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Building Career-Ready Students through Multidisciplinary Project-Based Learning Opportunities - A Case Study

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One of the primary purposes of an engineering or construction management curriculum is to prepare students to enter the workforce upon graduation, ready to engage in a variety of responsibilities as a part of a multidisciplinary team. The transition from student to professional must occur quickly – often in as little as four-to-five years. Central to this transformation is the student's ability to translate the theories and principles introduced in the classroom into tangible skills appropriate to their particular discipline and work effectively with a variety of people from multiple disciplines. While there are many pedagogical approaches that seek to accomplish this goal, project-based learning explicitly presents students with the opportunity to put theory and principle into immediate use. Such project-based learning opportunities are commonly employed in senior design courses as a culminating experience but are typically held independently within each discrete discipline or department. While this simplifies the administration of the courses, it foregoes the opportunity for multidisciplinary collaboration. Upon graduation and gaining employment, students are likely to find themselves on a project team that integrates people of varied engineering disciplines and educational backgrounds. In recognition of this, the accreditation bodies for engineering, construction management, and interior design programs, the Accreditation Board for Engineering and Technology (ABET), the American Council for Construction Education (ACCE) and the Council for Interior Design Accreditation (CIDA) have all incorporated multidisciplinary work-skills as a required student learning outcome. Specifically, ABET states that students should have "an ability to function on multidisciplinary teams," (Accreditation Board for Engineering and Technology). ACCE requires that students "apply construction management skills as a member of a multidisciplinary team," (American Council for Construction Education) and CIDA requires that "student work demonstrates the ability to effectively collaborate with multiple disciplines in developing design solutions." (Council for Interior Design Accreditation)

In the building design, engineering, and construction environment, the need for such collaboration is particularly significant given the prevalence of design-build and alternative project delivery methods. The Design-Build Institute of America (DBIA) estimates that as of 2013 design-build project delivery market share reached nearly 40% - a 35% increase in market share from 2005. (Reed Construction Data/RSMeans Consulting) In order to prepare students to meet the demands of the engineering, design, and construction profession, it is incumbent upon educators to prepare students to work productively as a part of a multidisciplinary team. In practice, fostering a multidisciplinary learning environment requires significant coordination between the various departments or programs of the parent institution. While some institutions have explicitly developed opportunities for students of various engineering disciplines to work together on projects throughout their educational experience, others remain relatively segregated in their course offerings. In the event that coordinated multidisciplinary course offerings are not available, it is often necessary to look beyond the base curricula to develop opportunities for student collaboration. Externally sponsored student competitions represent a possible source of opportunities for multidisciplinary collaboration, and in the case of the subject institution, such projects laid the foundation for developing curricula that support multidisciplinary efforts within the college. The projects in question were the US Department of Energy Solar Decathlon, and the Sacramento Municipal Utility District Tiny House Competition. Each project leveraged students from multiple disciplines within the campus to successfully design and build energy-efficient, transportable dwellings.

The US Department of Energy Solar Decathlon is a biennial competition in which university students from around the world compete to design and build and operate 600-1000 square-foot homes that that are solar-powered, energy-neutral, attractive, and affordable. The homes are built at the competing universities' campuses then transported to a competition site where they are reassembled, operated, and judged across 10 equally-weighted categories. In order to compete, university teams submit applications to the US Department of Energy (DOE) from which 20 teams are selected for the competition.

During the 2015 cycle, the DOE awarded each team a sum of $50,000 to assist with the design and construction of the homes. Each team was responsible for securing the balance of funds necessary to design, build, transport and operate each home for the duration of the completion. The total construction cost for each home varied from $120,000 to $350,000 as estimated by a panel of DOE judges. (US Department of Energy) The actual cost to participate was significantly higher due to the need to transport each home to the competition site – which for some teams represented a several-thousand-mile round-trip journey – and provide room and board for each person on the team for about a month. Anecdotally, the total amount spent by each team ranged from around $200,000 to $2 million throughout the two-year process.

Participation in the Solar Decathlon 2015 carried several objectives for the subject university. The design-build nature of the project offered opportunities for collaboration between several departments within the university and, notably, the opportunity for students to experience a full project cycle. Furthermore, the project provided the possibility for students to apply the theories and principles from the traditional engineering, design, and construction curricula to a project with tangible results. From an engineering perspective, the home was designed to demonstrate that net-zero-energy could be achieved through the use of passive heating and cooling techniques augmented with currently available technology. Nearly all systems and components were specifically chosen for their availability. (See Appendix A for diagrams of the home) This approach was in contrast to other competing teams that, in many cases, incorporated pre-market-ready components.

In order to address the multiple criteria for success, a team was assembled including undergraduate students from four departments within the university. Construction Management

(CM) students formed the core of the team. The CM students solicited designs from Interior Design students, engineering solutions from Mechanical Engineering students, as well as support from graphic design and public relations students on campus. Some students were able to incorporate the work of the project into their coursework. Others worked on the project in a purely volunteer manner.

Expectations for team unity were not explicitly addressed. As a result, the project progressed as a team of teams. CM students acted as the hub around which the subsidiary teams operated. (See Figure 1) While this approach held certain inherent benefits (the ability for elements of the project to progress in parallel, for example) it also had some negative impacts on the ability of some sub-teams to gain a sense of ownership of the project. In some instances, sub-teams would complete their work and move on to other classes or projects. The communications students, for example, were all members of the Public Relations Society of America student chapter (PRSA), and took on the communications responsibilities for the project as if the broader Solar Decathlon team were a client. Two groups of mechanical engineering students addressed features of the home that contributed to the energy and water balance criteria as a part of their senior design project class. The engineering students frequently operated in relative isolation from the rest of the teams. In doing so, some opportunities for collaboration were missed. Deliverables were passed from the sub-teams to the CM students, reviewed and revised based on comments received during review.

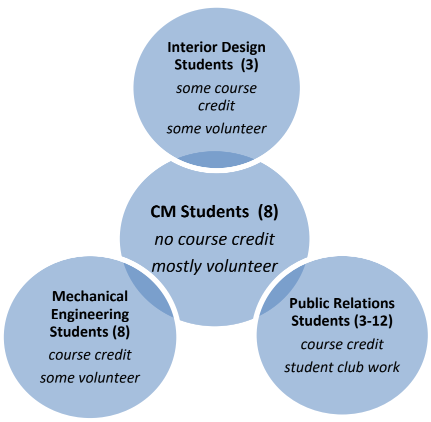


Figure 1 Solar Decathlon Team Structure

The initial design phase was incorporated into a junior-level design class within the Interior Design program. Individual students spent a semester preparing unique designs. Throughout the semester there were two preliminary design reviews and a final design showcase. During the reviews, construction management students and faculty, as well as local industry representatives reviewed each design and provided feedback to the designer with regard to constructability, principles of energy efficiency, and overall aesthetics. Still, the designers worked in relative isolation. Upon completion of the design phase, the CM students took the lead on constructing the building – a process that took about six-months to complete.

The size and scope of the project, and the fact that most students participated in the project in addition to their course load, contributed to the relatively isolated team structure. In order to meet the deadlines for the project, teams often worked in parallel and collaboration became a luxury that time did not always allow. Of further note is the fact that all of the team members were undergraduate students – a condition that gave rise to many student-learning-opportunities but also strained the schedule due to the fact that students were frequently learning basic skills as they were completing tasks from design through construction. The level of effort required to complete the project was considerable. Faculty from three departments spent two years (including summer and winter breaks) shepherding the students through the project deliverables. In the culminating summer, one faculty member spent four months working with the students to build the project during which time the other faculty involved were dedicated to fundraising and materials procurement – a considerable challenge. It should also be noted that of the 20 schools that were invited to compete, only 14 were able to complete a home in time for the competition. In most instances the reasons for withdrawing from the competition were cited as being a lack of financial and human resources. In fact, the faculty and students from the subject institution elected not to compete in the subsequent Solar Decathlon in favor of competing in the Sacramento Municipal Utility District (SMUD) Tiny House Competition – a project smaller in size, but equivalent in scope.

The Tiny House Competition hosted by the Sacramento Municipal Utility District, SMUD, was a net-zero energy solar competition modeled after the department of Energy's Solar Decathlon. Each of the ten competing college teams were required to submit a proposal to build an off-grid solar powered tiny house that was constrained to less than 400 sq ft and a $25,000. The house had to meet electrical and plumbing usage requirements of a two occupant home to simulate routine home life. The competition was judged on several categories; energy balance, livability, and communication. The house had to maintain a comfortable living temperature and be completely functional. The judging of the house was conducted over a four-day period with a final public day where students were to give a tour of the house and stage a twenty foot square lot for visitors to walk through. The public day grossed over 20,000 attendees when a projected 3,000 attendees were expected.

Discipline Project Roles	
Discipline (No. Students)	**Role**
Interior Design (1)	Conceptual Layout, Elevations, Aesthetic Features, Colors, Livability
Construction Management (3)	Construction Documents; Bill of Materials, Construction Plans. Build Site Preparation; Tool Storage, Site Power,
Mechanical Engineering (6)	Building Energy Calculations; Thermal, Controls, Plumbing
Civil Engineering (4)	Structural Calculations; Shear, Loading Distribution
Communication (3)	Tours, Presentation Materials, Display Materials

Figure 2 Project Roles, Responsibilities, and Task

The faculty had the objective of preparing career ready students while producing a competition ready home. The scale and scope of the tiny house was much more manageable compared to the larger Solar Decathlon entry. The interdisciplinary teams were organized to work together concurrently. The students would have the benefit of working on the project alongside interior design students, mechanical engineering students, civil engineering students and construction management students. The project discipline roles are shown in Figure 2. One of the ancillary project objectives was to serve as a platform to showcase innovative energy usage ideas and construction methods in order to achieve a competitive advantage over the other teams. In contrast to the Solar Decathlon project, the Tiny House featured some equipment designed and built by students that may be considered pre-market. For example, one group of students was responsible for designing and fabricating a solar-thermal collector utilizing solar-thermal vacuum tubes that provided the heat and hot water for the home.

The project team was structured such that all-inclusive meetings were held throughout the project. Each discipline met each week to distribute tasks and take direction from the faculty advisor for upcoming deliverables. Each week, tasks were delegated to the entire team. The interior designers would frequently work with the mechanical and civil engineers on layout and structural requirements and then meet with the construction management students to begin generating construction documents. Each step of the design process from conceptual to final construction documents was completed with all of the students providing input concurrently.

The design and documentation phase of the project took an entire year before fabricating a custom trailer base. The tiny house construction process was completed in two months with a team of twenty multidisciplinary students and two faculty. The budget for the tiny house was one-tenth that of the Solar Decathlon project, enabling the entire project to be manageable as a student learning opportunity with time for training to execute each task. This allowed faculty time to be dedicated to the learning aspects of the project such as; documentation, construction plans and trade carpentry skills.

Keeping each discipline active at each meeting enabled a concurrent design approach and facilitated discussions based on perspectives from each of the students' respective fields. During the build phase of the project all students worked together on the build site on every aspect of the tiny house from framing, sheeting, insulating, interior and exterior finishes, plumbing and electrical tasks. Each student was able to get hands on experience building a complete house. The student motivation to work on the project increased during the build phase as progress was tangible and very gratifying for students. Providing a dedicated build site and welcoming environment that students wanting to learn trades could come and be taught on a schedule that allowed was a key success factor for a project of smaller scale than the Solar Decathlon. In all aspects, the students from various disciplines worked together in a fully integrated manner (See Fig. 3) as opposed to the somewhat segregated team structure illustrated in Figure 1. Although no specific cost-benefit analyses have been performed with regard to the Tiny House and Solar Decathlon projects, the principle investigators for each project favor the format of the Tiny House competition. The scope of the Tiny House project mirrored that of the Solar Decathlon at a much more manageable scale. The smaller nature of the Tiny House project

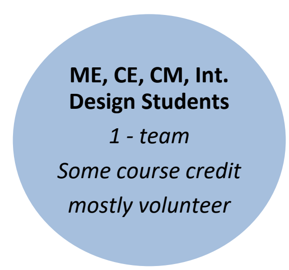


Figure 3 Tiny House Team Structure

allowed for greater collaboration between disciplines and required a fraction of the fundraising and travel logistics presented by the Solar Decathlon – a much easier undertaking for an institution with limited resources to devote to such a project. (Schematics of the Tiny House can be seen in Appendix B)

After reviewing the successes, failures, and lessons learned from both the Solar Decathlon and Tiny House competitions, the researchers have decided to continue to integrate student teams from multiple disciplines in project-based-learning opportunities. Both the Tiny House, and the Solar Decathlon house are now back on the subject university campus. In deciding what to do with the buildings, the researchers, in conjunction with the university administration, have elected to keep the homes on campus indefinitely. The Tiny House will be incorporated into the campus Science and Technology Outdoor Research Center (STORC) where it will be the platform for future student research projects involving energy storage and generation. The Solar Decathlon house is being altogether reconfigured using student-led multi-disciplinary teams.

In order to re-build the Solar Decathlon house on campus, the home will need to be located in keeping with the university's development plan. One of the long-standing needs of the university is a visitor's center for the university arboretum – a three-acre parcel of land on campus with trees and shrubs from around the world. Among the primary challenges in locating the Solar Decathlon house within the arboretum is the absence of any existing utilities to the area, and the fact that there is little-to-no sun exposure for solar generation.

The home was initially designed to be grid-tied and connected to municipal water and sewer services. In order to facilitate its relocation to the arboretum, the university faced the question of how to bring utilities to the site – a process that would likely be very disruptive to the arboretum flora. In response to this challenge, and with the support of the university and outside funding, the researchers have elected to use multi-disciplinary senior-project teams to develop systems that will allow the home to operate completely off-grid. The work will be comprised of three primary project teams each comprised of students from mechanical (ME), electrical (EEE) and civil engineering (CE) as well as CM students – all new to the project as the original students have since graduated. All of the work will be incorporated into their senior-project coursework. One group of students (CM, ME, and EEE) will design and build a remotely-located photovoltaic system that will power the house using battery storage. Another group (CM, CE, and ME) will address the issue of rain-water collection, storage and distribution to the home. This will include a grey-water collection and filtration system in order to reduce overall water demand. A third team will design a composting toilet system. Instead of structuring the teams based around common disciplines as was the

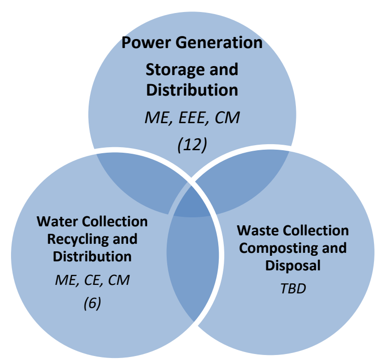


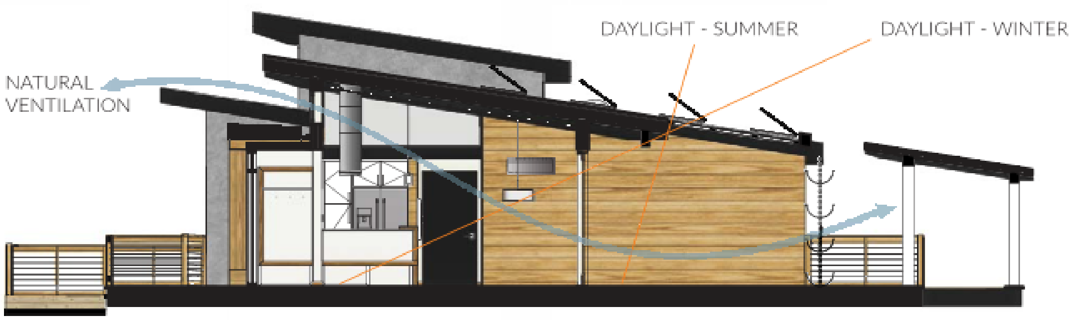
Figure 4 Integrated Team Structure

structure for the initial Solar Decathlon project (see Figure 1), the teams for this work will be structured based on the specific sub-project for which they are responsible (See Figure 4). In this fashion, the teams will still be able to work in parallel to advance the project while also gaining the ability to collaborate across multiple disciplines.

For most engineering students, the design phase represents the only experience they get before entering the workforce. Taking a project from design through construction as was the case with the Solar Decathlon and Tiny House provides an experience that not many graduating college students have. In doing so, students are prepared through a tangible experience that exposes them to various disciplines and trades. In such experiential learning environments, the success and quality of the final outcome of the project isn't necessarily as important as the experience itself. Still, in order to secure future funding, projects must be completed and function as intended. By breaking a project into subtasks and forming multi-disciplinary teams to complete each subtask, the benefits of parallel progress may be realized while fostering a collaborative environment.

Appendix A – Solar Decathlon House Schematics

FLOOR PLAN



EAST/WEST SECTION

Appendix B – Tiny House Schematics

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