A Multidisciplinary Design and Analysis for a Green Roof Installation

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Abstract

A multidisciplinary project is described in this paper that has produced a recommendation for the installation of a green roof on a campus building. A green roof is when plants are grown on top of a roof, which reduces the solar load on the air conditioning system and improves the sustainability of the design. The program within which this was done offers the Bachelors of Science in Engineering (BSE) degree, with five emphasis areas available to the students: mechanical, civil, electrical, industrial, and mechatronics. The emphasis area selected by a student determines certain electives but each student is free to take as many as four engineering electives in different disciplines, allowing multidisciplinary topics and even some elective courses at many levels throughout the curriculum.

The building that this project addressed is one that until recently housed the Engineering Department with a flat roof design: poured concrete slabs supported by concrete beams, covered and sealed with black synthetic rubber membrane. There is roof access by both a stairwell and an elevator, so it would be an ideal building to install a green roof, since educational signage and tours would be easily accommodated. The design work for the green roof planters was done by two mechanical engineering emphasis students who were enrolled in a special topics course. The mechanical aspects of the design included the consideration of thermal and weight loads, specifications of the size, type and price of the planters and irrigation system and an economic analysis of the cost and potential savings. This design relied on structural calculations done by civil engineering students.

To provide these structural calculations, students in one of the civil engineering emphasis electives, Structural Analysis, were given a series of assignments to determine the design loads acting on the building and the distribution of forces caused by those loads. Students in another civil engineering elective, Reinforced Concrete Design, were given assignments throughout the semester to determine the strength of the members of the roof and supporting structure. These assignments and example results are discussed in the paper.

The final design report has been shared with the campus-wide Environmental Stewardship Committee and to the Physical Plant for consideration of the investment. This project is a demonstration of a service-learning effort that includes technical engineering analysis done in service to the university for the cause of environmental sustainability.

Introduction

Recent studies and surveys of practicing engineers have highlighted the increasingly interdisciplinary nature of the engineering world. For today's students to be ready to succeed in the workforce, they will need to be able to participate and eventually lead interdisciplinary teams of engineers. For engineers to work in the realm of environmental sustainability, an interdisciplinary approach is essential to make an effective impact. In addition, environmental

issues are of concern of many students, and students can easily see the need to apply their engineering knowledge to formulate solutions to environmental concerns. This makes environmental topics a good one to model interdisciplinary and engineering solutions in class projects and examples.

This article describes a student project for the design of a green roof for a campus building. The engineering department at the University offers a Bachelors of Science in Engineering (BSE) degree, with several emphasis areas. Two students in the mechanical emphasis enrolled in a special topics course to research and design a green roof. Two different civil emphasis classes also participated in the project by doing supporting calculations. These calculations were done within the class as part of the regular class material.

By combining efforts in an interdisciplinary manner, a final design was proposed. The students got experience working on a real life project on a building that they walk past every day they are on campus. The final report has been shared with the campus-wide Environmental Stewardship Committee and also with the Physical Plant in hopes that the recommendations might be implemented. This paper describes the project in hopes that other engineering faculty might be able to make use of any of these ideas in their own programs to produce engineering students experienced in interdisciplinary engineering efforts.

Design of a Green Roof

A green roof is a planted space on top of a building. They can be used for several different reasons, including growing edible garden crops[1], increasing thermal insulation of buildings, and reducing the "heat island effect" of urban spaces. Key elements of a green roof include the growing media (the dirt), the planters to contain the media, the plants, and an irrigation system. Each of these is dependent on the structure and the climate, and each is dependent on the others: selection of appropriate plants reduces the need for irrigation.

The two mechanical emphasis students had long been interested in environmental sustainability issues and were interested in designing a green roof system that could be implemented on campus. The building that the green roof was being designed for was the Technology Center, more commonly called the Tech Center. It originally housed the Engineering Department, and was one of the first buildings built for campus. When it was constructed, it was intended to have a second story put on top at a later date, so the roof was designed to be a floor to that second story, and there are two flights of stairs and even an elevator that connect to the roof. The second story was never added, and the roof of the building therefore was expected to be sufficient to support the green roof. This expectation was confirmed by the analysis done in the civil electives. The roof of the Tech Center is clearly visible from several other campus buildings, so a green roof would be visible from the new Engineering building and from the upper floors of the Library. This makes it an ideal location from the point of view of visibility and potential tours.

Analysis of Force Distributions

The Structural Analysis class is a fundamental course for the civil engineering emphasis students in our program. In this course students learn to calculate loads on a structure, simplify structural systems into idealized models, and calculate the distribution of forces through those structural systems. The students of this course were involved in this project by a pair of assignments that they were give over the course of the semester.

The first assignment required the structural analysis students to calculate the major loads acting on the Tech Center. Given the blue prints for the building, they were expected to calculate the wind and snow loads expected in this location as well as the dead load of the structure itself. In a subsequent assignment the students were tasked with determining the distribution of forces through the roof system and columns of the Tech Center due to these existing loads. For this task they were allowed to use the structural analysis software package, RISA. Figure 1 shows the force distribution in a typical frame of the building as modelled by one of the structural analysis students.

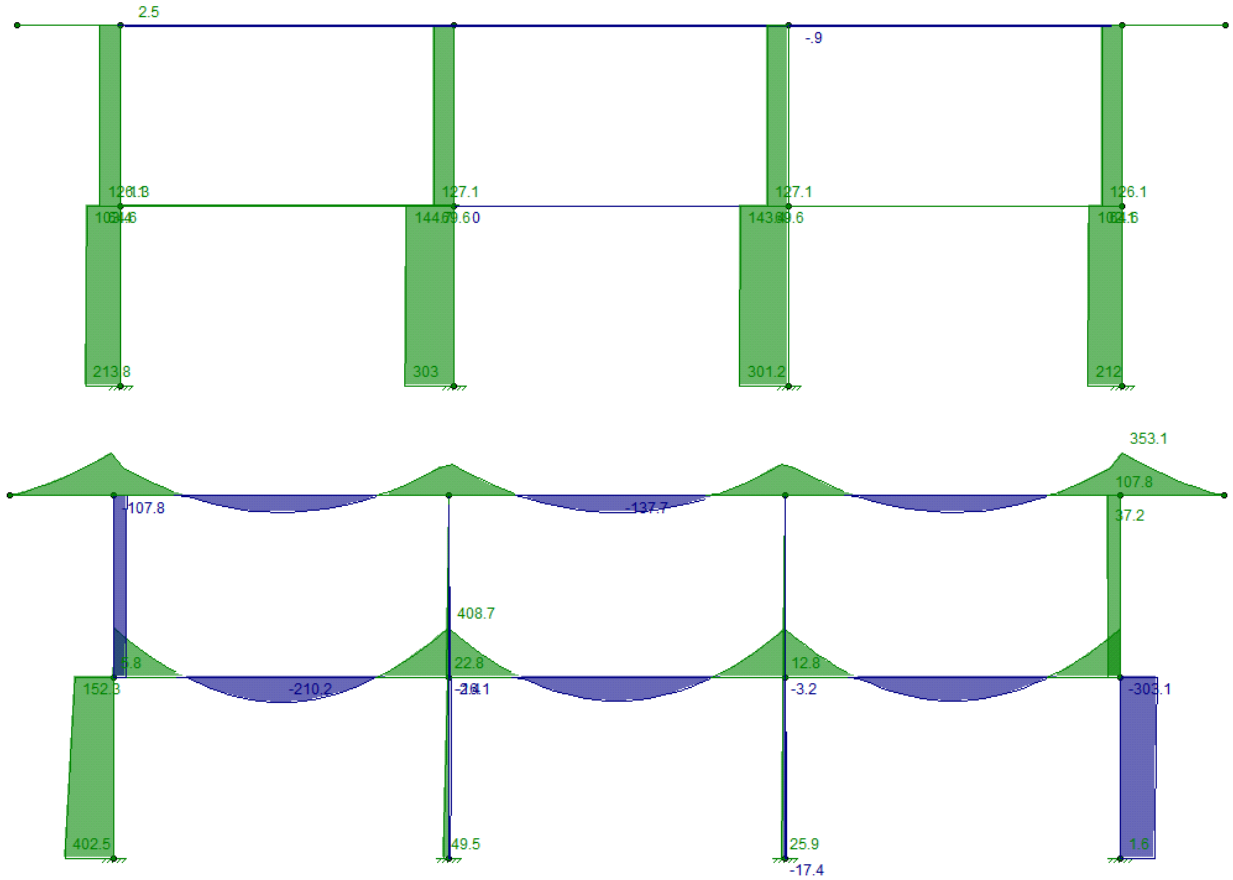

Figure 1. Axial forces (above with values in kips) and moments (below with values in kip-ft) in the typical frame of the Tech Center under existing loads

Compared to previous years, the students of this Structural Analysis course performed much better in subsequent assessments of their abilities to model structural systems and to use the

structural modeling software. This hands-on activity modelling an actual structure on campus seems to have aided in their understanding of structural behavior and motivated their efforts in using the structural analysis software.

Strength of Reinforced Concrete Elements

The Reinforced Concrete Design class is a senior level elective for civil engineering emphasis students in our program. In this course students learn to calculate the capacity of concrete structural elements and to design reinforced concrete structures. The students of this course were involved in the Tech Center project to calculate the capacity of the key elements in the roof system of the structure. This was done through homework assignments and in-class exercises. After making a visit to the Tech Center to see the concrete sections as-built, the Reinforced Concrete Design students seemed excited and motivated by these calculations of the capacity of a real structure.

The results of these analyses was that the roof strength was sufficient to be able to support any of the available commercial green roof designs in the central portion of the roof, even taking the additional water retention and snow events into account.

Research and Analysis

The two students enrolled in the special topics course researched the history and current designs of green roof technology. They identified and discussed a number of examples which varied in range from modular container systems on conventional roof membranes to a local library which was built into an embankment with prairie and other native grasses planted in 16 inches of soil. The total roof area is 17,250 square feet (roughly 1600 m^2), and includes a skylight system in the center, shown in Figure 2. This local example and an example green roof from another public university in our state were included in hopes of impressing the University administration that this is a project worth considering.

Figure 2: Local library roof, with skylight fixture visible.

The students also identified research that has taken place on the savings from green roof installations, including one case study from the shared building of the Cook County offices and Chicago City Hall. Only the City Hall side of the building has a green roof, apparent in the aerial photograph of Figure 3, and the difference in roof temperature between the two sides has been observed to be over 70 ^{o}R (over 40 K temperature difference). An annual cost savings in air conditioning expenses on the green roof part of the building was estimated to be \$40000.[2]


Figure 3: Green roof on the City Hall buliding in Chicago, IL

Their research unearthed an additional cost savings potential in the increased lifetime of the roof membrane. The roof membranes under a green roof planting are not subjected to the UV radiation and their lifespans can be double the lifespan of a typical roof membrane. The roof membrane currently installed in the Tech Center has a few years before the end of its expected life, but has already been patched a number of times. Expectations for changing the roof membrane in the next few years were taken into account in the final design.

Some of the analysis of the roof included making infrared images of the roof on a summer day with an ambient temperature of 94 ^{o}F (34 ^{o}C). Figure 4 shows the image taken of the roof, indicating that the peak temperatures on the roof were almost 160 ^{o}F (71 ^{o}C), and the majority of the roof appeared to be at least 130 ^{o}F (54 ^{o}C). To provide an estimate of what the temperatures of a green roof might be, an image was made of the grass next to the building, and the temperature was observed to be approximately 100 ^{o}F (38 ^{o}C) in the sun, which was only a little above ambient air temperatures.

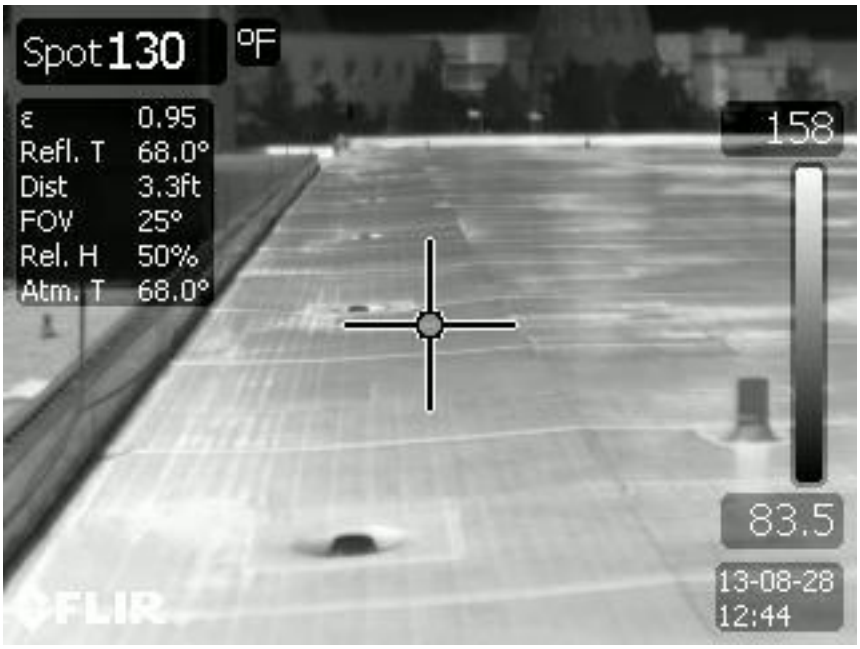

Figure 4: Infrared thermal image of the roof of the building.

The students found that studies that had been done on the suitability of different species of plants were not done in the local climate region, although some had been done close. The recommended rooftop plants from those studies were considered to be a starting point for the species, but the absence of academic work in this area suggested to these students that their green roof design should be an experimental installation.

The students also conducted an economic analysis of the per-square-foot cost of installed green roof systems, which considered the economic savings from energy and also from extended roof life. These calculations featured into their design.

Recommended Design

Based on their findings and the analyses done, the final recommendation by the students was that modular containers be used to install a green roof on the Technology Center. Since total weight was not a concern, this was based primarily on the ease of removal when the roof membrane needed to be replaced. The recommendation included the model of the container as well as the media and some of the plant species to be used. No permanent irrigation system was recommended, since the modular systems can retain sufficient rainwater and in the case of dry conditions, the campus grounds crew already irrigates landscaping around the building and could easily handle irrigating the roof.

The recommendation was also made that 10% of the total roof area be dedicated to experimental plant growth, to contribute to the research on plants compatible with the climate. This could be done with the faculty from the biology department, who already run and maintain greenhouses on campus for instructional and research purposes.

The economic analysis of the green roof installation was based on estimated costs based on other green roof installations and reports that the students could find. The estimated installation cost was between $15 and $20 per square foot, and the average maintenance cost over the lifetime was estimated at $15 per square foot, yielding a total cost of between $30 and $35 per square foot of roof. Savings from the installation of a green roof can be realized by the increased lifespan of the roof membrane, a reduction in roof repair costs and in the decreased energy loss from the roof, especially in hot weather. These potential savings over the entire life span have been estimated at $32 per square foot. This would make the green roof nearly equivalent to the conventional roof, but with a higher up-front investment cost. In the case of the University, donations could be solicited to cover some or all of the initial costs.

Conclusion

A design for a green roof facility on a campus building was completed with partnership between two different engineering emphases: civil and mechanical. This partnership demonstrated to the students that various disciplines of engineering work can work together to develop environmentally conscious engineering work. In addition, the incorporation of a building on campus into the homework and class assignments seemed to have given the students an increased motivation to complete the assignment and a higher interest in the class material than previous years. The final design recommendation for the green roof also included a broadening of the interdisciplinary collaboration to include faculty and students from the Biology department to develop an experimental station to foster further green roof installations in the local area. The green roof project described here was a successful one for the fostering of interdisciplinary activities, and environmental projects are, in general, good ones for this purpose.

Acknowledgments

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