Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #46197

Design Build Capstone Project – Pedestrian Bridge (Case Study)

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ABET Inc. requires the curriculum within an engineering program to include a culminating major engineering design experience that incorporates appropriate engineering standards and multiple constraints and is based on the knowledge and skills acquired in earlier course work. Many programs use a capstone design project or experience to fulfill this requirement. The paper outlines a case study on how the civil engineering program at the United States Air Force Academy uses a real-world design-build project to serve as the culminating design experience. The study outlines the project description, how students engage with stakeholders, the design process itself which includes examples of standards and constraints, as well as the construction and project management associated with the project. The paper also addresses what type of content is intentionally taught as part of the course, along with the overall impact on student learning and achievement. Ultimately, the design-build capstone provides an authentic and exciting design challenge that motivates students and promotes their learning and development as engineers.

Introduction

The civil engineering program is one of six ABET accredited engineering programs at the United States Air Force Academy (USAFA). In addition to requiring students to achieve seven different student outcomes, Criterion 5 (Curriculum) of ABET[1] states that the curriculum must include a culminating major engineering design experience that 1) incorporates appropriate engineering standards and multiple constraints, and 2) is based on the knowledge and skills acquired in earlier course work. The curriculum must also meet civil engineering program criteria that include designing a system, component, or process in at least two civil engineering contexts.

Howe and Wilbarger[2] conducted a survey of engineering capstone courses in the United States to gain an understanding of how they were structured. Their research found that most capstone courses contained a mixture of classroom and project components, with an increase in both the variety and quantity of projects that were externally sourced through industry. The culminating design experience in the USAFA civil engineering program had been a project that was nested within a single semester construction management course. The project had a real-world customer and was thus linked to industry, similar to what Howe and Wilbarger[2] described. Although the project met all the requirements for a culminating design experience, the department made the decision to transition to a year-long culminating major engineering design experience. The decision was made as part of the continuous improvement process and took input from students, internal program assessments, and what other programs around the nation are doing. Using a real-world project is not unique to the USAFA, as others have outlined how such projects are well suited to meet the ABET requirements and have been demonstrated to motivate students to work harder than they may have in a traditional class. While the list is not comprehensive, several examples are included below.

Padmanabhan et al[3] describes how North Dakota State University has recently refined their capstone course experience to use real-world projects that integrate students, faculty, and practicing professionals.

Leidig et al[4] describe how Purdue University has developed and integrated a community-engaged design program into their capstone design. The program, Engineering Projects in Community Service (EPICS) partnered with Engineers Without Boarders USA to provide a capstone experience for senior design students from the Division of Environmental and Ecological Engineering in the 2019-2010 academic year.

Good and Smith[5] describe how undergraduate civil engineering capstone design projects can play a vital role in creating sustainable water, sanitation, and hygiene (WASH) designs, and how students can benefit from participating WASH design projects that engage and collaborate with communities.

Wambeke[6] described how a similar type of project was used at the United States Military Academy to engage the community and found the project was well-suited to support students in meeting or exceeding ABET outcomes and noted the perceived benefits of having a real-world project in the capstone course.

CIVENGR 451 & CIVENGR 451 – Civil Engineering Capstone Design I & II

The two-course capstone experience for the USAFA civil engineering program was first executed during the 2023-2024 academic year. CIVENGR 451 (Civil Engineering Capstone Design I) occurs in the fall and CIVENGR 452 (Civil Engineering Capstone Design II) occurs in the spring. Each course is worth 3.0 credit hours, and has the following objectives:

1. Work effectively within a design team in a professional and ethical manner.
2. Apply the civil engineering design process and conduct iterative analysis and design of a solution to a challenging, ill-defined and open-ended problem.
3. Apply knowledge of math, science, and engineering to design a system, component, or process in more than one civil engineering context in accordance with applicable codes and regulations.
4. Incorporate contemporary issues, such as economic, environmental, social, political, ethical, health and safety, manufacturing, and sustainability, as applicable into the solution of an engineering problem.
5. Communicate and justify an engineering design through oral and written form.

Students work within small teams, and each team has a unique project that falls within one of three overarching areas: design, design-build, reached-focused design. The focus of this paper is how a design-build pedestrian bridge project serves as one of the USAFA civil engineering capstone projects.

Design-Build Pedestrian Bridge Project: The town of Palmer Lake is located about 12 miles north of the USAFA. The town recently obtained 28 acres that had been vacant, with the intent of integrating it with adjacent property that is managed and maintained by the town's trails and parks division. One of the challenges facing the town is the fact that Monument Creek separates the new property from areas that already have existing trails. Historically, hikers have simply placed wood or logs/sticks across the stream (Figure 1); however, they get washed out as soon as the stream flow increases, and the makeshift "bridges" are certainly not a long-term solution for safely crossing the stream. The town reached out to the USAFA about establishing a partnership to assist with designing and constructing at least one bridge. The remainder of this paper describes how the USAFA civil engineering program partnered with Palmer Lake to use the design and construction of a pedestrian bridge as one of the capstone design projects.

Figure 1: Makeshift "bridge"

The town agreed to provide representatives from their parks and trails division to serve as points of contact for the students to interact with. The town also agreed to provide funding for all the materials and cover any fees associated with obtaining a building permit. Additionally, they accepted responsibility for the bridge and any associated maintenance in the future. The students did all the design work and performed all the construction activities.

The USAFA capstone team consisted of 10 students and one faculty advisor. The team organized itself as a design-build firm with the understanding that the team would need to provide at least two design options for their client, as if they were competing against other firms for the bridge project. One of the first activities involved meeting with stakeholders from Palmer Lake. At the start of the fall 2023 semester, the team met with five individuals from Palmer Lake, including the town historian who provided a photo of a bridge that had been in the general vicinity from over 100 years ago (Figure 2). The Palmer Lake representatives showed the students the site where they wanted the bridge to go, provided some general guidance about the intended use and aesthetics, and stated they had a budget of $15,000; however, they left the specific project requirements vague and open-ended. Although the stakeholders did not specify this, they did ask if the team could potentially find a way to incorporate some trees that were locally harvested into the design. Based on the site location and guidance from the stakeholders, students were able to determine the span was going to be about 35 feet and would need to be capable of accommodating pedestrians, bicyclists, and potentially equestrian users. The team conducted a survey of the site including the bank and stream profiles (Figure 3). They also performed a dynamic cone penetrometer test and took samples of the soil at the locations where the abutments would eventually be placed.

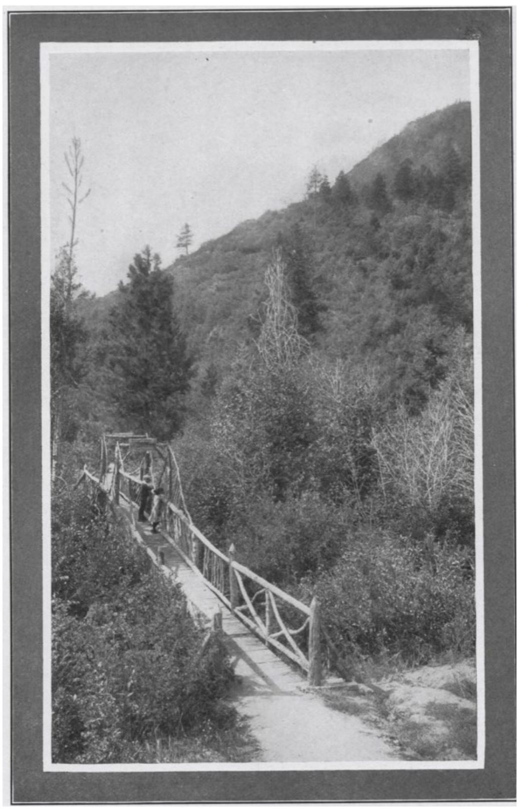

Figure 2: Bridge circa 1900

Figure 3: Site Survey

The capstone team designed three options during the fall semester, one using Glue-Laminated (GLULAM) Beams, one using steel wide-flanged shapes, and the other using Open Web Steel Joists (OWSJ) for the primary structural elements. They designed the bridges in accordance with the Load and Resistance Factor Design (LRFD) Guide Specifications for the Design of Pedestrian Bridges, the Pikes Peak Regional Building Department, and the US Forest Service's Transportation Structures Handbook. Live, snow, and self-weight loads were analyzed as part of the structural analysis and incorporated into the design of the bridge. Teams designed the footings and associated formwork, structural elements of the bridge, the decking, and the railings for the bridge. They also evaluated the watershed area and discussed historical flows with members of Palmer Lake and a FEMA representative from the Pike Peak Regional Building Department. Although the students had previously learned how to size steel W-shapes and OWSJs in a Steel Design course, the USAFA civil engineering program does not have a specific wood or timber design course; therefore, the instructor taught the students how to properly size a GLULAM beam using the National Design Specification for Wood Construction. The team also developed a method to test the locally harvested trees and determined the size that would be adequate to use for railing posts on the bridge. The team presented both design options to Palmer Lake stakeholders near the end of the fall semester, and the stakeholders selected the GLULAM beam option. Once the structural design option was selected, the team finalized the design and developed a comprehensive list of materials. One challenge related to the final design was to determine how they could ensure the centers of the railing posts (all with slightly different diameters) were aligned so that stainless steel cables could be run horizontally along the bridge without zigzagging back and forth between the posts. Once the bark was stripped from each post, they built and used a template to pre-drill holes for the cables and created notches where the post would be attached to the GLULAM beams. The challenge served as a great learning experience related to the constructability of a design idea.

Early in the spring semester, the final design was reviewed and approved, and a construction permit was granted by the Pikes Peak Regional Building Department. The remainder of the spring semester was focused on the procurement of materials and construction activities. The team prefabricated some portions of the bridge, such as the abutment formwork and the railing posts, on campus in a laboratory environment but completed most of the construction on site. The bridge was completed prior to the end of the semester at a cost of just under $12,000. About 30 members of the town, including the mayor, attended a ribbon cutting ceremony to "officially" open the bridge at the end of April 2024. A few images of the construction process and the completed bridge are shown below.

Assessment and overall impact on student learning and achievement:

The rubric shown below was used as a tool to assess the project relative to the CIVENGR 451 and CIVENGR 452 course objectives and five of the ABET student outcomes (outcomes 1, 2, 3, 5, and 7).

Civil Engineering Student Outcome	A	A-	B+/B	B-/C+/C	C-/ D / F
DESIGN. Identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.	Problem clearly identified with no assistance. Well above average Technical and creative solution. Consistently engaged and exceeded project criteria. Professional standards exceeded in most areas.	Problem clearly identified with some assistance. Strong technical and/or creative solution. Consistently engaged project criteria. Professional standards exceeded in some areas.	Problem identified with some assistance. Average technical solution with minimal creativity. Met most of the project criteria. Professional standards met in all areas.	Problem identified with significant assistance. Marginal technical solution with very little creativity. Struggled to meet the project criteria. Professional standards no met in some areas.	Failed to identify problem effectively. Sub-standard technical solution with no creativity. Failed to meet the project criteria. Professional standards not met in most areas.
BREADTH. Apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.	Appropriately identified all breadth areas of design. Produced solutions that met all identified breadth areas. Solutions exhibited strong technical understanding.	Appropriately identified all breadth areas of design. Produced solutions that met most breadth areas. Solutions exhibited good technical understanding.	Appropriately identified most breadth areas. Produced solutions that met most breadth areas. Solutions exhibited average technical understanding.	Failed to identify some breadth areas of design. Solutions did not meet all breadth areas. Solutions exhibited limited technical understanding.	Failed to identify breadth areas of design. Failed to produce solutions for any breadth areas. Solutions exhibited no technical understanding.
COMMUNICATION – WRITTEN. Communicate effectively with a range of audiences.	Exemplary in at least three areas and satisfactory in all others: 1. Substance 2. Organization 3. Style and Presentation 4. Mechanics & Correctness 5. Documentation	Exemplary at least two areas and satisfactory in all others: 1. Substance 2. Organization 3. Style and Presentation 4. Mechanics & Correctness 5. Documentation	Satisfactory or better all areas: 1. Substance 2. Organization 3. Style and Presentation 4. Mechanics & Correctness 5. Documentation	Marginal or better in all areas: 1. Substance 2. Organization 3. Style and Presentation 4. Mechanics & Correctness 5. Documentation	Not proficient in at least one area: 1. Substance 2. Organization 3. Style and Presentation 4. Mechanics & Correctness 5. Documentation
COMMUNICATION – ORAL. Communicate effectively with a range of audiences.	Well-rehearsed and professional presentation of technically rigorous content.	Above average professional presentation of technically strong content.	Average professional presentation of average technical content.	Below average presentation of average technical content.	Below average presentation of below average technical content.
TEAMWORK. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	Exemplary in most areas: 1. Providing leadership 2. Creating collaborative and inclusive environment 3. Establishing goals 4. Planning tasks Meeting objectives	Exemplary in two areas and satisfactory in all others: 1. Providing leadership 2. Creating collaborative and inclusive environment 3. Establishing goals 4. Planning tasks Meeting objectives	Satisfactory or better all areas: 1. Providing leadership 2. Creating collaborative and inclusive environment 3. Establishing goals 4. Planning tasks Meeting objectives	Marginal or better in all areas: 1. Providing leadership 2. Creating collaborative and inclusive environment 3. Establishing goals 4. Planning tasks Meeting objectives	Not proficient in at least one area: 1. Providing leadership 2. Creating collaborative and inclusive environment 3. Establishing goals 4. Planning tasks Meeting objectives
NEW KNOWLEDGE. Acquire and apply new knowledge as needed, using appropriate learning strategies.	Detailed review of existing work is completed. Engaged in learning new material, beyond the scope of the project. Exceeded expectations in area.	A review of existing work is completed. Fully engaged in learning new material across required aspects of the project. Met expectations in this area.	An incomplete review of existing work is completed. Struggled and/or unmotivated to pursue new material in major areas of the project. Marginally met expectations.	A review of existing work was not completed. Very limited pursuit of new material across the project and had detrimental impacts. Failed to meet expectations.	Failed in multiple regards to have the initiative and/or commitment to acquiring and applying new knowledge.

Table 1: Rubric to assess student outcomes

Several students offered comments related to how the project was one of their most developmental and rewarding experiences in their course-end feedback, which suggests a positive correlation with student learning. The bridge project was also recognized among 10 other capstone projects with the “Greatest Impact” award during the department’s projects day poster session, where teams presented their projects much like they would at an engineering conference. The town of Palmer Lake was extremely satisfied with the project and asked to partner with USAFA for two more bridges. The 2024-2025 project was the most requested project among students, which is indicative of students’ inspiration and motivation for these types of projects. The author feels this type of design-build project provides students with an authentic and exciting design challenge that motivates them and promotes their learning and development as engineers.

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