Lessons Learned: Applications of Sustainability Rating Systems in Civil Engineering Capstone Design Courses

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Abstract

This paper describes experiences over several years at two different universities of difficulties and successes in applying sustainability rating systems in civil engineering capstone sequences. Current civil engineering ABET program criteria requires that "The curriculum must prepare graduates to… include principles of sustainability in design." A logical place to meet this requirement is in the capstone design course. Early efforts focused on using the Leadership in Energy and Environmental Design (LEED) rating system. This turned out to have a number of challenges. One is that LEED focuses on buildings as opposed to infrastructure projects. Another is that many of the LEED points may be either out of the control of the civil engineer. As a result, the students' work was often uneven and sometimes unsatisfactory. The first author recently moved from Cleveland State University to Oklahoma State University, but continued teaching the capstone class. More recently, there has been more success in applying the Envision® Rating System, which is more broadly applicable to infrastructure than LEED. A local consulting firm, Freese and Nichols Inc., was found that was willing to introduce the student groups to the tools within the Envision Rating System, present case studies, and to coach them in how to apply it to their projects. This has led to multiple benefits. Because the material is presented by an outside consulting firm, rather than faculty, it is possible that the students attach more credibility to it. The effort is also timed better, coming in the middle of the project development stage, rather than toward the end.

In response to call for papers: Applications of Sustainability Rating Systems in Civil Engineering Curriculum

Introduction and Background

Sustainability has been becoming increasingly important in civil engineering. Robinson and Sutterer stated in 2003, "Sustainability must become a fundamental consideration in all civil engineering design and construction. As the leaders of change in fundamental civil engineering processes, it is the responsibility of civil engineering departments nationwide to lead the movement toward sustainable civil engineering development through research and education of their students." [1] Sustainability is one of the American Society of Civil Engineers (ASCE) four key programs[2]. It is also part of Canon 1 of the ASCE Code of Ethics, "Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties."[3]

Robinson and Sutterer cited as barriers to sustainability in education that many civil engineering faculty are not knowledgeable about sustainability and department leaders do not necessarily perceive a need[1]. They suggested, among other measures, adding sustainability to design problems and including sustainability in capstone design courses, with specific reference to the Leadership in Energy and Environmental Design (LEED) green building rating system[4]. They also stated that "Our goal is to make sustainability assessment as fundamental to future projects as checking for code compliance."[1]

Hansen and Vanegas discussed a broad guiding vision for sustainability education in the Architecture, Engineering, and Construction industry and available resources to achieve the vision. "Industry resources available to the those wishing to integrate sustainability principles into the civil engineering curriculum include organizations such as the U.S. Green Building Council (USGBC), which has developed a Leadership in Energy and Environmental Design (LEED) certification program, the UK's Building Research Establishment (BRE), the American Society of Civil Engineers (ASCE), the American Institute of Architects (AIA), and the International Council for Building Research Studies and Documentation (CIB), among others. Additionally, journals such as Environmental Management, the International Journal of Environmental Technology and Management, Environmental Building News and numerous conferences provide vehicles for learning what others are doing currently and for publishing findings." [5]

These references from 2003 and 2006 pointed to the USGBC LEED rating system as the best available at the time.

Inclusion in the Body of Knowledge and Accreditation Criteria

With the development of ASCE's 2nd Edition of the Civil Engineering Body of Knowledge[6], commonly known as the BOK2, sustainability began to assume increasing importance[7]. Lynch et al. discussed the importance of sustainability in infrastructure[7].

BOK2 outcome 10, Sustainability, proposed attainment at Bloom's level 4, "***Analyze*** systems of engineered works, whether traditional or emergent, for sustainable performance." An entire appendix was devoted to discussion of this outcome[6].

This outcome eventually made its way into ABET program accreditation criteria. For the 2016 – 2017 cycle, the Civil Engineering Program Criteria were revised to include: "The curriculum must prepare graduates to… include principles of sustainability in design..." [8]

Implementation into Capstone Design Projects

While the Civil Engineering Program Criteria do not explicitly require that sustainability be addressed within the capstone design project, that is usually the most logical place to include it. Further information is provided in the ASCE Commentary on the Program Criteria[9].

As an example, Sattler et al. developed a multidisciplinary capstone course with National Science Foundation (NSF) funding support focusing on sustainability. Senior students from civil and industrial engineering participated, designing a biodiesel refinery using vegetable oil waste from campus food service. This was the culmination of a series of prior courses that had embedded sustainability modules[10]. This approach avoided the common problem of lack of sufficient sustainability knowledge for students to incorporate it into a design project.

As Payne and Aidoo have observed, the integration of sustainability concepts into projects should be done at the conceptual phase, but is often instead done during the technical design phase. In their program at the Rose-Hulman institute of technology, sustainability modules are included in six courses prior to the capstone design course[11].

Implementation at Cleveland State University

At Cleveland State University, the senior design students were required to include a Leadership in Energy and USGBC LEED[4] assessment as part of each project. At the time this requirement was instituted, LEED was essentially the only available rating system. The curriculum did not include formal exposure to sustainability prior to the two semester capstone design course sequence. This course was taught several times by the first author between 2010 and 2016.

There were also tools available to help students use the LEED rating system. The American Concrete Institute (ACI) had a program to supply two important references to students free of charge[12] [13]. An outside guest lecturer, who was very active on the ACI Sustainability Committee, came in to speak to the students to introduce sustainability concepts and discuss their projects.

However, limitations of the approach became apparent over time. As the LEED system focuses on human-occupied buildings, it does not work well for non-building projects, such as roads or bridges, even though those projects are often appropriate for civil engineering capstone design.

Integration of sustainability in this course presented several challenges:

- Student knowledge about sustainability is highly variable, based in large part on treatment in prerequisite courses
- Students lack familiarity with the available rating tools and systems
- Some tools are not available for free

- When projects involve outside clients, those clients may not place much emphasis on sustainability
- Students may apply trivial and superficial treatments to sustainability, or may attempt to graft it on at the end of the project
- Students may put too much faith in marketing by trade associations, and state that "we used material X which is sustainable because their web site says so"

Even for building projects, many of the decisions that influence rating points are made by others on the time rather than the civil engineers. These include the use of low-flow bathroom fixtures, lighting, heating, ventilation, and air conditioning (HVAC) systems, and other features. Some students appeared to believe that such decisions should be completely left to architects and discounted their own roles and responsibilities for sustainability.

Another approach often taken by students was to complete the project, and then to graft on the sustainability features at the end, such as putting a green roof on a diving pavilion. In some respects, some of the LEED point elements fostered this tendency because they seemed to be items that could be added on at the end of the project. Over several years and course offerings, the sustainability treatment improved, but remained uneven.

Also, as sustainability and LEED points became more important to the engineering, architectural, and construction industries, trade associations became more adept at marketing their materials and technologies that contribute to project and environmental sustainability. Thus, there is a large but confusing and contradictory body of claims, which are difficult for students to sort out.

Implementation at Oklahoma State University

The first author recently moved from Cleveland State University to Oklahoma State University, but continued teaching the capstone class. The course differed in format in that it was a single semester 3 semester-hour course at Oklahoma State University, as opposed to a two course sequence at Cleveland State University, with two 2 semester-hour courses.

In the current iteration at Oklahoma State University, the course is team taught by the first two authors. At both universities, teams of three or four students worked on different projects, generally for outside clients. Some of the projects are selected specifically for students who are working on an environmental engineering emphasis within the curriculum. For example, the fall 2018 offering had five projects, one with an environmental focus, and the spring 2019 offering had eleven projects, three with the environmental focus.

As part of the course, the second author provided an overview of various sustainability rating systems. Other authors came in as guest lecturers to help introduce the Institute for Sustainable Infrastructure (ISI) Envision® Rating System[14]. Because the Envision system is broad and flexible, it is more applicable to civil and environmental engineering projects. The envision rating comprises 64 indicators or credits, organized into five categories, Quality of Life (QL), Leadership (LD), Resource Allocation (RA), Natural World (NW), and Climate and Resilience (CR)[14].

Within each credit, points are allocated for each of five levels of achievement, increasing from Improved, to Enhanced, to Superior, to Conserving, and finally to Restorative. A total of 809 points are available. They are not evenly divided among the categories.

- Quality of Life has 13 credits with 181 maximum points
- Leadership has 10 credits with 121 maximum points
- Resource Allocation has 14 credits with 182 maximum points
- Natural World has 15 credits with 203 maximum points
- Climate and Risk has 3 credits with 122 maximum points[15]

As part of the capstone course lectures, the authors led a two hour sustainability workshop. The third, fourth, and fifth authors are from Freese and Nichols, Inc., which includes sustainability as a core value and applies sustainable principles to project for the betterment of the communities that they live and work in. Freese and Nichols, Inc. is a Charter Member of ISI and has more than 50 employees who are Envision Sustainability Professionals (ENV SP) and credentialed to use the rating system.

During this workshop, the basics of the Envision Rating System were presented, and the student teams reviewed several case studies to become more familiar with the system and the available resources. Prior to the workshop, the students were provided with electronic copies of several resources:

- A copy of the Envision® Pre-Assessment Checklist spreadsheet
- A PDF copy of the 168 page Envision® Rating System Guidance Manual[15]
- Copies of the case studies illustrating use and interpretation of the rating system and guidance manual

After the introduction to the system and the resources, the student groups were provided with one page descriptions of three case studies. The three example case studies were Mahogany Ridge Light Rail Station, Belmont Water Distribution Upgrade, and the Airport Authority. Each example illustrated the interpretation of a specific credit. The questions asked of the student groups focused on what level of achievement the project should pursue, and what level of documentation would be need to justify the level. The students worked in their design groups and then the class compared the findings.

The Mahogany Ridge Light Rail Station example focused on the interpretation of Quality of Life (QL) Credit 2.5, Encourage Alternate Means of Transportation. The light rail station was designed to integrate with pedestrian and bicycle paths. The discussion focused on what features of the project justified the proposed level of achievement, and what more might be done to enhance the sustainability of the project.

Similarly, the Belmont Water Distribution Upgrade example focused on the RA1.1 Reduce Net Embodied Energy credit in the Resource Allocation (RA) category. This case study highlighted how to assess the embodied energy from materials extraction, processing, manufacturing and transport of ductile iron pipe. Comparison was made between more costly pipe with a shorter shipping distance compared to pipe imported internationally.

The third case study, for an Airport Authority, addressed Quality of Life (QL) Credit 2.6, Improve site accessibility, safety, and wayfinding. The airport authority needed to design a new airport terminal next to an old terminal, and maintain service during construction. The example illustrated project phasing and plans for access and egress routes during construction, with emphasis on safety and emergency access.

Next, the authors worked with each team by discussing their project and the integration of the available rating system tools and sustainability. Use of the Pre-Assessment Checklist requires answering 144 questions about the project, to be answered as yes, no, or not applicable. Through the answering of the questions within the Pre-Assessment Checklist, the student teams systematically reviewed macro-level sustainability concepts that could be applicable to their projects.

Results from Fall 2018 Semester Student Projects

As part of final reports and presentations, the student groups were required to report the results from the Pre-Assessment Checklist, along with what elements of the project they were using to strengthen sustainability. With the spreadsheet based Pre-Assessment Checklist, the teams check for each credit to determine if it will be achieved, not achieved, or is not applicable to the project.

So far, this approach has been used for three successive offerings of the course, in spring 2018, fall 2018, and now spring 2019. One change was made for the spring 2019 offering, to hold the sustainability workshop much earlier in the semester, so that it falls more within the conceptual design phase of the course.

In fall 2018, there were five design projects, each with a group of four students. Four of the projects were intended to be general civil engineering projects, and one was an environmental engineering project for students enrolled in the program's environmental engineering option. All of the four civil engineering projects were for the same Native American community, located less than an hour's drive north of the university, offering ample opportunities for client interaction.

Project 1 was to redesign the alignment of a sharp intersection to improve safety and traffic flow. As part of their final report, the group provided a three page sustainability chapter discussing their results. For example, they noted that the project attained 20 of 23 possible Quality of Life points, including QL2.4 Improve community mobility and access, QL2.5 Encourage alternative modes of transportation, and QL2.6 Improve site accessibility, safety, and wayfinding. In addition, this team thought that their project approach was strong in leadership, fairly strong in Natural World and Climate, and weak in Resource Allocation.

One example of student results in shown in Figure 1 for the first project discussed below on intersection redesign. This group presented achieved (Y), not achieved (N), and not applicable (N/A) as percentages.

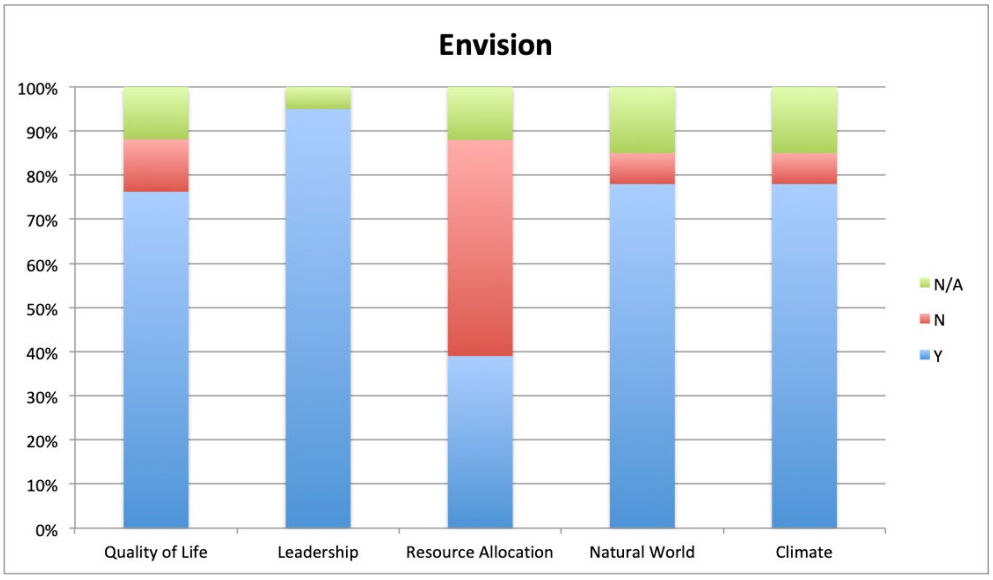

Figure 1: Typical Project Final Report Results (from student final project report)

Project 2 looked at alternatives for rehabilitation of a historic bridge in the middle of town. The bridge was a distinctive historic green pony truss which the community wanted to preserve. This group provided a four page sustainability chapter, most of which consisted of copies of the spreadsheet. It was one of the weaker efforts, focusing more on the elements of sustainability that did not apply than on those that did.

The third project team had the task of designing a park and fit trail for the community, including restroom facilities and a pedestrian bridge. While this project offered substantial potential, the sustainability section was merely a long paragraph and a figure showing what percentage of points applied in each category. On the other hand, the team integrated elements of Quality of Life and Leadership into other elements of the report. For example, the project included the design of a new dance pavilion that had to avoid disturbing Witness Trees that had spiritual significance for the community.

In contrast, the report for project 4 provided the most in depth sustainability analysis. This project analyzed an existing historical sandstone building that was in very poor shape in order to design repairs so that the building could be put back into use. Each of the five categories was addressed with at least a page of detailed discussion. Sample Quality of Life results are shown in figure 2.

The first four projects all involved specific sites. In contrast, the fifth project on "Process Design of Phosphorous Recovery for Concentrated Animal Feeding Operation" used an assumed generic rural location. Thus, there was no specific on the ground client and limited client interaction, and the project scored low on the leadership category. Because of the isolated nature of the assumed site for the project, and lack of nearby population, there was a small effect in the Quality of Life category. However, the group reported on opportunities to enhance sustainability in the categories of Climate and Risk, Natural World, and Resource Allocation.

Figure 2: Example Pre-Assessment Checklist results for Quality of Life (from student final project report)

Figure 3 shows the results of this group's Pre-Assessment Checklist. As with figure 1, the bars represent the percentage of credits within each category that were marked not achieved (No), achieved (Yes), or not applicable (N/A).

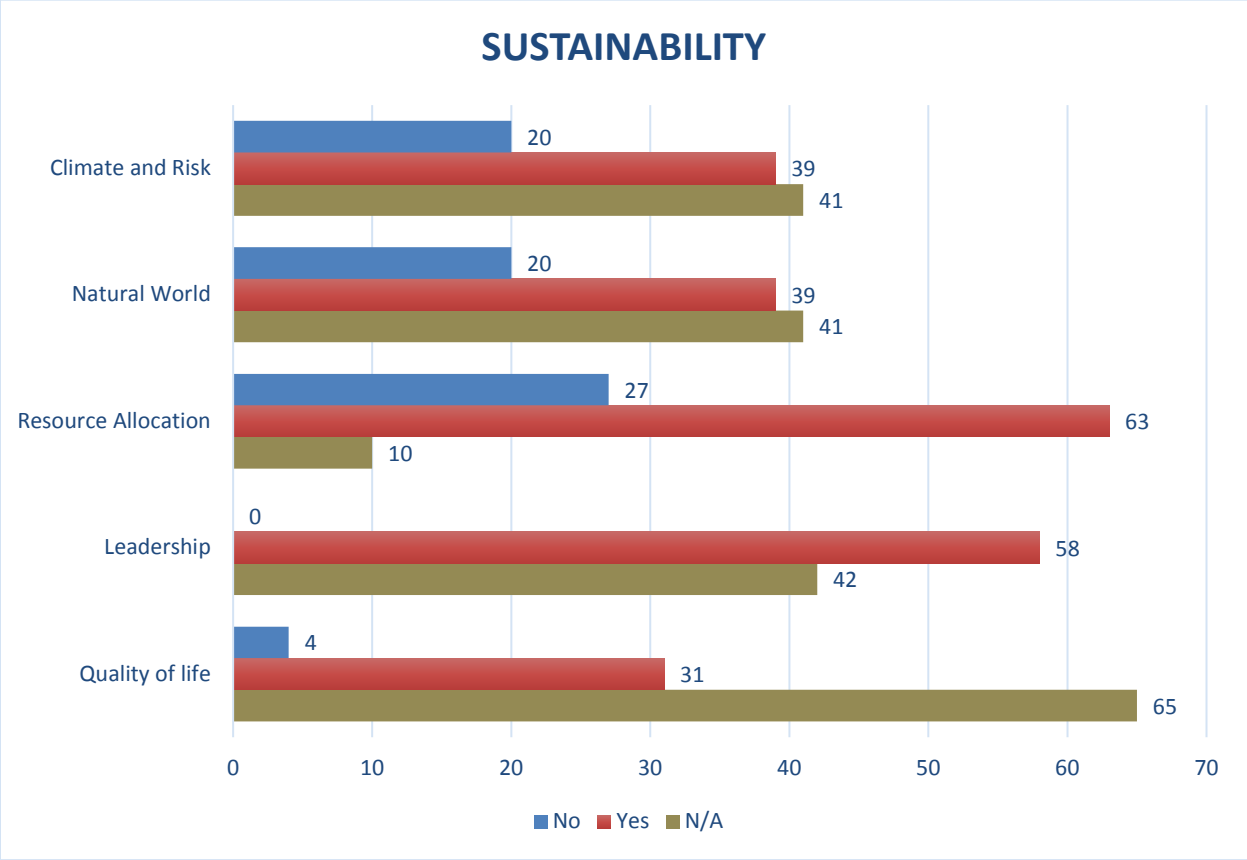

Figure 3: Typical Sustainability Chart on Point Systems from Envision's Categories (from student final project report)

Assessment

In addition to a final PowerPoint presentation and a comprehensive written report, the teams each made a two hour poster presentation during the class's final exam period. The poster presentations were formally assessed by both faculty and practitioners. Each assessed each group against the new ABET criterion 3 1 – 7 student outcomes[8], which do not directly address sustainability except buried in the definition of design constraints. Therefore, the assessment rubric, which was used for the first time for the fall 2018 course offering, did not have a specific question about sustainability.

Each poster, as required, had a sustainability section. Only one of the faculty and practitioner review sheets mentioned sustainability specifically, with respect to the park and fit trail project, noting "Sustainability was well covered through trail surface, tree protection, enviro-friendly toilets/ bathrooms and lighting." In the future, assessment can be improved by adding a question for the reviewers to specifically address sustainability.

The department has also received an internal grant from the university assessment office to fund two faculty members to review design reports during summer 2019 and to write an assessment summary. This review will encompass the five project reports from the fall 2018 semester as well as the eleven from the spring 2019 semester.

Observations and Conclusions

The literature and experience teaching capstone courses both suggest the importance of building on knowledge from prior coursework, when possible. Future work includes looking for opportunities to cover sustainability at different points in the curriculum, so that the capstone course has a stronger foundation to build on.

Reliance on outside client contacts for projects can mean that the students get mixed messages on sustainability. In some cases, the students have noted that the clients have told them that sustainability is a low priority. The course instructors point out that the sustainability analysis is part of the course requirement, and also that as consultants they have a responsibility and an opportunity to educate their clients about how the sustainability of a project can be improved.

Comparing the LEED rating system with the Envision Rating System, in the opinion of the authors it is evident that the latter is much better as a teaching tool and applicable to a broader range of civil and environmental engineering projects. There is potential benefit in moving past the Pre-Assessment Checklist to the actual application of the levels of achievement for each credit, but that would be considerably more time consuming. A good compromise might to be to focus on the level of achievement for about a half dozen or so of the most applicable credits.

With each successive course offering, there is an opportunity to use good examples from prior years as illustrations. The analysis from project group 4 for the fall 2018 offering can provide a good template for future class offerings.

One change that was implemented for the spring 2019 offering was to hold the sustainability workshop earlier within the semester. This time it was within the first month of the course, to give the teams time to integrate the sustainability analysis earlier in the planning.

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