0.67	4 / 0.93	3.73	1
Alternative 2	4 / 1.2	3 / 0.6	2 / 0.27	4 / 0.53	3 / 0.70	3.30	3
Alternative 3	3 / 0.90	3 / 0.60	3 / 0.40	4 / 0.53	5 / 1.2	3.60	2

IV. Section IV: Detailed Design of the Selected Conceptual Design

IV.1. Building Setup and Column Placement

Using the floor plans the group decided upon, columns were placed where they would not interfere with the allotted spaces. Figure IV-1 shows the floor plans from the first floor of the building. It can be seen from this figure all the location of the columns. As part of the architectural design of the building the group wanted to minimize the amount of columns that were in the lobby to create an open space environment. The columns were limited to six as shown in the figure. This enabled the group to use the center of the lobby for elevators, stairs, and extra space for the architect to use.

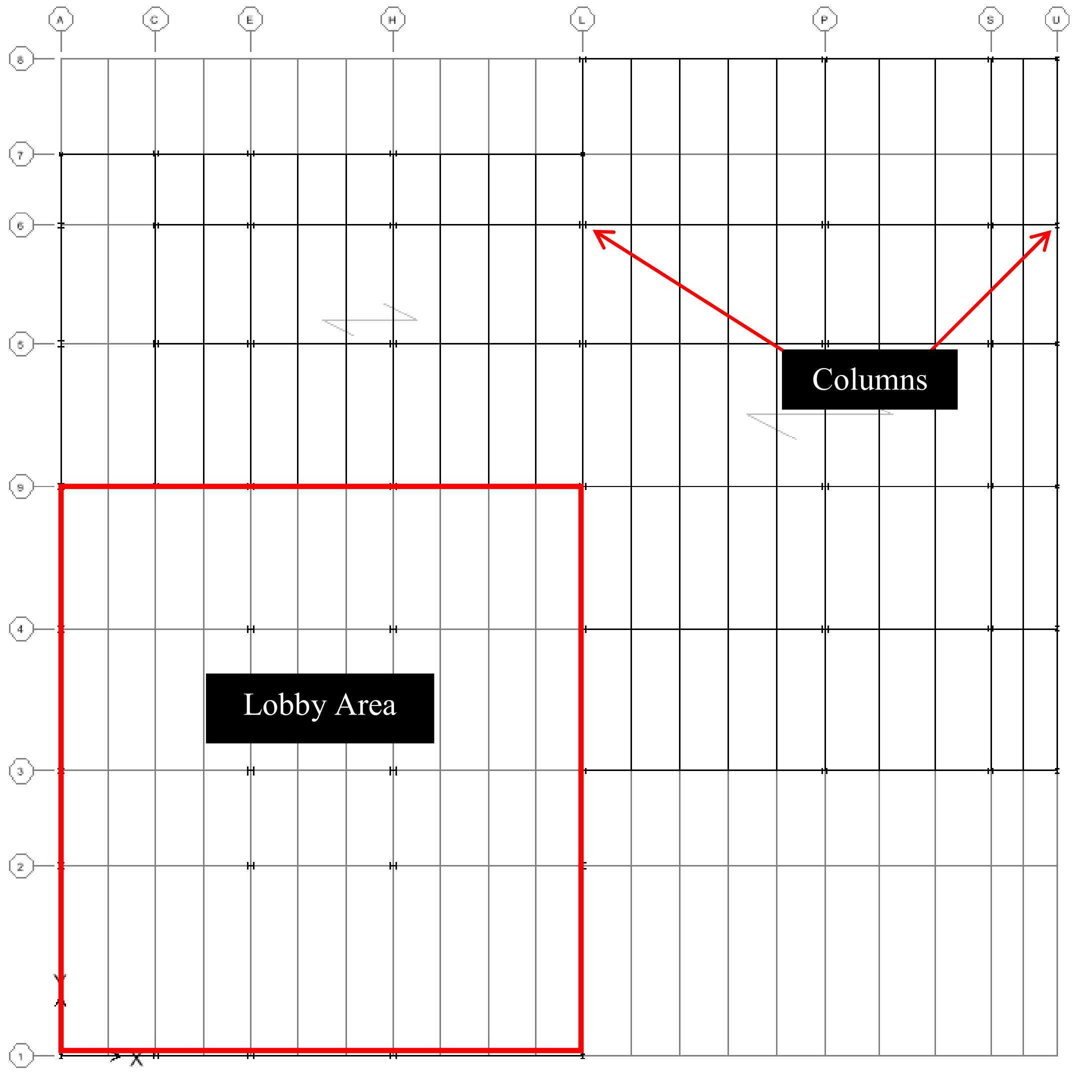

Figure IV-1. First floor plan showing the placement of the columns.

IV.2. Building Loads

The building was designed for four different types of loads; dead, live, snow, and wind. The loads used for the building were taken from the ASCE 7-05 "*Minimum Design Loads for Building and Other Structures*", general building codes. The loads were then used along with the *Load Resistant and Factored Designs* (LRFD) combinations taken from the in accordance with the American Institute of Steel Construction (AISC).

IV.2.1. Gravity Loads

The dead load for the building consisted of the self-weight of the structure plus mechanical and cladding loads. Cladding loads were assumed to be on the outside girders of the building only. These loads are from the windows and panels that would be placed on the exterior of the building. Because no cladding loads are given in the ASCE 7-05 code, the loads were found by using the material properties for commonly used windows and steel panels. The unit weight of the materials was then multiplied by the thickness and height of each story to find the uniform distributed load that the materials would exert on the girders. The mechanical loads consist of all the mechanical components of the building and these loads are given in ASCE 7-05. Table IV-1 summarizes the dead loads on the building.

Table IV-1. Minimum Distributed Dead Loads Based on ASCE 5-07.

Loading Type	Uniform (lb./ft^2)
Cladding	
Windows	8
Panels	15
Suspended steel channel system	2
Mechanical duct allowance	4

The live loads consist of all the parts of the building that are not attached to the building such as people, desk, chairs, computers, etc. Table IV-2 bellow shows the live loads that applied to the building. Due to the complexity of the floor plans and areas however, the maximum load that the floor would be exposed to was applied to the entire floor for the design.

Table IV-2. Minimum Distributed Live Loads Based on ASCE 5-07.

Occupancy of Use	Uniform (lb/ft^2)
Office Use	50
Computer Use	100
Lobbies	100
Corridors above the first floor	80
Corridors first floor	100
Libraries	
Reading rooms	60
Stack rooms	150
Schools	
Classrooms	40
Lecture Hall	60
Roofs	
Ordinary flat roofs	20
Roofs used for gardens or assembly purposes	100
Labs	250

The last gravity load that was considered was the loading from snow. The International Building Code (IBC) gives snow loads for Indiana as 15 – 30 psf depending on the case study area. The group assumed a value of 20 psf for the Fort Wayne area. This load was applied to the roofed areas only.

IV.2.2. Lateral Loads

As stated in the previous section, the building was also designed for wind loads. In order to obtain the wind loads, the design wind speed must first be determined. These wind speeds are determined by using a wind speed map. These maps give wind speed contour lines for the United States based on speed of a 3 second gust of wind. An example of the wind map is shown below in Figure IV-2 below.

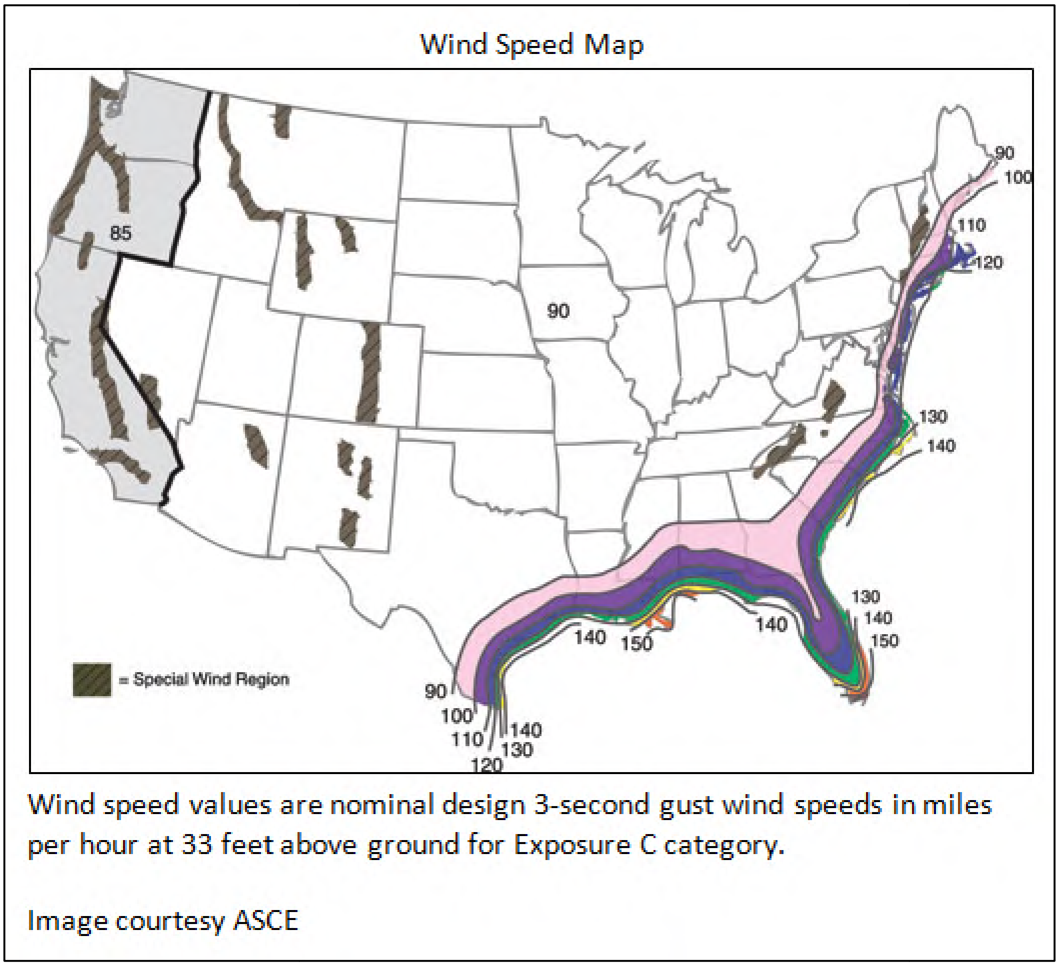

Figure IV-2. Wind map showing wind contour lines.

The design wind speed is then used in accordance with the ASCE 7-05 codes to obtain the wind pressure. The ASCE wind pressure equation that was used to determine the loading on the building was:

$$q_z = 0.00256K_z\, K_{zt}\, K_d\, V^2 \text{ (lb/ft}^2\text{)} \quad \text{(IV.2.2.1)}$$

where:

q_z = wind pressure
I = the importance factor
K_d = wind directionality factor
K_z = velocity pressure exposure coefficient evaluated at height z
K_{zt} = topographic factor
V = design wind speed

Once the wind pressure was calculated, it was multiplied by the longest distance of the building to obtain a uniform lateral load. It was then assumed that half of the load would go to each end of the building. Because wind pressure varies with height, the pressure at the top of the building would be greater than the pressure at the bottom. Therefore a linearly decreasing wind load was assumed along the height of the building as shown in Figure IV-3. It was further assumed that these loads would be brought to the joints by the exterior windows and panels. The final loading that was applied to the building at the lateral bracing frame is shown in Figure IV-4.

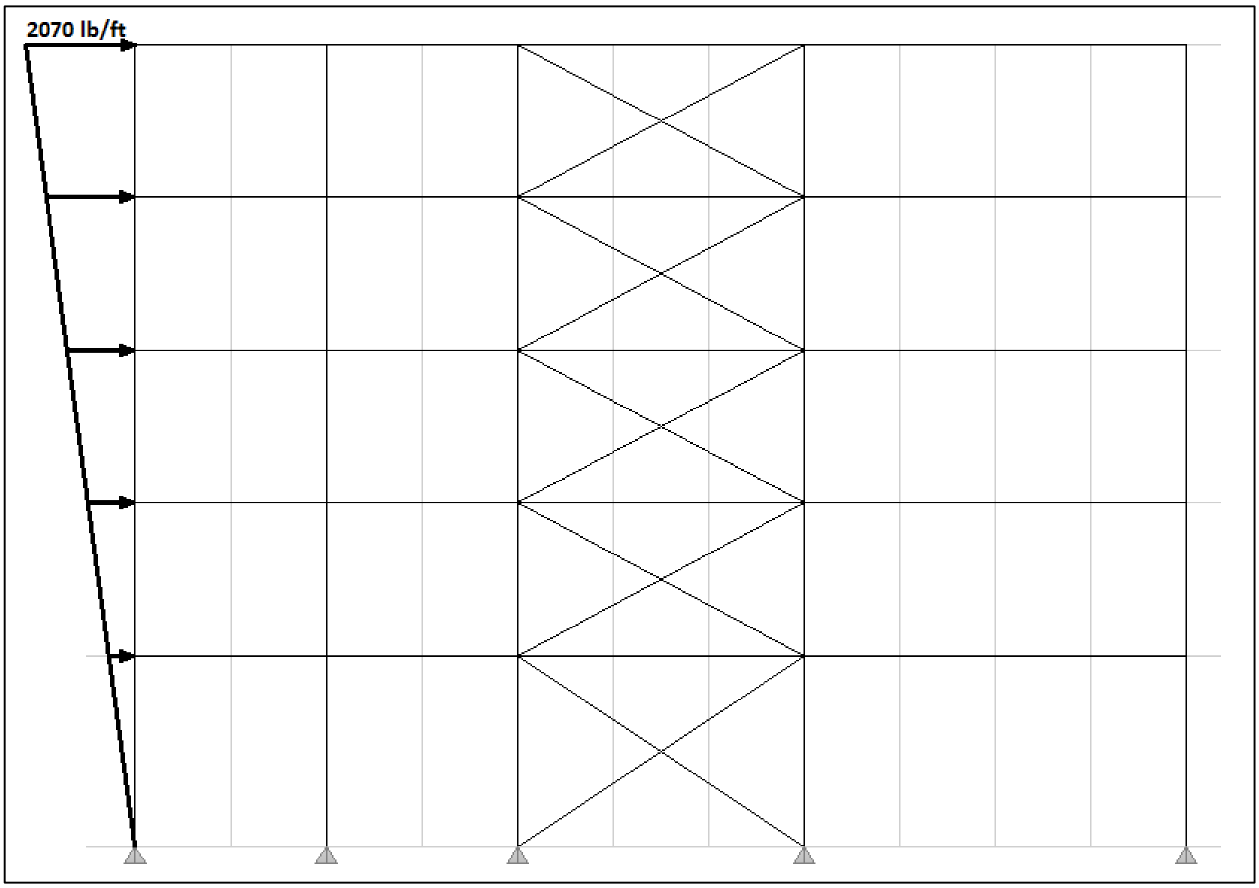

Figure IV-3. Linearly decreasing distributed wind load shown on 5 story section of building.

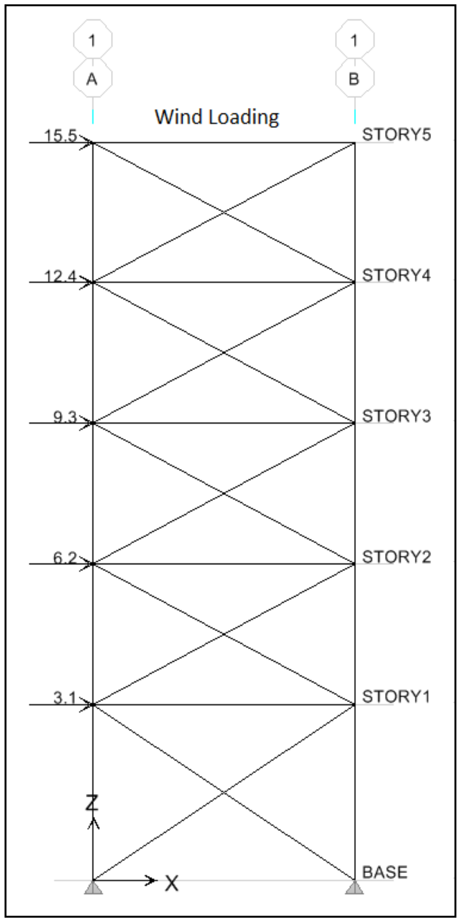

Figure IV-4. Wind loading applied to the joints of the lateral frame.

IV.3. Structural Systems

The building was designed with three different structural systems; gravity, lateral, and floor systems. The floor system is used to carry and transfer the loads on the structure to the gravity system. A concrete over metal deck was used for the floor system. An example of this type of floor system is shown in Figure IV-5 below. Typical and readily available metal deck sections were used. This flooring system also consisted of a composite beam and deck. This was used so that the floor beams and floor system act as one structural system, adding to the stability of the structure.

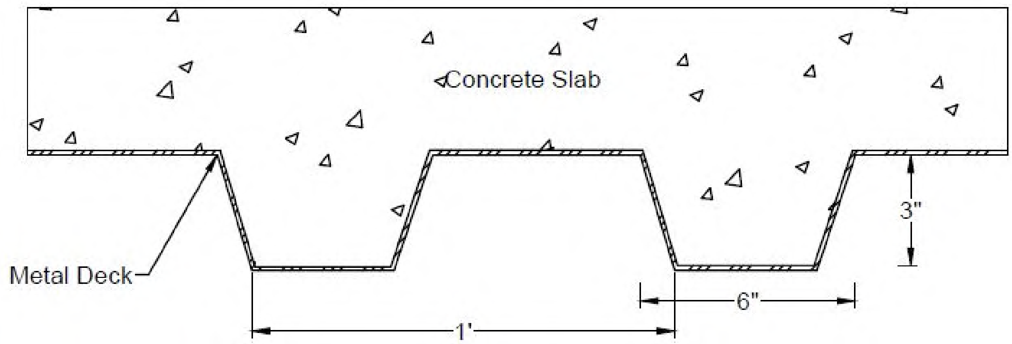

Figure IV-5. Example of a concrete over metal deck system.

The gravity system consists of floor beams, girders, and columns. The floor beams are used to carry the loads from the flooring system on the structure to the girders. The girders than take the loads from the floor beams to the columns and the columns take the total loads to the building foundation. For the gravity system each floor beam is pinned to the girders and the girders are pinned to the columns. This ensures that there are no moments at the connections between the floor beams, girders, and columns. All columns however, are continuous to maintain structural stability within the building. Wide flange (WF) steel sections were used for the beams, girders, and columns with ASTM A992 grade 50 steel.

The lateral bracing system is used to take the lateral loads, in this case wind, through the system to the foundation. An X-bracing lateral system was used in the building and an example of this system can be seen in Figure IV-4. Pinned connections were used for each brace in the system and ASTM A500 grade 50 square hollow steel sections (HSS) were used for the X-braces. These sections and grades were used because they are readily available. Figure IV-6 below shows available grades based off the ASTM specifications.

Table 2-1

Applicable ASTM Specifications for Various Structural Shapes

Steel Type	ASTM Designation		F_y Min. Yield Stress (ksi)	F_u Min. Yield Stress[a] (ksi)	Applicable Shape Series									
					W	M	S	HP	C	MC	L	HSS Rect.	HSS Round	Pipe
Carbon	A36		36	58-80[b]	▓	■	■	▓	■	■	■			
	A53 Gr. B		35	60										■
	A500	Gr. B	42	58									■	
			46	58								■		
		Gr. C	46	62									▓	
			50	62								▓		
	A501		36	58								▓	▓	
	A529[c]	Gr. 50	50	65-100	▓	▓	▓	▓	▓	▓	▓			
		Gr. 55	55	70-100	▓	▓	▓	▓	▓	▓	▓			
High-Strength Low-Alloy	A572	Gr. 42	42	60	▓	▓	▓	▓	▓	▓	▓			
		Gr. 50	50	65[d]	▓	▓	▓	■	▓	▓	▓			
		Gr. 55	55	70	▓	▓	▓	▓	▓	▓	▓			
		Gr. 60[e]	60	75	▓	▓	▓	▓	▓	▓	▓			
		Gr. 65[e]	65	80	▓	▓	▓	▓	▓	▓	▓			
	A618[f]	Gr. I & II	50[g]	70[g]								▓	▓	
		Gr. III	50	65								▓	▓	
	A913	50	50[h]	60[h]	▓	▓	▓	▓	▓	▓	▓			
		60	60	75	▓	▓	▓	▓	▓	▓	▓			
		65	65	80	▓	▓	▓	▓	▓	▓	▓			
		70	70	90	▓	▓	▓	▓	▓	▓	▓			
	A992		50-65[i]	65[i]	■	▓	▓	▓	▓	▓	▓			
Corrosion Resistant High-Strength Low-Alloy	A242		42[j]	63[j]	▓									
			46[k]	67[k]	▓			▓			▓			
			50[l]	70[l]	▓	▓	▓	▓	▓	▓	▓			
	A588		50	70	▓	▓	▓	▓	▓	▓	▓			
	A847		50	70								▓	▓	

■ Preferred material specification.

▓ Other applicable material specification, the availability of which should be confirmed prior to specification.

□ Material specification does not apply.

Figure IV-6. ASTM available grades.

IV.4. Model Building, Analysis, and Design Using ETABS

The building was modeled in ETABS analysis and design software with the groups determined dimensions and final conceptual designs. These dimensions were determined by the columns placements, floor beam spacing, and the building area constraints. The connections between the members were used as discussed in the previous section. The members in this model were added as design sections so that the software could design the best section due to the loading. As stated before all beams and columns are WF sections and cross braces are square HSS. The final three-dimensional model of the building is shown in Figure IV-7 below.

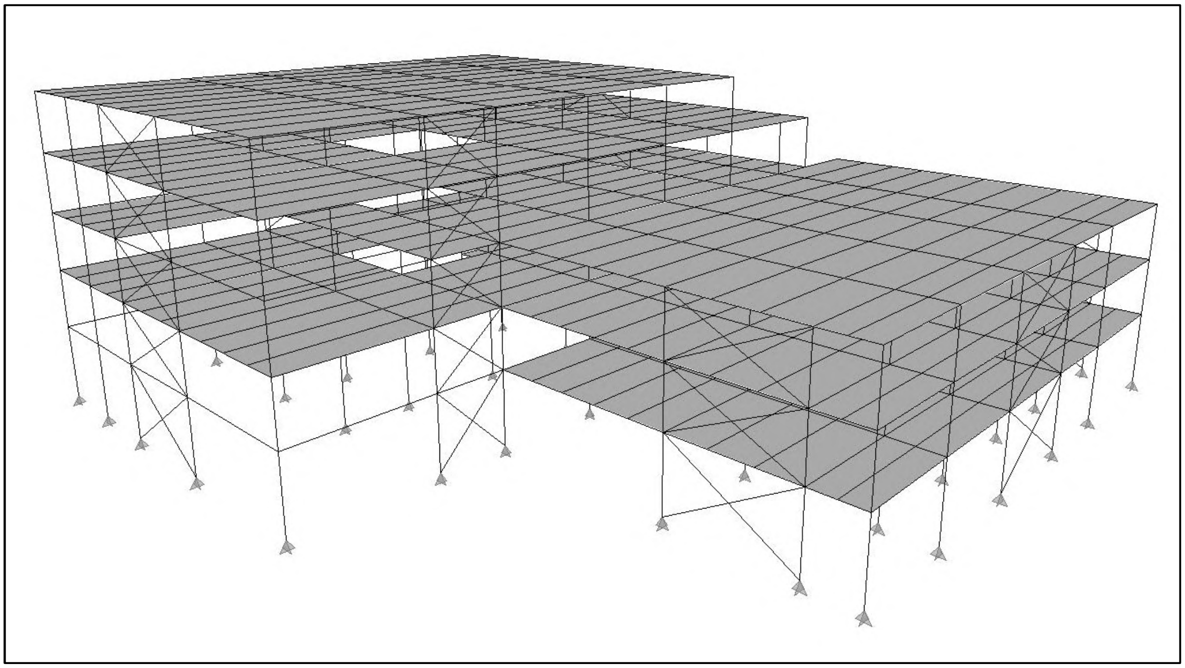

Figure IV-7. Three-dimensional model using ETABS.

IV.4.1. Slab Modeling and Design

The software used for the analysis and design of the building does not design the slab or floor system. Therefore before the loads could be applied to the building the concrete over metal deck floor system needed to be designed. All slabs in the building were designed as one way. This means that the load was transferred to the floor beams and girders in one direction. Two different slabs were designed for the building, a roof slab and a floor slab. Both slabs were designed based on ACI Code 9.5.2, which specifies the minimum thickness of a slab of normal weight concrete using Grade 60 reinforcement. Table IV-3 below shows examples of the minimum thickness of a slab for different support conditions based on the ACI code, where *l* is the clear span between beams. All slabs were designed as simply supported. Due to the clear span spacing and loading on the third floor roof, the composite roof slab was thicker than the rest of the buildings slabs. Based on the design and ACI code restrictions the roof slab had a thickness of 7.5 inches and the floor slabs had a thickness of 6.5 inches. Hand calculations for both slabs are shown in Appendix A.

Table IV-3. Minimum thickness h of non-prestressed one-way slabs.

Simply supported	$l/20$
One end continuous	$l/24$
Both ends continuous	$l/28$
Cantilever	$l/10$

These slabs were then created in the software along with the metal decks to create the concrete over metal deck system. They were applied to the building as areas and the building loads were added to them. All slabs were made rigid diaphragms in the software, which allow the entire slab to act cohesively. Figure IV-8 shows an example of the top view of the slab from ETABS. The white arrow in the middle of the slab shows the one-way direction of the slab.

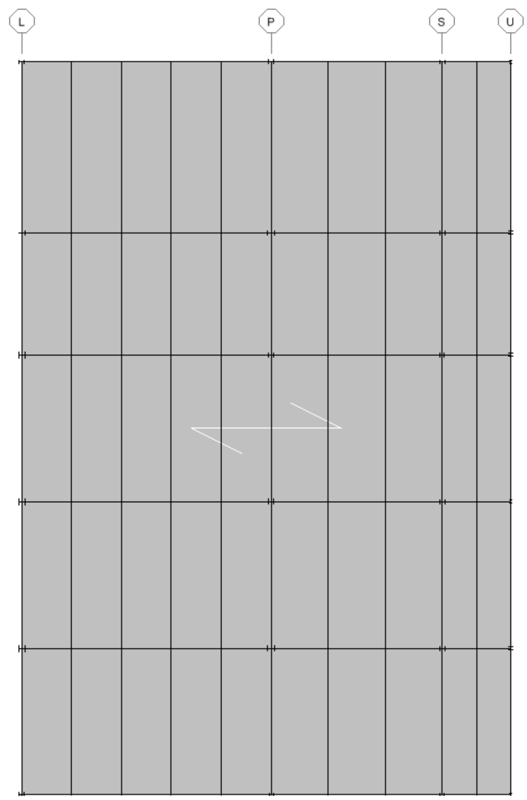

Figure IV-8. Slab section taken from ETABS.

IV.4.2. Building Analysis

The analysis was run on the building model using ETABS. From this analysis reactions, shear and moment diagrams, axial forces, and deflections can be found. Examples of these are shown in Figures IV-9 – IV-13, respectively.

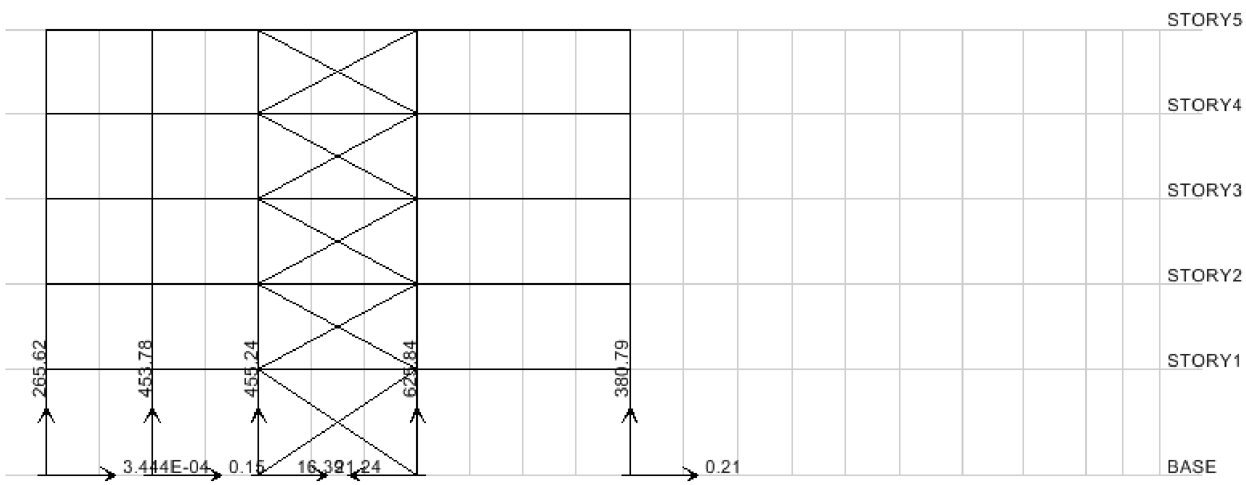

Figure IV-9. Screen shot taken from ETABS showing reactions.

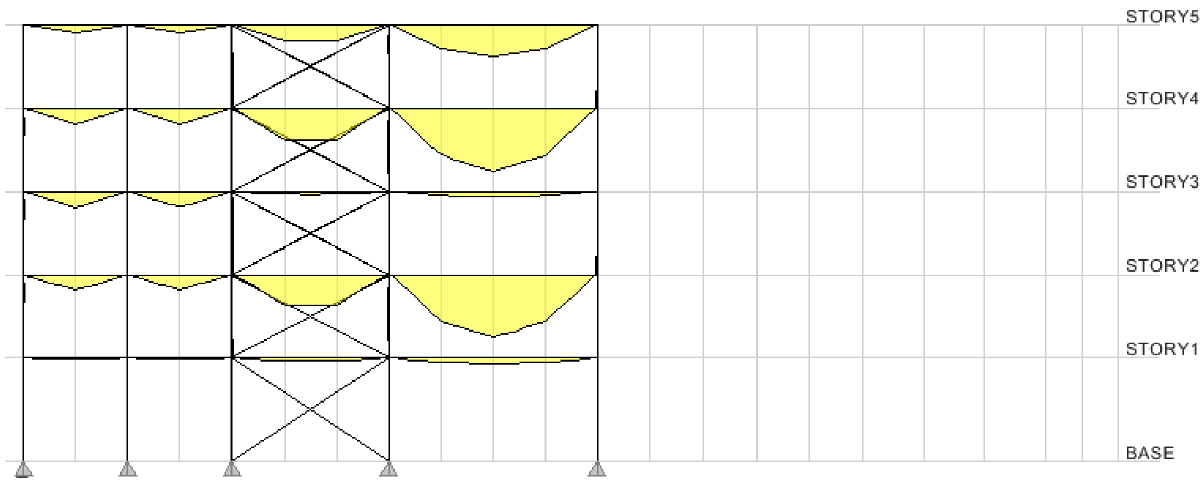

Figure IV-10. Screen shot taken from ETABS showing moment diagrams.

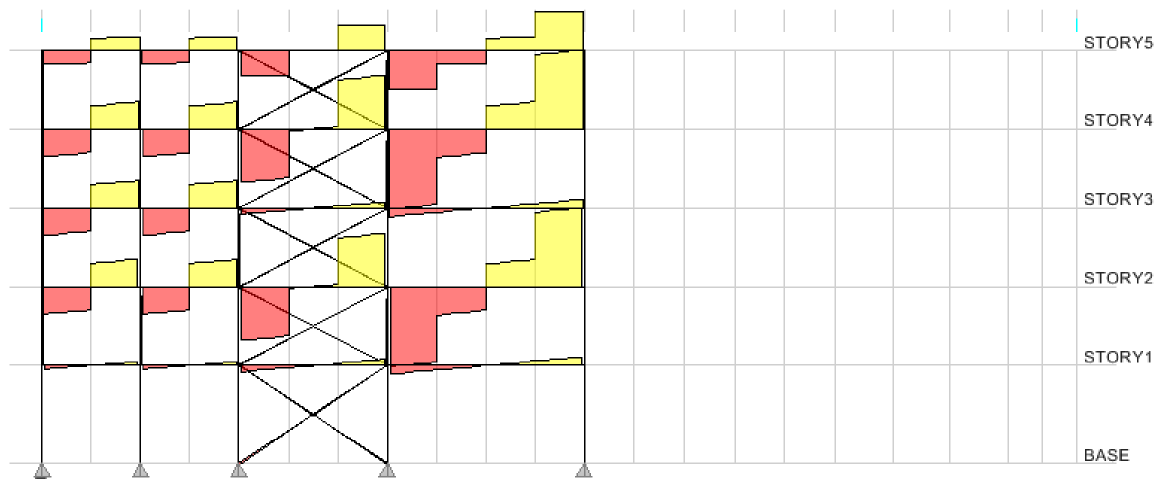

Figure IV-11. Screen shot taken from ETABS showing shear diagrams.

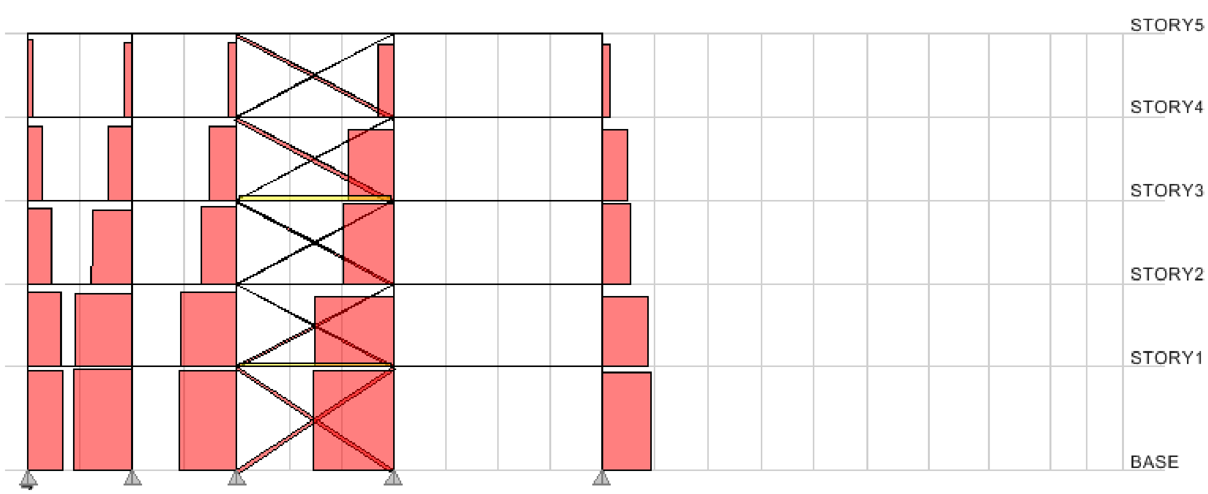

Figure IV-12. Screen shot taken from ETABS showing axial force diagram.

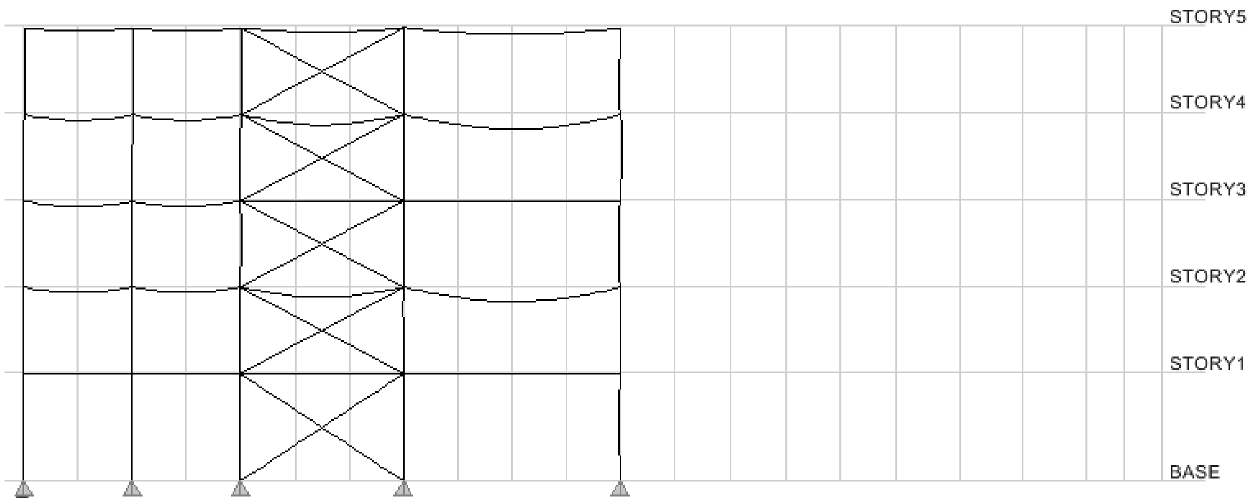

Figure IV-13. Screen shot taken from ETABS showing deflections of the beams.

Hand calculations were performed to check the reactions; these can be found in Appendix A.

IV.4.3. Gravity Building Design

ETABS was used to design all the sections of the building. The software designs the sections according to the AISC codes. A composite beam design was also used for the building. Typical sections as designed by the software are shown in Figure IV-14 and IV-15 below.

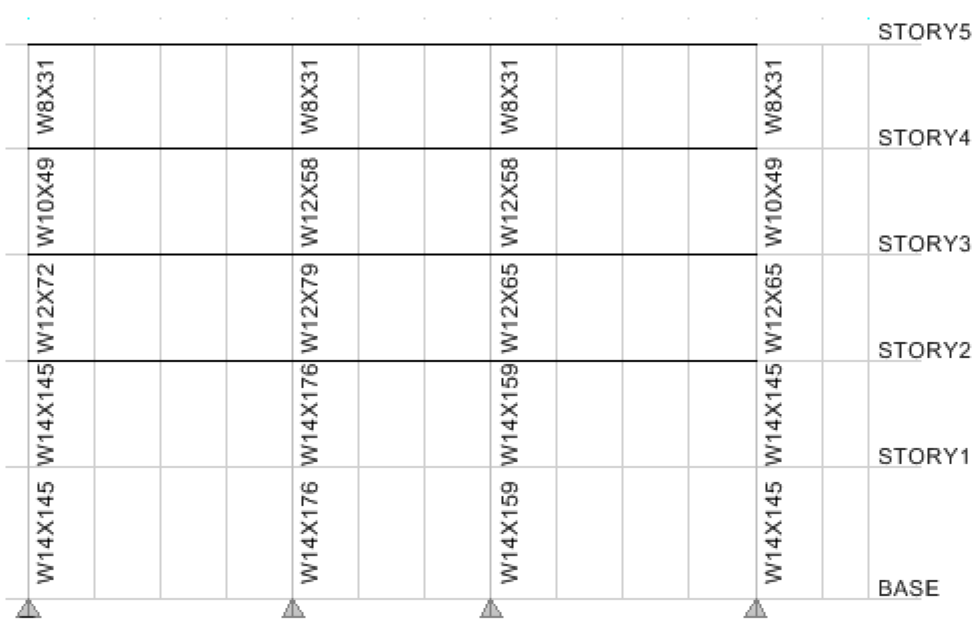

Figure IV-14. Column design sections from ETABS.

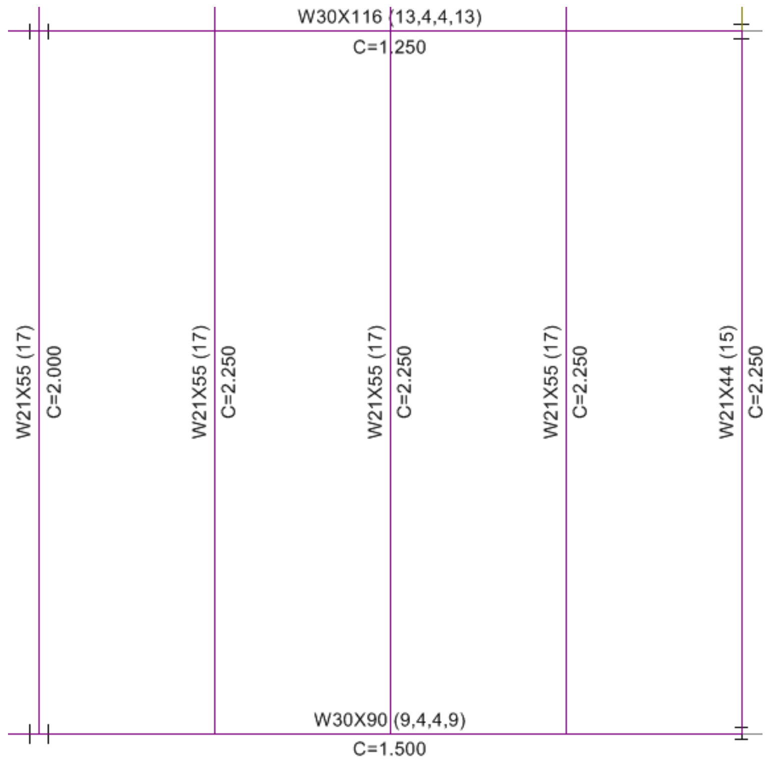

Figure IV-15. Composite beam design results from ETABS.

Figure IV-15 shows the results for the beam sections, the number of studs needed to make the deck and beams composite, and the amount in inches that the beam needs to be cambered. Example hand calculations for the check of the software's results are shown in Appendix A.

IV.4.4. Lateral Building Design

The building was designed for lateral loads using a separate lateral system model in ETABS. The X-bracing system was modeled in ETABS by itself with the wind loads at the joints as discussed in section IV.2.2 above. Also, due to the controlling load combination case according to the LRFD code, the dead and live gravity loads were also applied to the structure for the design. The controlling load case was found to be:

$$L_U = 1.2D + W + 0.5L \quad \text{(IV.4.4.1)}$$

A model of the complete bracing system with all the applied loads is shown in Figure IV-16 below. The figure shows the joint wind loads (left), applied in the positive x-direction, and the dead loads (middle) and live loads (right) applied in the negative z-direction.

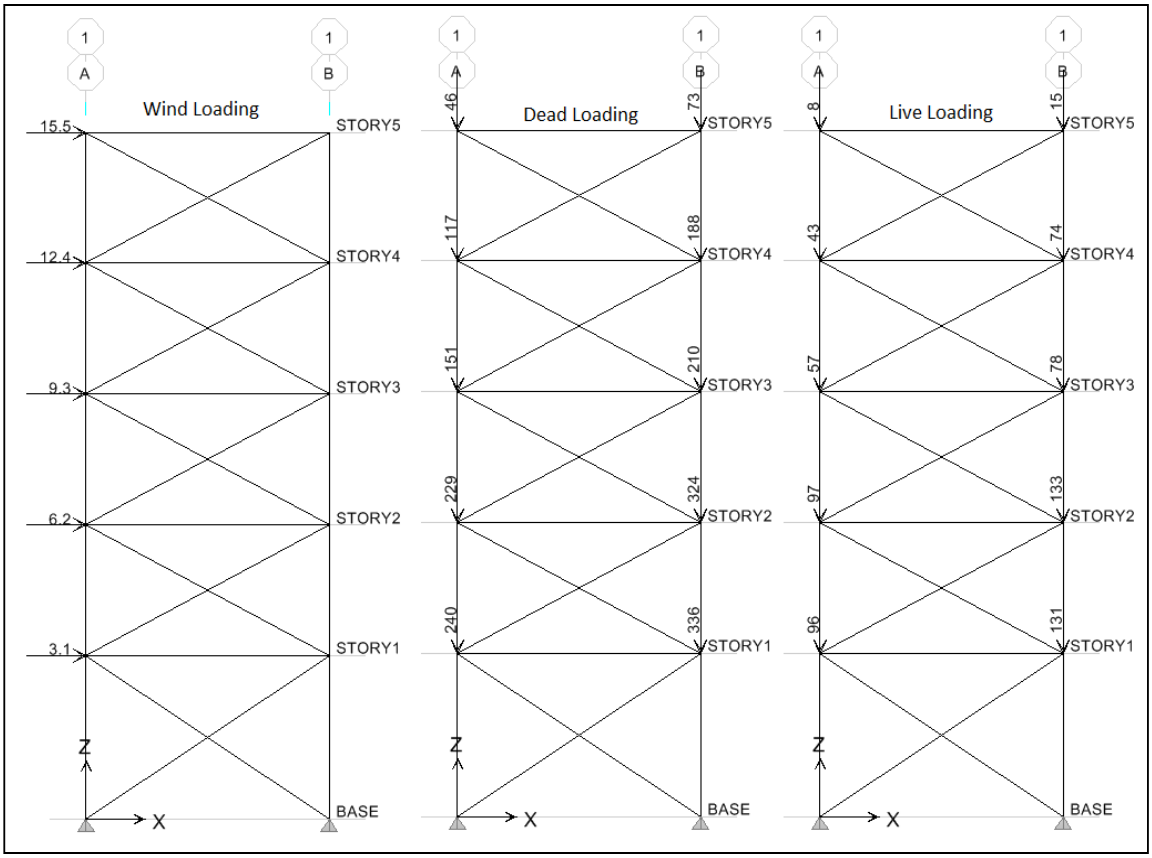

Figure IV-16. Loads on the X-bracing system due to the controlling load combination.

The analysis and design in the software was then run on the system and results were obtained for the lateral bracing system. The maximum design section of each floor was used for both braces because it is unsure which direction the wind will come from. The results from the design are shown in Figure IV-17.

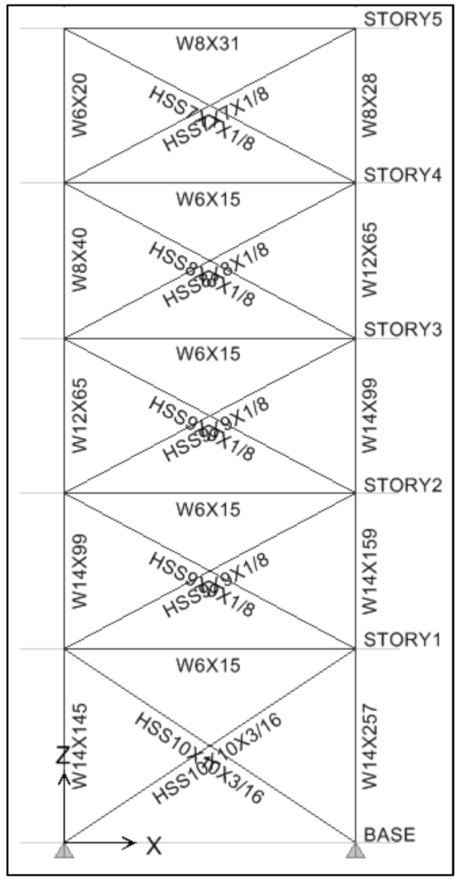

Figure IV-17. Design sections shown from ETABS.

The results from this design were then used for the other lateral braces in the building. At places where the building is only three or four stories, the results for the bottom three and four stories were used.

IV.4.5. Serviceability

After the sections were designed, the sway criteria based on ASCE codes was checked. Sway is limited so that partitions, cladding, and window are not damaged when the building is deflected laterally. Table IV-4 shows the drift results from story 5 compared to the ASCE typical drift requirements.

Table IV-4. Drift limits for partitions or cladding material (ASCE 1988).

Story No.	Disp-x	Drift - x	Typical Drift Requirements
5	0.4 in	0.026%	≤ 0.036%

The equation used to calculate the drift, as defined by ASCE is as shown below:

$$\text{Drift} = (\delta_n - \delta_{n-1})/h \qquad \text{....................................(IV.4.4.1)}$$

where: δ_n = drift of a story

δ_{n-1} = drift of the story below previous story

h = height of the story

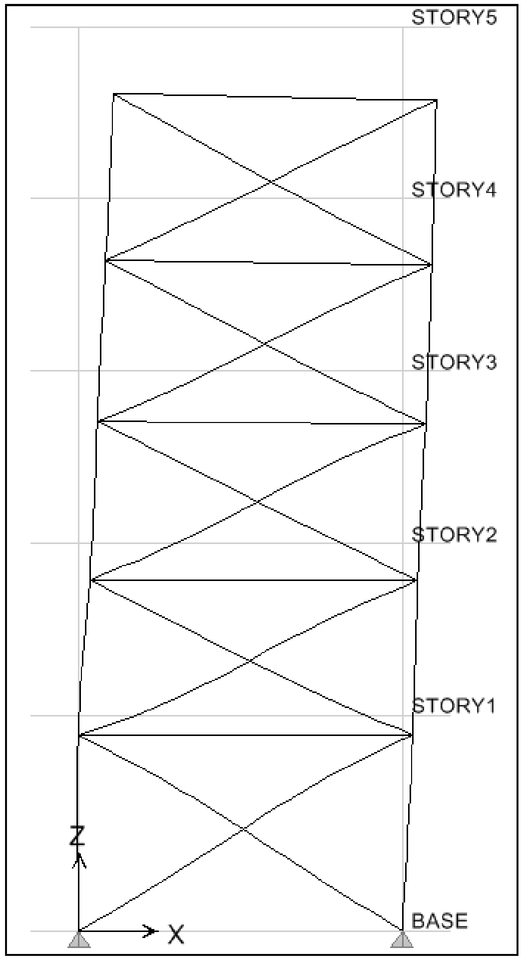

Figure IV-18. Deformed shape and drift due to combined loading.

The deflections in the beams were also checked based on the minimum deflection criteria set by ASCE. The vertical deflection of beams is limited to control cracks in ceilings and damage to windows and partitions. Deflection criteria can vary based on type or use of the structure or building. The group used the LRFD criteria as follows:

$$\text{Deflection} < \frac{\text{Beam Length}}{360}$$

IV.5. Final Design

After the gravity and lateral systems were designed, the systems were combined into one model and deflections were checked against the criteria discussed in section IV.4.5 above. From the combined structure the total columns, beams, X-bracing, and floor systems were found from the software's printouts. From the sections and floor systems the total cost, including labor, equipment, unit, and overhead was found using RSMeans 2010. A summary and total construction cost is shown in Table IV-5.

Table IV-5. Construction Costs Including labor, equipment, unit, and overhead costs.

Columns	$5,180,000
Beams	$17,300,000
X-Bracing	$12,960
Floor Systems	$70,700
Total (Millions)	$22.6

*Based on RSMeans 2010

Once the serviceability of the structure was met, the building was extruded as can be seen in Figure IV-19 below. This figure shows the complete structural systems including the gravity, lateral, and floor systems.

Figure IV-19. Final rendering of building in ETABS.

V. Section V: Final Design Model

Using the Revit Structure and Revit Architecture software, a 3-D model of the final building design was drawn. Several pictures were rendered and are shown below in Figures V-I and V-II.

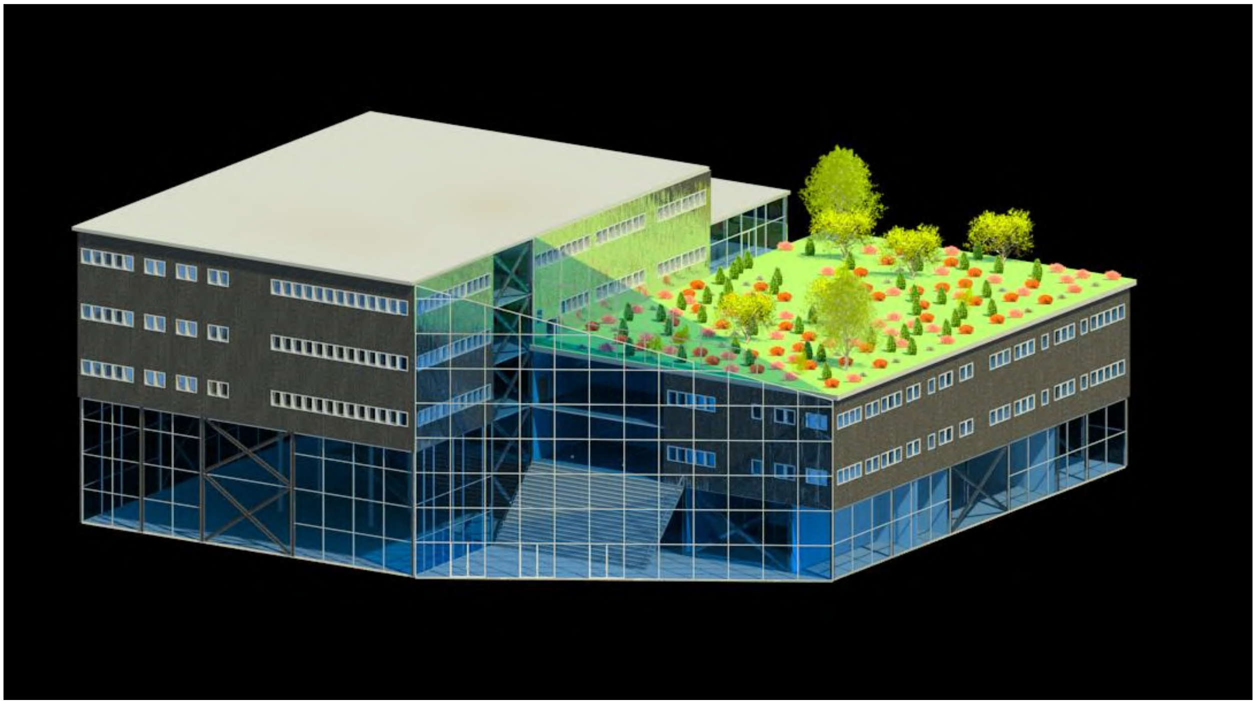

Figure V-1. Rendered picture of the final building design – Southeast view.

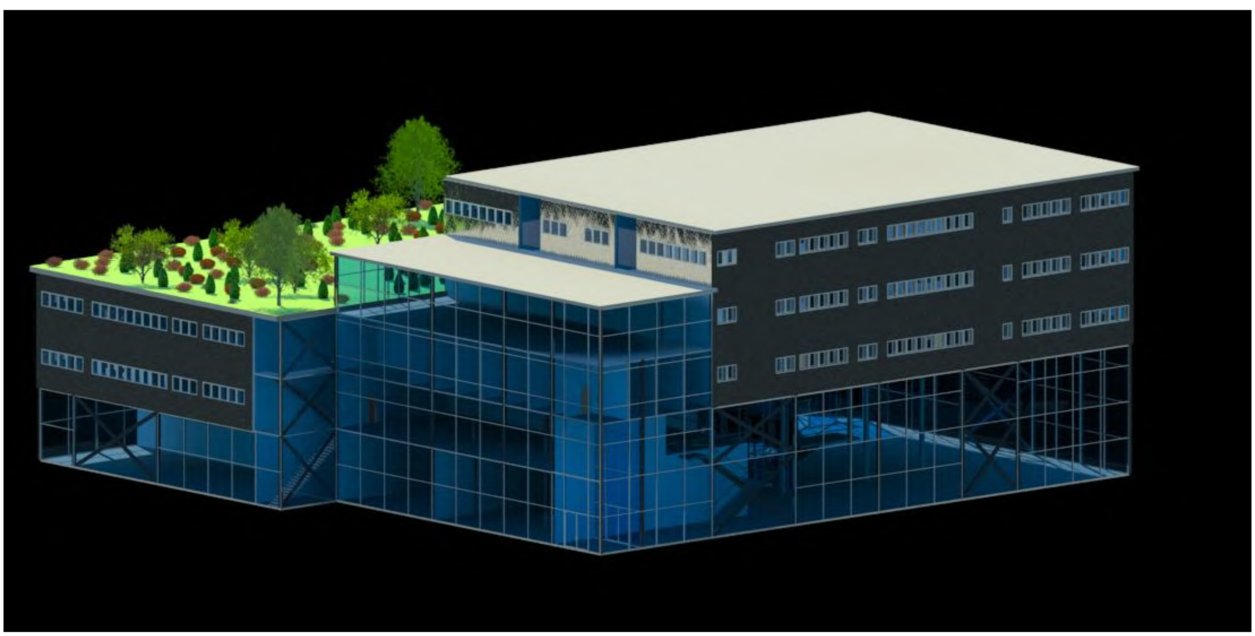

Figure V-2. Rendered picture of the final building design – Northeast view.

Figure V-1 shows the big glass panel at the main entrance of the building. Following the original inspirational drawings, the team was determined to have as much natural light as possible entering the building in order to create a more pleasant atmosphere to work and study. Especially in the lobby area, the natural light would provide a more relaxed environment where students, staff, faculty, and visitors can grab something to eat, sit and talk, or study in a more distended area. The stairs at the main entrance give direct access to the offices on the second floor and were purposely designed wider than necessary to give an image of *grandeur*. The idea is that students could sit out there during the cold winter days just as if they were outside but being protected from the wind, snow, and rain.

Figure V-II shows the building northeast facades, exposing the large window panels on the "student study area". Again, the idea is for students to profit of as much natural light as possible when studying or working in order to enhance their motivation and keep their spirits up.

The X-bracing can be seen on both pictures at the needed locations specified by the wind loading analysis. Aesthetically they provide a break for the regular window panels with metallic mullions at each façade.

All in all, this building is aesthetically pleasing and environmentally friendly as it strives to provide maximum natural light through large windows and adds green space to the campus with an attractive and relaxing roof garden.

VI. Conclusions

By designing a new building for the ETCS College the group was able to accommodate the future growth of the college. The building met the group's goals by providing a total building area of 133,900 sq. ft. This new building included areas such as: student study rooms, individual offices for professors, laboratory spaces within the building, student organization spaces, centers of excellence, large meeting rooms, a large lecture hall, and additional, adequate classroom space. The group's new design also provided better aesthetics with more than 60% of the building's exterior covering being windows and proposed that a roof garden be implemented on the roof of the third story. The group was also able to meet the reasonable budget requirement of staying under $55 million, with a total cost estimated at $36 million. By comparing design criteria against the groups design options, it was determined that an all steel building was the best design. This also allowed the group to achieve the “green engineering” design goal, because steel has a minimal environmental impact compared with the other alternative designs.

Additional considerations for this project that are outside the groups scope include; considering campus green space, looking into the IPFW Master Plan to determine whether the building is in conjunction with it, determining bus re-routs and parking requirements, looking into shadows that other buildings may cast on the new building, and attaching existing buildings to the new building in the future.

VII. References

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VIII. Section VIII: Appendices

VIII.1. Appendix A – Alternative 1 Hand Calculations

VIII.1.1. Reactions check

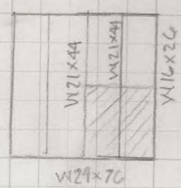
REACTIONS CHECK

LL = 20 psf
SL = 20psf
DL = 4 psf

$P_u = 1.2(D) + 1.6(L) + 0.5(S)$

$P_u = 1.2(24) + 1.6(20) = 60.8$ psf

TOP FLOOR



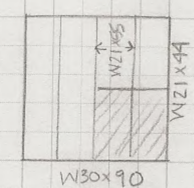
$P = 60.8(20 \times 20) = 24.3$ K

Load due to slab $= \frac{7.5}{12}(150)(20 \times 20) = 37.5$ K

Load due to beams $= 26(20) + 44(20) + 76(20) + \frac{44(20)}{2}$
$= 3.36$ K

Total $= 24.3 + 37.5 + 3.36 = 65$ K

4TH FLOOR



$P_u = 1.2(10) + 1.6(80) = 140$ psf

Load due to slab $= \frac{6.5}{12}(20 \times 20)(150) = 32.5$ K

Load due to beams $= 44(20) + 90(20) + 55(20) + 55(10)$
$= 4.3$ K

$P = 140(20 \times 20) = 56$ K

Total $= 56 + 32.5 + 4.3 \approx 95$ K

4th, 3rd, 2nd loading and slab thickness are the same

Therefore:

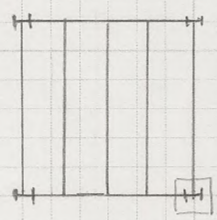
Reaction at corner column $= 95(3) + 65 +$ (column weight)

$\approx$ 380 Kip

VIII.1.2. Beam & Column Design Check

BEAM/COLUMN DESIGN CHECK

LL = 20 psf
SL = 20 psf
DL = 4 psf
Slab = 87.5 psf



$P_u = 1.2(D) + 1.6(L) + 0.5(S)$

$P_u = 1.2(91) + 1.6(20) + 0.5(20) = 151.2 \text{ psf}$

FOR ONE FLOOR BEAM

$w_u = 10(151.2) = 1.5 \text{ K/ft}$

$M_u = \frac{WL^2}{8} = \frac{1.5(40)^2}{8} = 300 \text{ Kip-ft}$

From Table 3-2 IN AISC

W21x44 ⟹ $\phi M_p = 358 \text{ Kip-ft}$ ✓

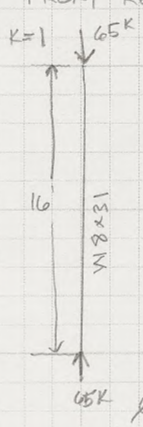
Shear

$V_u = 1.5(40) = 60 \text{ Kip}$

$\phi V_n = 217 \text{ Kip} > 60 \text{ Kip}$ ✓

Use W21x44 for floor beams

FROM Reaction check 65K is applied to corner column.



$P_n = F_{cr} A_g$

$\frac{KL}{r} = \frac{16(12)}{2.02} = 95.05 \leq 4.71\sqrt{\frac{29000}{50}} = 113.43$

$F_e = \frac{\pi^2 \cdot 29{,}000}{(95.05)^2} = 31.7$

$F_{cr} = \left[0.658^{\frac{F_y}{F_e}}\right] F_y = \left[0.658^{\frac{50}{31.7}}\right] 50 = 25.8$

$\phi P_n = F_{cr} A_g = 24(9.13)(0.9) = 197.2 \text{ Kip} > 65^K$ ✓

VIII.1.3. Wind Design

WIND DESIGN
STEEL BUILDING

$q_z = 0.00256\, K_z K_{zt} K_d V^2 I$ (lb/ft²)

K_z:

Use Exposure B ⟹ Table 6.5 from ASCE 7-98

$K_z = 0.96$

K_{zt}

Assume $K_{zt} = 1$ (for flat ground)

K_d

Assume wind acting alone ⟹ $K_d = 1$

From wind map for Indiana $V = 90$ mph

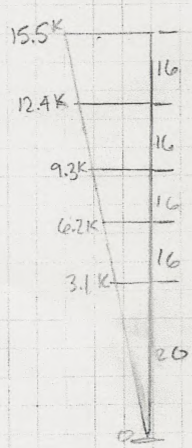
From ASCE 7-05 Table 1-1 ⟹ $I = 1.15$ (For college Facilities)

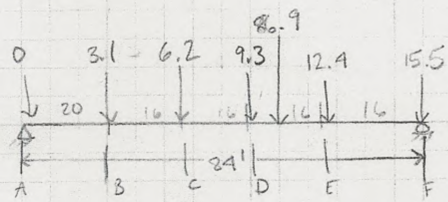
$q_z = 0.00256(0.96)(1)(1)(90^2)(1.15) = 23$ lb/ft²

Per 180 ft span $w = 23(180) = 4140$ lb/ft

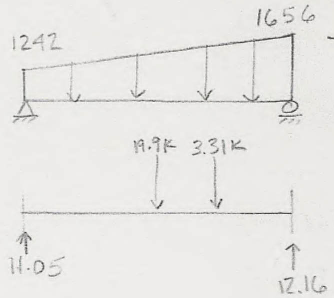
For 2 braces $w = \frac{4140}{2} = 2070$ lb/ft

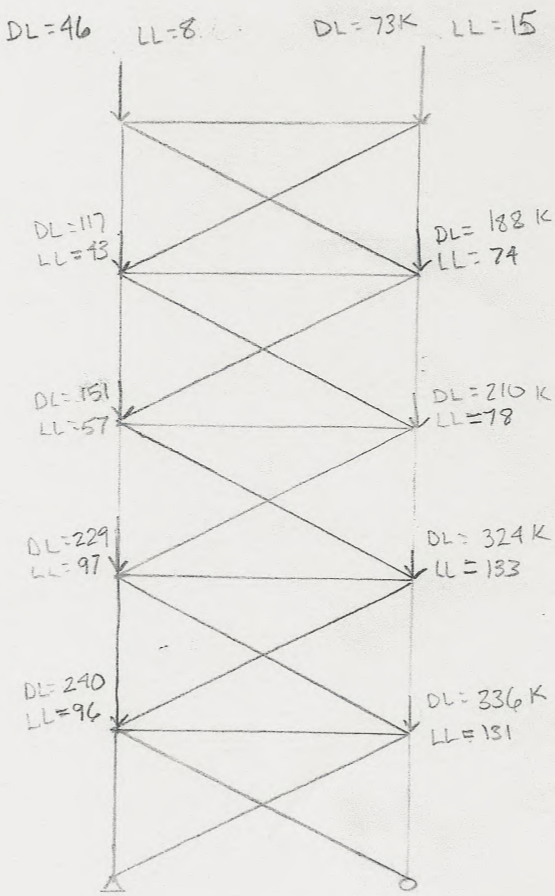
Assume walls take loads to joints ⟹ Use point loads





WIND DESIGN (CONT.)





VIII.2. Appendix B – Alternative 2 Detailed Design

VIII.2.1. ETABS results

VIII.2.2. Hand Calculations

VIII.3. Appendix C – Alternative 3 Detailed Design

VIII.3.1. ETABS results

VIII.3.2. Hand Calculations