Optimization of Green Roof Systems for Multifunctional Buildings: A Three-Year Integrated Civil and Environmental Engineering Design Course Experience

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Abstract

Every year, the instructors of the senior design course for Civil and Environmental Engineering develop course materials and projects to illustrate the various professional life aspects of practicing engineers, including successful project proposal writing, development of status reports, and final project delivery, analysis of ethics issues, and economics. The students are expected to work in multi-disciplinary teams to successfully complete a civil/environmental project need. Defining the technology opportunity space, a compelling practical need, and a project that capitalizes on the backgrounds of students in structures and materials, construction, geotechnical engineering, and construction management is challenging, as is the means by which the project results are communicated across disciplines and to the lay public.

When the opportunity presented itself to teach the senior design course, I decided to focus on green roof technology as an example of green infrastructure design, and an opportunity to enable the civil and environmental engineering undergraduates to work together on a single project, rather than on separate projects. the technology touches many aspects which are our bread and butter: structural analysis, stormwater management, and contaminant fate and transport (see also Figure 2. The green roof stormwater control strategy capitalizes on the expertise of civil engineers in the building design and construction for appropriate roof load capacity under various climatological conditions for new and refurbished (e.g. Brownfields) facilities (residential, commercial, and industrial). Environmental engineering expertise is required to evaluate the impact of green roof designs on permitting, design of retention facilities, and stormwater runoff.

The objective of this design course is for the students to capitalize on their specialized knowledge in CEE program areas, and leverage this into a project of high visibility and translational potential to practice

Methods

Capstone Course Objectives

To provide exposure to:

1. Project design.
2. Proposal writing and final report preparation.
3. Economic analysis of engineering projects.
4. Regulatory issues.
5. Engineering ethics and the role of professional code of ethics in decision making.

Goals in Shaping Design Course

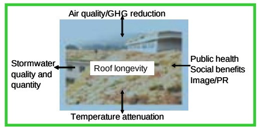
1. To address sustainability in CEE.
2. To design a project that is integrative across all CEE disciplines.
3. To employ innovative visualization methods to showcase CEE products.
4. To create visibility for CEE capstone design projects in the College of Engineering.

Evaluation Metrics: Engineering Design = Communication

Task	Deliverable	Evaluation	Timeframe	Grade (%)
Technical/Cost Proposal	Proposal and short presentation.	Team	Week 3	20
Homework 1	Engineering economics.	Individual	Week 4	
Homework 2	Structural analysis.	Individual	Week 5	
Homework 3	Stormwater hydrology.	Individual	Week 6	20
Ethics essay	1-2 p response to case study.	Individual	Week 7	10
Interim Report 1	Roof load and rainfall data.	Team	Week 6	
Interim Report 2	Structural analysis.	Team	Week 8	
Interim Report 3	Cost/benefit analysis.	Team	Week 11	20
Project Presentation	20 min PowerPoint.	Team	Week 13	10
Public presentation	3D renderings of project.	Team	Week 13	0
Draft Design Report	5 p summary; thorough analysis in appendices.	Team	Week 12	
Final Design Report	Updated and corrected report.	Team	Week 14	30

Results

Project Focus: Assess Cost/Benefit for Green Roof Designs



Structural reinforcement.
Waterproof membranes.
Maintenance.
Premium cost over traditional roofs.
- Conventional roof $167 ± $28 per m^2.
- Extensive green roof $232 ± $45 per m^2.

Reduction in runoff by 40-60%.
Decrease in roof surface temperature by up to 40¼C.
Increase in roof life by 2-3 fold.
Uptake of air pollutants (e.g. NOx by up to 0.27 $kg/m^2/y$).
- Public health savings of $1,680-6,380 per Mg.

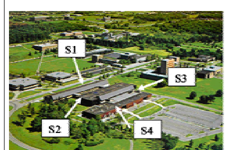
Green Building Functionality, Design Criteria, and Scale

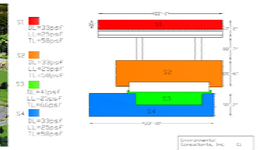
Building	Functionality	Design Criteria	Scale (m2)
WalMart facility	Single storey retail	Capture 10 year storm event; ROI < 20 years	10,000
Environmental and Water Resources Engineering Š University campus	Multiple storey administrative and research	Capture 10 year storm event; ROI< 20 years	1,000
Art and Architecture Building Š University campus	Multiple storey administrative and research	Capture 10 year storm event; ROI < 20 years	8,000
Public Hospital	Multiple storey administrative and services	Capture 10 year storm event; ROI < 20 years	6,000
Public Hospital Š University campus	Multiple Storey administrative and services	Maximum stormwater retention; incorporation of playground; two roofs	12,000
Industrial Facility	Single storey, heavy manufacturing	Capture 10 year storm event; cool process water to 20¼C for discharge	125,000
Office building	Multiple storey, administrative	Capture maximum storm event without structural reinforcement; emphasis on city-wide scalability	6,000

Between 2004 and 2006, up to sixteen teams per year of four students (each composed of a mix of structural, geotechnical and environmental engineering majors) worked on a number of buildings capturing public and private facilities with multiple functionalities.

The opportunities were chosen based on stakeholder interest, public priorities or city/district wide policies, and the design criteria were either artificially imposed or set by the stakeholder. The objective was for the student teams to work through structural, environmental, and economic issues to achieve an optimized solution to the problem.

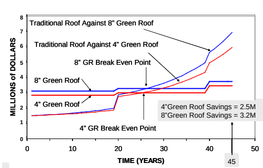
Detailed Project Example: Art & Architecture Building





1. Aerial photograph and load analysis of the current roof of the A&A building (DL, dead load; LL, live load; TL, total load).
2. Designations S1-S4 represent the roof sections considered in the design analysis; hence, section S1 in the aerial photo refers to the top roof section in the load diagram.

Lifecycle Cost Analysis of Two Designs for the Art & Architecture Building



Costs/benefits included:
Benefits: energy, storm-water, air quality, roof replacement
Costs: green roof infrastructure, maintenance, structural reinforcement

1. The energy inflation rate and cost of structural reinforcements are the most significant factors affecting uncertainty of break even times.
2. the net present value analysis indicates that the green roof (reinforcement included) premium investment will be recovered after 25-26 years.
3. The lifetime savings of the green roof (45yrs) in the $2.5-3.2 M range.

Discussion

Student feedback during the three-year pilot has been increasingly positive as to the design challenge and requirements. A formatted response (here, the 2005 AY) is represented in the Table, for a student response of 35 out of 58.

As a department policy, it is argued that no corrective action to the course is required if the combined strong and fair responses total 75%; in this case, exposure to regulatory issues was viewed as being inadequate by the students, and hence, was corrected in 2006.

A more informal debriefing at the end of class indicates that the students appreciate the multi-disciplinary approach and open-ended solutions space, and the opportunity to translate the designs into virtual visualizations.

Course Evaluations vs. Course Objectives (AY 2005)

Course Objective	To what degree has this objective been met?					Total
	Strong	Fair	Weak	None	No Response	
1. To provide an exposure to project design.	31%	43%	20%	3%	3%	100%
2. To provide an exposure to proposal writing and final report preparation.	83%	17%	0%	0%	0%	100%
3. To provide exposure to economic analysis of engineering projects.	40%	51%	9%	0%	0%	100%
4. To provide exposure to regulatory issues.	9%	31%	57%	3%	0%	100%
5. To provide an exposure to engineering ethics and the role of professional code of ethics in decision making.	26%	63%	11%	0%	0%	100%

Conclusion

Lessons Learned

1. Sustainability in building design provides a compelling, exciting and common theme requiring participation of all disciplines.
2. Designing a course for the entire department challenges equal opportunity for students to apply their skills.
3. Value of remedial homework and lectures was mixed; some students take relevant courses concurrently.
4. There is a need for curriculum adjustment with the end-goal in mind.
   What should the content of supporting courses be to take on an integrated design task?

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