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An EML Project on Steel Beam Design

Dr. Seyed Mohammad Seyed Ardakani P.E., Ohio Northern University

Dr. Ardakani is an Assistant Professor of Civil Engineering at Ohio Northern University. He has previously served as Project Engineer at Englekirk Structural Engineers and Lecturer at South Dakota State University. He obtained his Ph.D. in Civil Engineering from University of Nevada, Reno. His research interests include seismic performance and design of reinforced concrete structures, computational modeling of structures, and engineering education.

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Abstract
Students get to know how to apply the AISC requirements for the design of steel beams in the first steel design course. This is usually done through straight forward and predefined problems and parameters, which is not always the case in the real world. The current paper describes a two-week-long project on the addition of a balcony to the new engineering building at Ohio Northern University. The purpose of the project is to help students get more familiar with the typical loading and framing plans of steel structures, the design process, and improve their entrepreneurial mindset by applying Kern Entrepreneurial Engineering Network (KEEN) learning objectives on curiosity, making connections, and creating value via analyzing and designing multiple framing plans and selecting the superior design through NABC approach. A beam design problem was given on the final exam, which was similar to the previous year when the students were not assigned any project. The comparison of the grades showed that the project has improved the overall understanding of students on beam design. The direct assessment was conducted by rubric evaluation and an anonymous survey was used for the indirect assessment of the project. The students' feedback indicated that students enjoyed the simplicity and open-ended, yet challenging nature of the project.

Introduction
Project-based learning (PjBL) has been widely used in engineering education. Several studies have shown the effectiveness of PjBL in terms of increasing understanding, motivating students, taking ownership, and helping to bridge the gap between the classroom and workplace by preparing students with skills such as leadership, team building, critical thinking, and problem solving [1, 2]. In this methodology, an assignment with multiple tasks is normally used to drive the students learning activities to produce a final product in the form of a design, model, and device or service that can be utilized in real world. PjBL is similar to problem-based learning (PBL) in terms of involving teams of students in open-ended and challenging assignments, which resemble the real-world situations as well as identifying solutions and reevaluating their methodology. The difference between the two approaches is that the PjBL covers a broader scope and may include several problems. In addition, PjBL focuses on the final product by applying or integrating previous knowledge while the emphasis of PBL is on the acquisition of new knowledge [3]. Torres and Sriraman implemented an actual concrete construction project from a local construction company in a project management course. The students were introduced to the project by the president of the company, which gave them an opportunity to ask their questions. The photographs as well as the engineering drawings and reports of the project were shared with students. The milestone formatting of the project was implemented in the study and the students were assigned milestone deliverables and one project packet due at the end of the semester. They concluded that the students learned the essential construction management skills using the PjBL method and enjoyed the actual concrete construction project and the milestone deliverable method [4].

Currently universities are utilizing entrepreneurial-minded learning (EML) as well. Through EML students get to solve a problem in a fashion that creates value, which helps to create engineers to make an impact in the workplace [5, 6]. EML course modulus can be created by incorporating behavioral or complementary skills into student-centered pedagogy. Examples of such skills are demonstrating constant curiosity, exploring a contrarian view of accepted solutions, assessing and managing risk, evaluating economic drivers, examining societal and individual needs, understanding the motivations and perspectives of others, conveying engineering solutions in economic terms, identifying an opportunity, investigating the market, evaluating customer value and economic viability, protecting intellectual property, and validating market interest. Particularly, EML builds upon active pedagogies such as PBL by integrating curiosity, identifying opportunity, and creating value [7]. It is important to understand that entrepreneurship, in this context, is not necessarily about teaching students how to start a new business, but rather to develop the mindset of innovation necessary to recognize opportunities and make the most of them. Gerhart and Melton applied EML within the context of PBL and presented a framework to demonstrate how to incorporate stakeholders, opportunity identification, and value creation in a fluid mechanics course [7]. EML is being promoted by Kern Entrepreneurship Education Network (KEEN) and implemented at many institutions. 3Cs of the entrepreneurial framework are defined as:

1. Curiosity. Students are encouraged to demonstrate constant curiosity about our world, and explore different solutions, which empowers them to investigate the rapidly changing world and motivates them to become life-long learners.
2. Make connections. Students integrate information from many sources to gain insight, assess, and reveal innovative solutions.
3. Creating value. Students get to create value by identifying unexpected opportunities and learning from failure to meet the needs of a changing world [7, 8, 9].

The main objective of the current paper was to introduce a simple EML project on beam design to a steel design course and investigate whether this could improve the performance of students and their understanding of beam design or not. Such implementation of the EML project including the project description, assessment criteria, observations of the instructor, and examples of student work are presented in the paper.

Project Description

The steel design course is offered for senior civil engineering students at Ohio Northern University. The students in the course had the opportunity to visit the new engineering steel building, which was under construction at the time, to get more familiar with the common elements of a steel building. Based on the author experience, beam design is one of the most challenging topics of the course for students to grasp. Therefore, it was felt that assigning a real world project on the new engineering building would be beneficial. The project was implemented during the fall semester of 2018. The learning objectives of the project were as follows:

- Apply the AISC Steel Construction Manual specifications on shear, bending moment, and deflection to design steel beams.
- Develop a propensity to ask more questions, which is attributed to curiosity.

- Connect content from previous courses such as structural analysis to determine the loading, which is related to connections.
- Create solutions through investigating different framing plans that meet stakeholders needs and craft a compelling value proposition tailored to specific stakeholders, which is attributed to curiosity as well as creating value.
- Meet commitments to the rules developed by the team and work with individuals with complementary skillsets, expertise, etc. to produce effective written reports and verbal presentations.

Project Overview

The class consisted of 22 students. Students were asked to organize into groups of two to three to design a balcony that is applied to the underlying design problem described below.
Each group represents a fictitious startup company in order to bring their consulting service to the market. Each company must pitch a proposal in an effort to convince the client that the design is a suitable and cost-effective solution to the problem that is in some way unique and more advantageous than other companies.

Problem Description

To increase the motivation of students, the project was defined as a task from the dean of the college of engineering: Prof. Yoder, the dean of college of engineering at Ohio Northern University, has asked the architect to add a balcony to the second floor of the new engineering building. Due to the time and financial constraints, the dean and architect have decided to hire a group of internal experts on steel design to evaluate and identify the most cost-effective and constructible framing plan with the following requirements:

- The balcony to be designed on the west side of the second floor between Gridlines A and K. Figure 1 shows the partial plan of the second floor. It should be noted that the structural drawings of the building were shared with students.
- The width of the balcony must not exceed 6 ft.
- The W- shapes must be used for beams.
- The yield strength of steel must be 50 ksi.
- Commercial software such as SAP2000 and Tedds may be utilized for analysis and design.

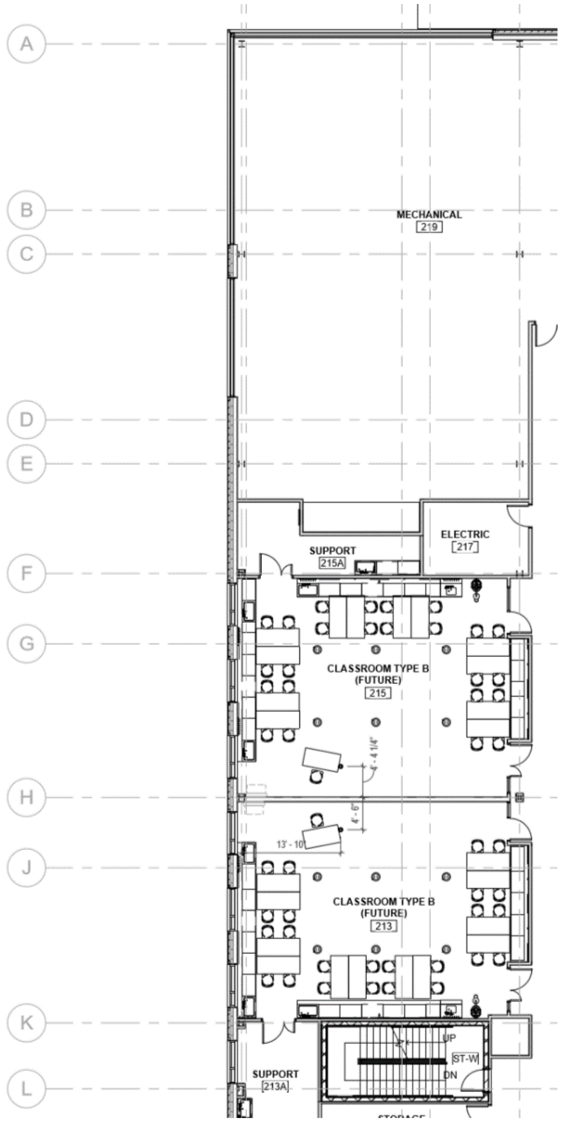

Figure 1. Partial Plan of the Second Floor of the New Engineering Building

Project Deliverables, Grading, and Due Dates:

1.) Team Charter (5%)

- Finalize your team members and select a name for your team/company. List the set of rules and expectations for your team. Some examples of rules may be proper preparation and attendance at group meetings, honest communication when conflicts arise, etc. Each team member must sign the sheet thereby indicating acceptance to comply with the rules and expectations. In addition, submit a list of questions related to this project that demonstrates your curiosity while express your interest in the project.

- Note: This set of rules and expectations is for your use and benefit. The instructor will make a copy and return it to you.
- **Due:** Wednesday, November 28, 2018

An example of the team charter is presented below.

Internal Experts
Est. 2018

Memorandum

To: Seyed Ardakani, PhD, PE
From: [redacted]
Date: 11/27/18
Re: Team Charter

We are the Internal Experts and we have internal expertise on structural applications and designs. Thank you for considering us as your design solution consultant for the balcony system for the Ohio Northern University (ONU) College of Engineering. As a structural firm, we take great pride in developing safe, functional, and economic solutions for a wide range of projects. As for the new ONU Engineering Building, we are determined to develop a balcony that will meet your needs and will be a great addition to your future building. Below are the Internal Experts core values and business practices as well as RFI's for the project. Thank you again for considering Internal Experts as the firm to design your project.

Rules and Expectations:

- Attend at all meetings
- Respect each other's ideas
- Voice honest concerns
- Constructive communication when conflicts arise
- Manage time effectively
- Equal work amongst group members
- Participate in all discussions
- Act in a professional manner
- Prepare professional documents
- Address co-workers in respectful way
- Work as a team rather than individuals
- Produce high quality proposals
- Present information confidently and clearly
- Submit proposals on time

RFI's:

- Does the balcony have any aesthetic requirements to match the building?
- Will the architect provide the design and we provide the structural elements?
- How many alternatives designs do you require we produce?
- Is there a snow drift loading that we will need to account for?
- What is the budget for the balcony?
- Is aesthetic more important than cost?
- Will there be load information given such as wind, snow, seismic, etc.?
- Are welds or bolts the desired connection method?
- Is a full construction bid desired or just material for the addition?
- What protective coating will be used to protect the steel?
- What is the maximum live load expected?
- What will be the dead load of the furniture on the deck?
- How many entrances will lead out to the balcony?
- What is the height requirement of the balcony from the floor?
- Is there a desire for emergency escape routes from the balcony?
- What is the purpose of the balcony? Leisure? Work space? Etc.?
- Will there be a possibility for expansion to the balcony in the future?

Internal Experts Design Team

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Other examples of such rules set by students were:

- Attendance of 95% or higher at meetings
- Positive attitudes
- Provide feedback to other group members on their work
- Manage time effectively

- Work as a team rather than individuals
- Present information confidently and clearly
- Act in a professional manner
- Each member must contribute and provide input for each step of the project
- When conflicts arise in the group, a decision is made by 2/3 vote
- Any individual work must be doubled check by a fellow group member
- Open communication between partners
- No one will be on their phone during the meetings
- Only one team member will speak at a time.
- All team members will divide work evenly and produce their best work on their assigned parts
- Give honest effort in proceeding with the project

The purpose of the rules was effective team work and communication among group members as well as a reminder of how to avoid the common pitfalls. The students were not evaluated on adherence to their own rules.

Stimulating the curiosity of students is one of the most important goals of any educator. If successful, the student will be motivated to continue to learn and explore the course material outside of the classroom and find connections with other information or applications. To stimulate the curiosity of students, Question Formulation Technique (QFT) was utilized. The QFT enables students to generate technical questions, which makes the process of problem solving easier and helps them to take ownership of materials and become self-directed learners. It is important for a student to be aware of what they do not know and be able to articulate it in the form of a question [10]. Thus, each company was asked to submit a list of questions.

Samples of such questions were:

- What loads are expected to be on this balcony?
- Does the balcony have any aesthetic requirements to match the building?
- Will the floor be concrete, tiles, or what type of material?
- Should we design deflection for live load only or dead and live?
- Should the balcony be cantilever or can we support it using columns?
- What are some potential cost estimation sources?
- What is the minimum width of the balcony?
- Is there a budget for design?
- Should LRFD or ASD be applied to the design?

The questions were graded, answered, and returned to each group. In addition, common questions were discussed and elaborated in the class to avoid any confusion because the stakeholder or client feedback is essential to understand what is deemed as valuable. All groups scored at least 90% on their questions. This was intended as a tool to encourage students to ask further questions, which was successfully achieved.

Each company must pitch a written proposal to convince the client that the design is a suitable and cost-effective solution to the problem that is in some way unique and more advantageous than other companies:

2.) Written Proposal (70%)

- Producing alternative design solutions is a beneficial step in the engineering design process. For this project, your alternative designs will be considered competing solutions to the problem. Each solution must be viable (i.e., meet the constraints set forth in the problem statement) and unique. Each member of the team is required to investigate and design a different framing plan as a solution. In addition, it is required to submit loadings and hand calculations or SAP2000 results for each alternative design.
- The alternative design solutions must be compared through an evaluation metrics. The selection of the final design should be based on NABC approach and at least the following criteria: Cost and Ease of Construction.
- For the selected design, create a full-scale drawing in AutoCAD. The drawing should include at least a plan view and the size of the members, similar to the current drawings.

The written product proposal should include the following:

  - **<u>Introduction section</u>** that motivates the underlying problem, briefly describes the approach to the solution.
  - **<u>Problem Description section</u>** that describes the problem and identifies the design constraints and evaluation metrics.
  - **<u>Alternative Solutions and Analysis section</u>** that should describe each design alternative, hand calculations or SAP2000 results, the approach to advocate for the superior design alternative, the selected design, and AutoCAD drawings. Be sure that all plots and figures are embedded within the proposal (not as attachments). Use NABC approach to advocate for the selected design. The approach should be emphasized, as well as the benefits per cost compared to the superior design alternatives. It is also necessary to clearly restate the underlying need and identify based on the evaluation metrics why the preferred design is selected.
  - **<u>Conclusion section</u>** that briefly summarizes the problem and the selected design. Summarize the critical aspects of the approach and benefits that make it (the superior solution) better than the alternative. Describe the lessons learned from the project.

- **<u>Due</u>:** Friday, December 7, 2018 by 5 p.m.

Exploring multiple solutions further stimulates the curiosity of the students. The alternative designs were to be considered competing solutions to the problem. The selection of the final design should be based on <u>N</u>eed-<u>A</u>pproach-<u>B</u>enefits-<u>C</u>ompetition (NABC) approach. NABC framework developed by Stanford Research International to teach engineering students how to articulate value propositions. The framework highlights the market needs, solution approach, solution benefits, and competition dimensions of any created solution. The objective is to create a solution that delivers customer's value and need and is clearly greater than the competition's. The NABC framework starts with a clear articulation of underlying Need the idea addresses. What are the important customer and stakeholder needs? A need should relate to an important and specific user-client segment with the end customers clearly stated [11, 12]. Then, the Approach to meet the need is described. What is the unique approach and compelling solution for addressing the specific client need? This should be drawn or simulated to help convey the vision required. As the approach develops through iterations, it becomes a full proposal or business plan, which can include cost, staffing, deliverables, a timetable, etc. [11, 12]. The Benefits of the approach to the specific stakeholders must be highlighted and should demonstrate a favorable benefit to cost ratio. What are the client benefits of our approach? Each approach to a client's need results in unique client benefits, such as low cost, high performance, or quick response. Success requires that the benefits be quantitative and substantially better - not just different [11, 12]. Finally, the Competition should be analyzed to show how the idea improves upon the competing solutions [11, 12]. Why are our benefits significantly better than the competition? Everyone has alternatives. We must be able to tell our client why our solution represents the best value. To do this, we must clearly understand our competition and their value proposition and our client's alternatives [11]. Since students may not be familiar with the method, it is beneficial to show a video introducing the framework [13] and share an example of applying the method. A good example might be video on-demand, which was pitched to a cable broadcast company, circa 2006. Need was a $5 billion business opportunity for movie rentals, which the company did not have any market share at the time. Furthermore, customers do not like picking up and returning rentals as well as late fees. Approach was developing a system for the company to provide the customers with videos on demand using cable. This enables people to have access to all movies by using one of unused channels with the same price as video store rental, which means there will be no change to the system and no capital needed to be invested by the company. Benefits were market share of 20% and receiving $5 revenue per rental. In addition, the customers were not worried about late fees and could have the same experience as VCR/DVD without the need to return. The competition was online rentals, but they do not provide the customers with spontaneous rentals and sending videos back is not convenient [11]. In the current study, Need was given with a well-defined problem. The problem was to add a balcony to the second floor of the new engineering building. The Approach was limited through project requirements such as shape, yield strength, location, and the width of the balcony. The Competition was limited by requiring students to design alternative viable solutions and using the alternative solutions as the Competition. Each member of the group had to investigate and design a unique framing plan. Finally, the Benefits were to be articulated through evaluation metrics considered in the design such as cost and constructability. An example of the written proposal is shown in Appendix 1.

3.) Peer Evaluation (10%)

Two rubric evaluations are conducted. Failure to complete the peer reviews by the deadline will result in zero score for the peer evaluation portion of the project.

- **Due:** Wednesday, November 28, 2018 & Friday, December 7, 2018

4.) Presentation (15%)

- Each team is to give a 5- minute presentation on the constraints of the design, a concise review of alternative solutions, the superior design, and evaluation metrics used. Describe your NABC value proposition for your superior design. The group must briefly describe the underlying problem (i.e., the need), describe the functionality of the alternative solution (approach), and finally indicate which evaluation metrics led to the choice of your superior design and why those metrics are reasonable (benefits per costs).
- **Due:** Friday, December 7, 2018. Submit your presentation by 12 p.m.

Direct Assessment

The following grading was used for the project:

1- Team charter- 5%: selection of a name for the company, listing the set of rules and expectations for the team, and submitting questions. All students scored at least 90% on their questions.

2- Written proposal- 70%: problem description, constraints, alternative solutions, analysis and design of each solution including hand calculations or software results, selection of superior design through NABC approach, AutoCAD drawings for the selected design, and conclusions. The students were given three weeks to finish this task. The proposal was assessed through evaluation rubrics. Table 1 illustrates the rubric. All students scored at least 90% on Introduction & Problem Description. 86% scored at least 90% and 14% scored 75% to 90% on Constraints & Criteria sections. For the Analysis and Design section, 36% scored at least 90% and 50% between 75% and 90% while 14% scored 60% to 75% indicating the first objective on apply AISC specifications to design steel beams and the third objective on connect content from previous courses were met. 64% scored at least 90%, 14% scored 75% to 90%, and 22% scored between 60% and 75% on Alternative Solution. On the Superior Design Selection based on NABC approach, 50% scored at least 90%, 36% scored 75% to 90%, and 14% scored 60% to 75%. This indicates that the objective on create solutions and craft a compelling value proposition was met. 86% scored at least 90% and 14% between 75% and 90% on AutoCAD Drawings. For the Conclusions section, 64% scored at least 90% and 36%

between 75% and 90%. Overall, 45% of students scored at least 90% and 55% scored 75% to 90% on the written proposal. This indicates that the last objective was met.

3- Peer evaluation- 10%: team members were asked to evaluate their peers through rubrics on different skills such as working with others, attitude, time management, quality of work, contributions, and problem solving. The students were asked to submit their peer evaluation twice, one in the middle and the other at the end of the project. The rubric is presented in Table 2. 90% of students scored at least 90%, 5% between 75% and 90%, and 5% below 60% on this evaluation indicating the last objective was met.

4- Presentation- 15%: each company was asked to prepare a 5-minute presentation on the constraints of the project, a review of alternative solutions, the superior design, and description of NABC approach for the superior design. All students scored at least 90% on this evaluation. This shows that the last objective was met.

Table 1. Written Proposal Evaluation Rubric

Content						
	Excellent	**Above Avg.**	**Average**	**Marginal**	**Unsatisfactory**	**Pts**
Introduction & Problem Description	**5 pts** Provides excellent high-level description of problem: project importance and client need well-defined; outlines report	**4 pts** Provides good high-level description of problem: project importance and client need defined	**3 pts** Provides decent description of problem: some importance of the project and some aspects of the need established	**2 pts** Missing high-level description of problem: project importance and client need minimally or poorly addressed	**1-0 pts** Missing high-level description of the problem: project importance and client need not addressed	
Constraints & Criteria	**10 pts** Clearly & concisely identifies important constraints and criteria	**9-8 pts** Clearly identifies some important constraints and criteria	**7-6 pts** Identifies some constraints and criteria	**5-4 pts** Lacks in constraints and criteria	**3-0 pts** Severely lacks in constraints and criteria	
Alternative Solution	**10 pts** 2/3 alternatives presented and thoroughly considered.	**9-8 pts** 2/3 alternatives presented and sufficiently considered.	**7-6 pts** 2/3 alternatives considered and reasonably presented.	**5-4 pts** < 2/3 alternatives considered and/or 2/3 alternatives minimally/poorly presented.	**0 pts** No alternatives considered.	
Analysis and Design	**15 pts** All alternatives expertly analyzed and designed by hand calculations or commercial software; excellent presentation of results	**14-13 pts** All alternatives sufficiently analyzed and designed by hand calculations or commercial software; good presentation of results	**12-10 pts** All alternatives fairly analyzed and designed by hand calculations or commercial software; reasonable presentation of results	**9-6 pts** Not all alternatives analyzed and designed; poor presentation of results	**5-0 pts** Analysis and design of alternatives are missing, are completely erroneous, or are incomprehensible.	
Superior Design Selection	**10 pts** Expertly describes the need; expertly describes the design approach; expertly articulates the benefits per cost; thoroughly justifies superior design over design alternatives	**9-8 pts** Describes correctly the need; describes correctly the design approach; articulates the benefits of the solution based on criteria; sufficiently justifies superior design over design alternatives	**7-6 pts** Describes mostly the need; describes the design approach; articulates some benefits of the solution; somewhat justifies the superior design over alternatives	**5-4 pts** Misses the main ideas of the need; describes aspects of the design approach; missing some benefits of the solution; marginal justification of superior design over alternatives	**3-0 pts** Poor discussion of need, approach, benefits, no selection of superior design	
AutoCAD Drawings	**10 pts** Thoroughly creates AutoCAD drawings of the plan view with the size of members for the superior design.	**9-8 pts** Sufficiently creates AutoCAD drawings of the plan view with the size of members for the superior design.	**7-6 pts** Reasonably creates AutoCAD drawings of the plan view with the size of members for the superior design.	**5-4 pts** Poorly creates AutoCAD drawings of the plan view with the size of members for the superior design.	**3-0 pts** AutoCAD drawings miss details; no AutoCAD drawings	
Conclusions	**5 pts** Concise summary of problem & solution; insightful discussion of redesign/lessons	**4 pts** Good summary; good discussion of redesign/lessons	**3 pts** Decent summary; some mention of lessons and redesign ideas	**2 pts** Poor summary; little mention of lessons or redesign ideas	**1-0 pts** Poor or no summary; no mention of lessons or redesign	

Table 2. Peer Evaluation Rubric

CATEGORY	**4**	**3**	**2**	**1**
Working with Others	Almost always listens to, shares with, and supports the efforts of others. Tries to keep people working well together.	Usually listens to, shares, with, and supports the efforts of others. Does not cause "waves" in the group.	Often listens to, shares with, and supports the efforts of others, but sometimes is not a good team member.	Rarely listens to, shares with, and supports the efforts of others. Often is not a good team player.
Focus on the task	Consistently stays focused on the task and what needs to be done. Very self-directed.	Focuses on the task and what needs to be done most of the time. Other group members can count on this person.	Focuses on the task and what needs to be done some of the time. Other group members must sometimes nag, prod, and remind to keep this person on-task.	Rarely focuses on the task and what needs to be done. Let others do the work.
Attitude	Never is publicly critical of the project or the work of others. Always has a positive attitude about the task(s).	Rarely is publicly critical of the project or the work of others. Often has a positive attitude about the task(s).	Occasionally is publicly critical of the project or the work of other members of the group. Usually has a positive attitude about the task(s).	Often is publicly critical of the project or the work of other members of the group. Often has a negative attitude about the task(s).
Time-management	Routinely uses time well throughout the project to ensure things get done on time. Group does not have to adjust deadlines or work responsibilities because of this person's procrastination.	Usually uses time well throughout the project, but may have procrastinated on one thing. Group does not have to adjust deadlines or work responsibilities because of this person's procrastination.	Tends to procrastinate, but always gets things done by the deadlines. Group does not have to adjust deadlines or work responsibilities because of this person's procrastination.	Rarely gets things done by the deadlines AND group has to adjust deadlines or work responsibilities because of this person's inadequate time management.
Quality of Work	Provides work of the highest quality.	Provides high quality work.	Provides work that occasionally needs to be checked/redone by other group members to ensure quality.	Provides work that usually needs to be checked/redone by others to ensure quality.
Contributions	Routinely provides useful ideas when participating in the group and in classroom discussion. A definite leader who contributes a lot of effort.	Usually provides useful ideas when participating in the group and in classroom discussion. A strong group member who tries hard!	Sometimes provides useful ideas when participating in the group and in classroom discussion. A satisfactory group member who does what is required.	Rarely provides useful ideas when participating in the group and in classroom discussion. May refuse to participate.
Problem-solving	Actively looks for and suggests solutions to problems.	Refines solutions suggested by others.	Does not suggest or refine solutions, but is willing to try out solutions suggested by others.	Does not try to solve problems or help others solve problems. Let others do the work.

Discussion

An indirect assessment through an anonymous survey of the project was conducted by the instructor. 20 out of 22 students enrolled in the course submitted their responses. The survey asked students to rate each question on a scale of 1 (strongly disagree/none at all) to 5 (strongly agree/throughout most of the project). Table 3 shows the average of the results from the survey. For the entrepreneurial dimension, questions two, five, and six target creating value. Question 4 is related to curiosity and questions 1 and 3 target making connections. Questions 11 and 12 target the communications skills on the technical aspect of the project. Students overwhelmingly agreed that the project motivated them and gave them a better understanding of addressing customer's needs and using critical thinking skills to find solutions. Students found that they improved a myriad of skills including creating framing plans, load calculation, beam design, report writing, and overall communication, not only with each other, but with their client.

Table 3. Survey Results

Dimension	No	Survey Question	Average Rating
Entrepreneurial	1	The real-world application motivated me to do my best work	4.6
	2	Create value for a customer or stakeholder	3.8
	3	Integrate information from many sources to gain insight	3.7
	4	Apply critical thinking to ambiguous problems	4.0
	5	Examine a customer's needs	4.4
	6	Convey engineering solutions in economic terms	4.3
Technical	7	Identify the components of a typical balcony	4.7
	8	Determine loadings	4.5
	9	Determine the beam sizes for various framing plans	4.7
	10	Choose an actual framing plan that meets the design requirements	4.6
	11	Report the solution to a customer	4.3
	12	Work with your team	4.6

Figure 2 displays the relative frequency for each survey question. For question 1, 70% of students strongly agree and 25% agree that the real world application of the project motivated them while 5% were neutral. The project goal on creating value for a customer was successful as over half of students (55%) agreed, 40% were neutral, and only 5% disagreed. 40% of students strongly agreed and 15% agreed that they could integrate information from multiple sources to gain insight. 25% were neutral. 15% disagreed and 5% strongly disagreed. Survey question 4 asked whether students applied critical thinking throughout the project. As shown in Figure 2, 30% strongly agreed, 45% agreed, 15% were neutral, and 10% disagreed. Students overwhelmingly (90%) reported integrating information from many sources while 5% were neutral and only 5% disagreed. According to the results for survey question 6, over 80% of students agreed that they were able to convey engineering solutions in economic terms throughout the project. One-fifth were neutral. Students strongly (65% strongly agreed and 35% agreed) agreed that they improved their skills on identifying the components of a typical balcony (question 7) as well as determining the beam sizes for various framing plans (question 9). The project successfully improved students' skills on determining loads (question 8) as 50% strongly agreed and 50% agreed. Based on the results for survey question 10, 65% strongly agreed and 30% agreed that the project improved their skills on choosing an actual framing plan that meets the design requirements. 5% were neutral and none disagreed.

Questions 11 and 12 evaluated the communications skills. Over 90% agreed that the project successfully enhanced their skills on writing effective reports and reporting the solution to the customer while 10% were neutral and none disagreed. Similarly, 85% (75% strongly and 10% agreed) agreed that the project helped them to improve their skill on working with their peers. 15% were neutral and none disagreed.

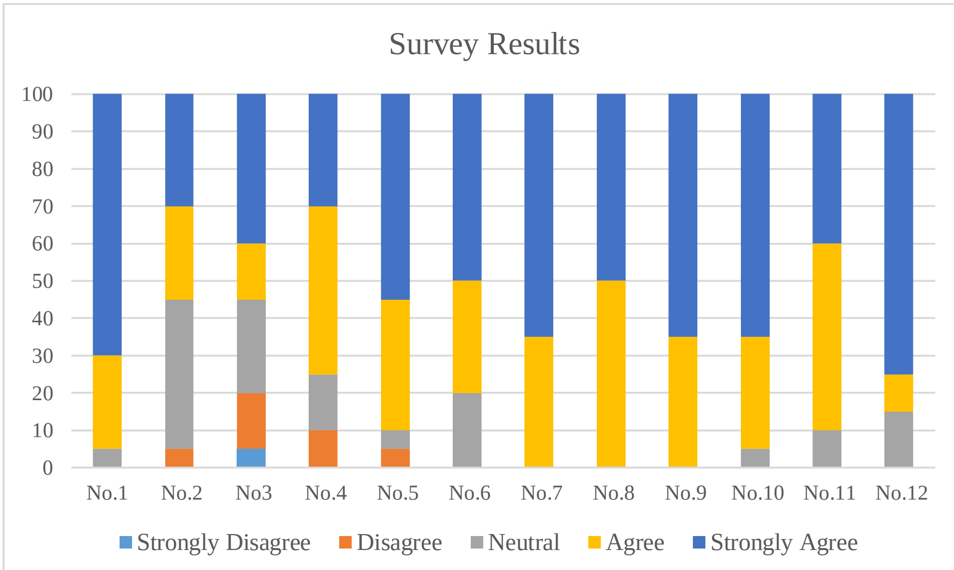

Figure 2. Relative Frequency for Each Survey Question

As seen in Table 3 and Figure 2, the project was successful in targeting both technical and entrepreneurial skills of students and was well received by them. This is in accordance with the direct assessment of students work as 45% of students scored at least 90% and 55% scored 70% to 90% on the written proposal.

Based on the results of the open-ended feedback portion of the survey, students enjoyed the real world aspect of the project and liked using the actual drawings of the building. Furthermore, they liked the open-ended and simple, yet challenging nature of the project. The fact that students had to look back at old materials from other courses and apply them to new learned materials was also appreciated by them. On the other hand, students asked for more time on the project and believed two weeks was not enough. The author recommends to assign the project early since students are normally overwhelmed with other projects and exams at the end of the semester. It is also recommended to break the deliverables down further into several milestones with specific deadlines.

In order to assess whether assigning such project would improve the performance of students on beam design, the scores of this group of students who were assigned the project were compared to students from previous year who were not exposed to any project. The comparison was done through giving a similar beam design problem on the final exam. The problem is presented in Appendix 2. Each group consisted of 22 students. Figure 3 displays the comparison of the two groups. Blue is corresponding to scoring of 90% or better, orange 75% to 90%, grey 60% to 75%, and yellow below 60% of the total points. 32% of the group with the project scored 90% or more while 27% of the other group scored the same. For the group with the project, 50% of the students scored 75% to 90%. The percentage for other group was 45%. As seen, a lower number of students with the project scored 75% or less. 23% of the students with no project scored 60% to 75% while 13% of the other group scored within the same range. This indicates that the project was mostly beneficial to the students scoring between 60% and 75%. It seems that the students were able to take ownership of the project and learn from their peers, which is consistent with the results of the anonymous survey. 5% of the students of each group scored below 60%. In addition, the average score on this problem and overall for the group with the project was 3% and 10% higher, respectively while both groups had similar average scores on midterm exams.

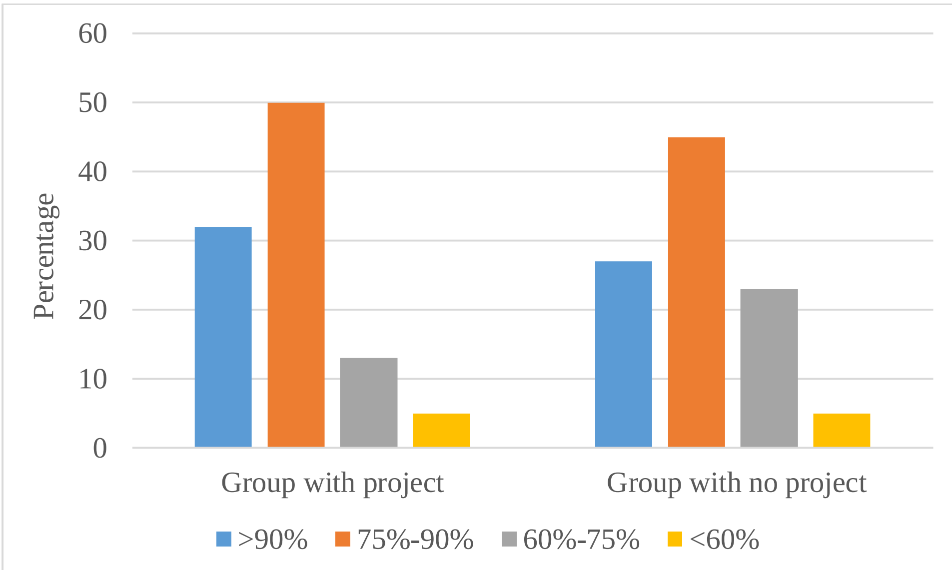

Figure 3. Comparison of Two Groups of Students

Summary and Conclusions

The paper describes an implementation of EML in a steel design course. The students were asked to design a balcony as an addition to the second floor of the new engineering building. Based on students' feedback and observation of the instructor, the implementing project using the framework discussed herein can expose students to EML effectively and improve their performance. It should be noted that such EMLs could also be successfully used for other design courses.

Acknowledgements

The author acknowledges the financial support of 2018-19 KEEN Pedagogy Mini-Grant at Ohio Northern University. The input from Dr. Heath LeBlanc and the support of Thomas Zechman, Assistant Dean of College of Engineering in coordinating the site visit and providing the students with structural plans of James Lehr Kennedy Engineering Building are greatly appreciated.

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Appendix 1

An example of the written proposal:

Balcony Design Project

[redacted]

[redacted]

Steel Design Project

12/7/2018

Beam and Sons

Introduction

The Dean of the College of Engineering at Ohio Northern University asked architects to design a balcony that will be built onto the second floor of the new engineering building. Due to time and finances, Dean Yoder decided to internally hire a group of steel design experts, Beam and Sons, to come up with the most cost-effective and constructible framing plan. Beam and Sons came up with two possible designs and then chose the final design using the NABC process and evaluation metrics.

This project is important as it adds a new, modern aesthetic look that compliments Ohio Northern University's (ONU) new engineering building. Although it may be considered a small project, it makes ONU more competitive to other schools and gives the school a better look. Pressumptionally, the client, Dean Yoder, saw this opportunity and thought it would be a great project for some recent Civil Engineering graduates to take on, with the mindset of benefiting the university, engineering college, and ONU civil engineering graduates as they get more experience.

The general approach to the solution of this problem is to come up with a design where there are cantilever beams aligning with the columns on the existing engineering plans and then support beams in between to ensure the load will be held. Once a design layout is decided upon, Beam & Sons needed to see if it would be able to withstand the required loads such as live, snow, and dead loads. The snow loads were found in the original plans and was utilized for the balcony addition as well whereas the live loads were found in ASCE 7-10, which included the loading of furniture. The dead loads had to be calculated based on the balcony area including concrete slab thickness, the composite metal deck, the weight of the railing, and the self weight of beam. The initial dead load can be calculated with everything previously mentioned except the self weight of the beam. This is because the self weight can not be incorporated into the selection until after all the previous loads are checked for adequacy. After those loads are checked the self weight can be considered into the required moment and rechecked for adequacy.

Once the various loads mentioned above were found, they went through further calculations that included tributary width to make sure they were all in lb/ft. After everything had the same unit, the loads were put into five different LRFD loading combinations to calculate the greatest possible loading the frame may be put under and of which the balcony beams would be designed from. After the greatest load combination is calculated the required moment, inertia, shear, and deflection will then be determined. Depending on the design chosen, there will be different equations, selected from the Steel Construction Manual by AISC to calculate each of the four requirements just mentioned.

The lightest beam will chosen initially at first based on the required moment and then checked for adequacy for required inertia, shear, and deflection. Different beams will continuously be checked until the lightest shape that is adequate in all four requirements is selected. Once the various beams for each design are chosen, the designs will then undergo the an evaluation process. The first thing checked will be a cost analysis to see how much the steel will cost for each design. The number of beams and beam weight on each design also influences the decision process because if a design has less beams than another, it is more desirable as it is easier to construct which reduces cost. Once all information is gathered, each design will be evaluated in a decision matrix which will be used for assistance for selecting the final design.

The two designs selected involves cantilever beams and simply supported beams. The first design is five cantilever beams that hold that are strategically built so that the ends and the middle beam sit on the column of the existing building. This design also involves four simply supported beams on the edge which will help with loading support and gives a structure for railing to latch onto. The second design has three cantilever beams, each placed on an existing column as well and also has two simply supported beams in between the three cantilever ones. This design has two longer simply supported beams which will help with loads and giving a structure for railing. These designs can be seen in Appendix A. Refer by page number

Problem Description

Dean Yoder has decided to put a balcony on the second floor of the new engineering building so he asked the architect to implement it into the design. Due to management constraints such as time and finances, the Dean decided to keep the project internal and has asked Beam and Sons to design the balcony. Initially he wanted it between grid lines A and K on the current engineering plans, however, after the Dean thought about it, he decided the balcony should span between grid lines F and K on the plans, connecting the two classrooms through the addition. The balcony must be between three and six feet long and must use a "W" shaped beam where Fy= 50 ksi.

With the constraints stated above, the company decided to make two different possible alternative solutions using the LRFD standards to fulfill the request of Dr. Yoder. When look at the engineering plans, grid lines F through K connect two classrooms which is approximately 63 feet long and the engineering firm decided to let the balcony expand 5 feet out. Along with the design of the balcony, railing needs to be designed as well which impacts cost.

To determine what design should be chosen for the balcony, a decision matrix was made to assist in the best design. Some factors included in this matrix are: cost, total frame weight, and ease of construction/ safety factor. The total frame weight takes into account how heavy the beams are which impacts cost. The ease of construction/safety factor considers how many total members there are in a frame and the weight of each individual beam because if there are more beams to construct, the cost of labor increases along with the fact that the heavier a beam is the more dangerous it could be to construct.

Alternative Solutions and Analysis

For all designs given there are a few variables held constant and the calculation process mentioned in the "Introduction" section above that is the same for all beams. Both drawings had the balcony spanning the entire distance between grid lines "F" and "K" on the engineering plans, which totals 63 feet in length. The balcony protrudes out five feet on the second floor and this is because it is an adequate amount of space, similar to 6 feet, but can save some on costs. This creates a total perimeter of 73 feet since the balcony comes out five feet each side. After taking the longest span in the design divided by the beam length, it was found that all beam designs were a one way system. There were two constants that were apart of the frame/floor which includes concrete that was 5.5 inches thick and was of normal weight (which has a loading of 150 pcf) and that there was a two inch thick composite metal deck (2.6 psf) of which the concrete sits on. The railing system is the same for each design which was calculated to be 3.74lbs/ft so the weight is held constant for the dead load calculations. The snow load was found on the current engineering drawings given and was given to by 22 psf. The maximum live load was found to be 60 psf in ASCE 7-10, which includes the live load of furniture. The equation for deflection allowed is the same for all beam calculation which is L/240, where L is the beam length in inches, because the design is a balcony which has both dead and live loads. The modulus of elasticity was 29,000 ksi for each beam as well as each beam having an Fy= 50 ksi. After a beam is selected, that beam's self weight is implemented back into the dead load and then the required moment is rechecked to ensure it is still adequate. All beam calculations were done to LRFD standards as required in the constraints. There are three cantilever beams in each design, two at the very ends and one in the middle so that each cantilever beam is designed on a column to help with torsional buckling.

Design 1:

The first design that was constructed includes five, five foot long cantilever beams, evenly spaced out at 15.8 feet long with a 15.8 foot simply supported beam on it's outer edges. A complete drawing of the design can be seen in Appendix A. In order to get the complete composition, three different beam designs had to be calculated in order to fit the layout chosen. The first beam designed was the three interior cantilever beams, the second beam designed was the two outside cantilever beams, and the last beam designed was the four simply supported beam going in between each cantilever beam. See Figure 1 below for the basic design idea presented.

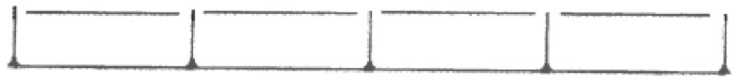

Figure 1: Fundamental Concept of First Design

To give more of an elaboration on the design process for the first design, the tributary widths for the three middle cantilever beams was found to be 15.8 feet which was then used to find the required loading combinations which calculated out to be 3.046 k/ft. Once this required loading was found, the required moment was found using Table 3-23, Case 19 in the Steel Construction Manual which resulted in 38.1 kip- foot. The allowed deflection was found to be 0.25 inches which was then used to find the required inertia after rearranging the max deflection equation from Case 19 mentioned. The loading used in this equation was the dead load and live load added together then divided by 12 to get the loading in inches which resulted in the required inertia to be 38.69 in^4.

Based on the required moment calculated and using Table 3-2 in the manual, the first beam selected was W10X12 which is the lightest and had a design moment of 46.0 k' which was greater than the required moment found which means it is adequate. The design interia for this beam was found to be 53.8 in^4 (found in Table 3-3) which is larger than the required interia found which is adequate as well. The beam self-weight is then taken into consideration in the dead load and the new required moment is 38.3 k' which is still adequate. The required shear is then found using Case 19 and was found to be 15.3 kips (including the self weight of the beam) which is less than the design shear that equals 56.3 kips (found in Table 3-2). The max deflection is then checked to ensure it doesn't exceed 0.25 inches. The deflection was found to be .18 inches which is less than 0.25 inches which means the entire beam design is adequate so the lightest beam design used is W10x12. For complete calculations please look at the "Inside Cantilevers" calculation in Design 1 under Appendix C.

The second beam design was the two end cantilevers on the balcony. The only difference between these two beams and the three interior beams is that the tributary width of the outside beams is half of that of the interior beams, which was 7.9 feet. Since this tributary width is different, the loading calculations change and after computing,, the required loading is 1.53 k/ft. Similarly to the three cantilever beams, Case 19 in Table 3-23 was used to get the required moment, shear, and deflection equations. The required calculated out to be 19.13 k', the allowed deflection was 0.25 (including the dead and live loads), and the required interia was 19.40 in^4. Using the found required moment, W8x10 was selected to be the lightest beam to potentially be used.

The design moment for this beam was found to be 32.9 k' and the maximum interia was 30.8 in^4 where both of these are greater than the required moment and inertia, respectively, which makes the beam adequate up to that point. After taking the self weight of the beam into consideration the new required moment was 19.3 k' which is still less than the maximum moment. The required shear was calculated to be 7.68 kips which is less than the design shear, 40.2 kips, and the deflection (including the self weight into the dead load) was determined to be 0.16 inches which is less than the maximum deflection, 0.25 inches. The beam was found to be adequate in all aspects, therefore W8X10 was the selected beam for the two outside cantilevers. For complete calculations of the two outside cantilever beams, please refer to the "end cantilever beams" section Design 1 of Appendix C.

The last beam designed for the first design was the outside, simply supported beam that spanned 15.8 feet long in each of its four sections. The tributary width of these beams were 2.5 feet and so based off of that, the loading combination calculations required loading came out to be 0.4869 k/ft. Since this is a simply supported beam, Case 1 on Table 3-23 was used to find the required moment, shear, and deflection. The required moment was determined to be 15.1 kip-ft and the allowed deflection was 0.79 inches. Using the max deflection equation, the required interia came out to be 20.3 in^4. Using Table 3-2, the lightest shape selected was W8X10 based on the required moment. The design moment from that Table for this beam was 32.9 k' which is greater than the required moment.

Using Table 3-3, the design interia was found to be 30.8 in^4 which is less than the required interia. After taking the self weight of the beam into consideration, the recalculated required moment was 15.5 k', which is still less than design moment. The required shear was computed to be 3.93 kips which is less than the designed shear, 40.2 kips (found in Table 3-2). The max deflection of the beam (including self weight) was then determined to be 0.11 inches which is less than the max deflection therefore W8X10 is adequate in all aspects. For complete calculations, please refer to the "outside beams" section of Design 1 of Appendix C. To see the complete layout for design one, please refer to Figure 3, Appendix A.

Table 1: Cost of Beams for Design 1

Beam Location	**Beam Class**	**Beam Type**	**Length (ft)**	**# of Beams**	**Cost ($)**	**Weight of Beams (lb)**
Interior	Cantilever	W10x12	5	3	263.40	180
Exterior	Cantilever	W8x10	5	2	143.00	100
Exterior	Simply Supported	W8x10	15.77	4	772.84	630.8
Total				**9**	**1179.24**	**910.80**

Design 2:

The second design that was constructed includes three cantilever beams and two simply supported beams, each evenly spaced out at 15.8 feet long and five feet long. There are also two 31.5 foot, simply supported beam on it's outer edges. In order to get the complete composition, four different beam designs had to be calculated in order to fit the layout chosen.The first beams are the two edge cantilever beams, the second beams designed being the middle cantilever beam, another design being the two interior simply supported beams, and the last design being the outer simply supported beams (each 31.5 feet long). Since the distance between each beam is the same as the first design (15.8 feet), the tributary width does not change meaning the middle cantilever and two edge cantilever beams are the same as design one. Therefore, there are only two beam calculations needed for Design 2, which are the simply supported beams. See Figure 2 below for the basic design idea presented.

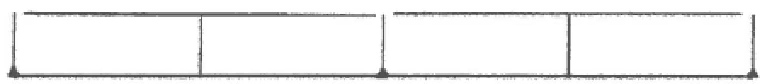

Figure 2: Fundamental Concept of Second Design

To give more of an elaboration on the design process for the second design, the tributary width for the two simply supported beams was found to be 15.8 feet which was then used to find the required loading combinations which calculated out to be 3.046 k/ft (the same as Design 1). Once this required loading was found, the required moment was found using Table 3-23, Case 1 in the Steel Construction Manual which resulted in 9.52 k'. The allowed deflection was found to be 0.25 inches which was then used to find the required inertia after moving around the max deflection equation from Case 1 mentioned. The loading used in this equation was the dead load and live load added together then divided by 12 to get the loading in inches which resulted in the required inertia to be 5.91 in^4.

Once the required moment and inertia were found, Table 3-2 was used to find a possible beam that was the lightest weight. Using the required moment, W8x10 was selected and had a design strength of 32.9 k' and a design interia of 30.8 in^4 (found in Table 3-3), both of which are greater than the required moment and inertia calculated, respectively. The required moment is recalculated to include the self weight of the beam, which was determined to be 9.56 k' which is still less than the design moment. The design shear (found in Table 3-2) was 40.2 kips and the required shear (using Case 1) was calculated to be 4.6 kips. The maximum deflection, including the self weight of the beam, was found to be 0.05 inches, which is less than 0.25 inches so the beam chosen is adequate in all aspect therefore was used in the design. For complete calculations refer to section "interior simple beams" under Design 2 in Appendix C.

The last beam designed were the two outer, simply supported beams on the frame that with a length of 31.5 feet and a tributary width of 2.5 feet. Since the tributary width is the same as the outer simply supported beams in design one, the load calculations were the same so the required loading was found to be .4859 k/ft. Similar to the simply supported beam just designed, this uses Case 1 in Table 3-23 to get the required moment, shear, and deflection. The required moment was found to be 60.2 kip-ft and the allowed deflection was found to be 1.56 inches. Using the max deflection equation for Case 1, the required inertia was found to be 162.6 in^4. To find the lightest possible beam design, Table 3-2 was used and the beam W12X14 was selected based based off of the required moment. This beam had a design moment of 65.3k' and a design interia of 88.6 in^4, where the design interia is less than the required inertia so this beam is no good!

Using Table 3-3 and the required inertia, the beam W14X22 was selected to possible use. This beam had a design inertia of 199 in^4 which is larger than the required interia, 162.6 in^4. The design moment moment for the beam was 125 k' (found in Table 3-2) which is greater than the required moment found. Once again using the equations from Case 1, the required shear was found to 8.07 kips (including the self weight) whereas the design shear was found to be 63 kips (found in Table 3-2). At this point, the self weight of the beam was taken into consideration and the required moment was recalculated to be 63.5 k' which is still less than 125 k'. The maximum deflection determined was found to be 1.35 inches and less than the allowed deflection of 1.56 inches therefore all aspect of the beam are adequate and W14x22 will be used. For complete calculations, refer to the section "Outside Beam" in Design 2 under the Appendix C. To see the complete layout for design two, please refer to Figure 4, Appendix A.

Table 2: Cost of Beams for Design 2

Beam Location	**Beam Class**	**Beam Type**	**Length (ft)**	**# of Beams**	**Cost ($)**	**Weight of Beams (lb)**
Interior	Cantilever	W10x12	5	1	87.80	60.00
Interior	Simple	W8x10	5	2	143.00	100.00
Exterior	Cantilever	W8x10	5	2	143.00	100.00
Exterior	Simply Supported	W14x22	31.53	2	712.60	1387.32
Total				**7**	**1086.40**	**1647.32**

After analyzing and determining the beams required for the balcony, the cost for each component was calculated. You can see these calculations in Tables 3 and 4; the total flooring cost is $1977.50 and the cost of the balcony railing came to equal $11,680. As seen in Table 4 Beam & Sons will be utilizing the stainless steel cables and with aluminum railing. This system was dramatically cheaper than the glass frame alternative. To summarize all the material costs of the project, Table 5 was created. The flooring and railing features chosen were held constant for calculations and cost in both designs.

Table 3: Cost of Floor Features

Feature	**Weight**	**Size**	**Unit Cost**	**Total Feature Cost ($)**
Normal Weight Concrete	150 psf	63'x5'x5.5"	$90/yd^3	481.25
Type 18 Composite Metal Deck	2.6 psf	63'x5'x2"	$4.75/ft^2	1496.25
Total	**152.6**	**63'x5'x7.5"**	------	**1977.50**

Table 4: Cost of Railing Features

Feature	**Unit Cost ($/ft)**	**Length (ft)**	**Total Feature Cost ($)**
Stainless steel Cables with Aluminum Railing System	160	73	11,680
Glass Frame System	300	73	21,900

Table 5: Design Costs

Component	Cost ($)	Total Design Cost ($)
Railing	11,680	13,657.50
Flooring	1977.5	
Beam Layout (Design 1)	1179.24	14,836.74
Beam Layout (Design 2)	1086.40	14,743.90

Preferred Design:

explain how the numbers were assigned

After constructing a decision matrix (Table 6 in Appendix B) , for the purpose of aiding in the selection of Beam & Sons final design, it was determined that Design 1 should be selected. If you consider an N.A.B.C. (Need, Approach, Benefit, Competition) approach then the process for coming to this conclusion can be seen as;

<u>Need [N]:</u> In the new engineering building at Ohio Northern University, the students and faculty need a relaxing space to escape to, spanning between the classrooms found within gridlines "K and F" on the Kennedy Engineering Building design sheets. This addition makes ONU more aesthetically pleasing while making the university more modern.

<u>Approach [A]:</u> This balcony will consist of 5 cantilever beams with 4 simply supported beams. The dimensions of this balcony were chosen to create an exceptional amount of space for students to use, while also managing and reducing the cost as compared to extending it another foot (which would reach the maximum span constraint). Beam & Sons designed a simple solution that sufficiently meets the needs of the client and keeps cost down compared to designing for the maximum width of the balcony.

<u>Benefit [B]:</u> Design 1 was selected through the assistance of a design matrix which can be seen Appendix B. It was very close decision to make, but overall the weight of the frame and ease of construction were the main factors in choosing this design. It was also only $100 more expensive than Design 2, which is a minimal difference and should not be harshly judged.

<u>Competition [C]:</u> The competition for each design is the other alternative as well as other teams bidding for the project.

Conclusion

The Dean of the Engineering College at Ohio Northern University requested that a balcony be built onto the new engineering building. He decided to hire internally a steel design team, Beam and Sons, to design a cost-effective framing plan due to finances and time. The beam (Fy= 50 ksi) should not exceed six feet, be between grid lines F and K, and should be to to LRFD standards. The design of the beam will make ONU more modern which makes the university more competitive against other schools.

After an N.A.B.C approach was considered, Design 1 was ultimately selected for implementation. This final design can be seen in Appendix A, Figure 3. This design was chosen because it was considered the easiest and safest to construct and also was far lighter than the opposing alternative, which was nearly twice as heavy. Design 1 did end up totaling $100 more than Design 2, but this amount is too miniscule to overlook the other attributes.

Through the process of completing this project, many lessons were learned. One main lesson is that there are many more factors to consider when actually designing components and beams as opposed to what we may do in class. A lesson learned is that the girders are recommended to be placed where the columns are to reduce the stress on the building's beams by reducing the amount of torsion placed on them. Another important that we learned was how to incorporate all the information we have learned in all our combined structural analysis classes and utilize our knowledge to complete a single project,which goes back to the point just made about having many more factors to consider than we are used to.

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Appendix A

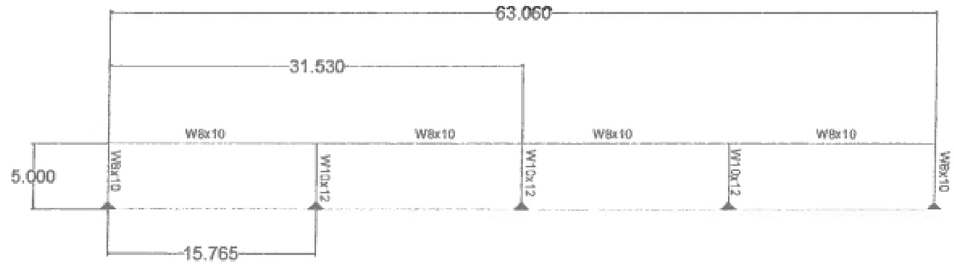


Figure 3: Balcony Beam Design 1

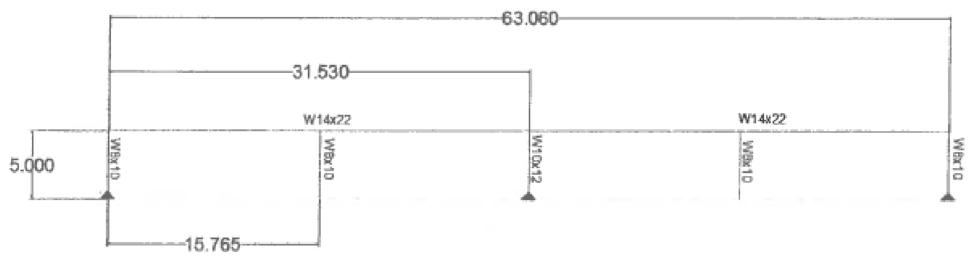


Figure 4: Balcony Beam Design 2

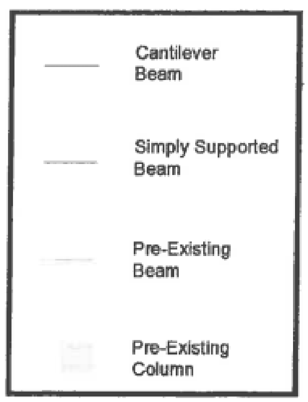


Figure 5: Beam Layout Legend

Appendix B

Table 6: Weighted Decision Matrix

Criteria	Result Weight (%)	Design 1		Design 2	
		Score	Total	Score	Total
Cost ($)	50	3	150	3.5	175
Beam Frame Weight	20	4	80	2	40
Ease of/Safety of Construction	30	3.5	105	3	90
Total	100	--------	335	--------	305
Matrix scores based on a 1-5 scale, where 1 is the worst and 5 is the best					

Beam + Sons

Design 1

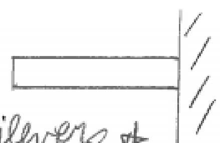
Need adequate Shear, Moment, and deflection

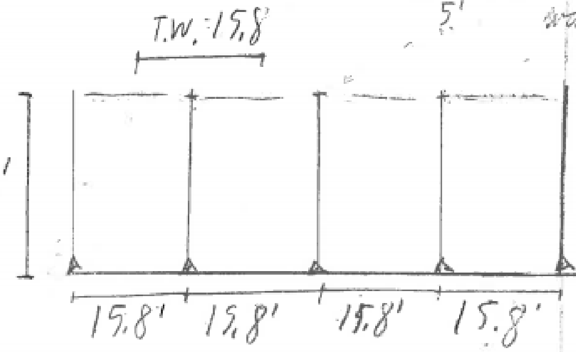
S = 22 psf   metal deck under
L = 60 psf   concrete = 2.6 psf
D =

concrete thickness = 5.5"

$\frac{15.8}{5'} > 2 \rightarrow$ one way

railing = 3.74 $\frac{lb}{ft}$





* inside cantilevers *

Use normal weight concrete $\rightarrow \gamma = 150 \frac{lb}{ft^3}$

$D = 150 \frac{lb}{ft^3} \cdot \frac{1'}{12"} \cdot 5.5" = 68.75 \frac{lb}{ft^2} \cdot 15.8 ft = 1086 \frac{lb}{ft}$

$L = 15.8' \cdot 60 \frac{lb}{ft^2} = 948 \frac{lb}{ft}$

$S = 22 \frac{lb}{ft^2} \cdot 15.8 = 347.6 \frac{lb}{ft}$

$D = 2.6 \frac{lb}{ft^2} \cdot 15.8' = 41.1 \frac{lb}{ft}$

$D = 3.74\ lb/ft$

$\rightarrow \Sigma D = 1130.8 \frac{lb}{ft}$

LRFD:

(1) $w_u = 1.4D = 1.4(1130 \frac{lb}{ft}) = 1.356 \frac{k}{ft}$

governs → (2) $w_u = 1.2D + 1.6L + .5(S) = 1.2(1130 \frac{lb}{ft}) + 1.6(948 \frac{lb}{ft}) + .5(347 \frac{lb}{ft}) = 3.046 \frac{k}{ft}$

(3) $w_u = 1.2D + 1.6S + .5L = 1.2(1130 \frac{lb}{ft}) + 1.6(347 \frac{lb}{ft}) + .5(948 \frac{lb}{ft}) = 2.305 \frac{k}{ft}$

(4) $w_u = 1.2D + 1W^0 + .5L + .5S = 1.2(1130 \frac{lb}{ft}) + .5(948 \frac{lb}{ft}) + .5(347 \frac{lb}{ft}) = 2.003 \frac{k}{ft}$

(5) $w_u = .9D + 1W^0 = .9(1130 \frac{lb}{ft}) = 1.017 \frac{k}{ft}$ → no uplift

case 2 governs

Appendix 2

The beam design problem on the final exam:

A 30-ft-span simply supported beam is laterally supported at the ends and midspan. The beam carries a uniform service dead load of 1.6 k/ft (not including the self-weight of the beam) and a concentrated service live load of 15 kips at midspan.

a) Determine the required moment per LRFD.
b) Determine the required shear per LRFD.
c) Determine the lateral-torsional buckling modification factor.
d) Use A992 and select the lightest W-shape. The maximum permissible live load deflection is L/360.