

Board 38: Experiential Learning Opportunities through Collaborative Projects

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Gareth Figgess is a professor of Construction Management at California State University, Sacramento. He teaches a range of courses including construction surveying and layout, soils and foundations, and construction graphics and visualization. Professor Figgess' professional background is predominantly infrastructure and heavy-civil related, but since joining the faculty at CSU Sacramento in 2013, he has pursued several research opportunities in sustainability and net-zero energy building design. Professor Figgess was the lead faculty advisor for the CSU Sacramento entry into the US Department of Energy Solar Decathlon 2015 and played a supporting role in the 2016 SMUD Tiny House Competition. Figgess holds a BS in Construction Management and an MBA. His research interests include sustainability, water conservation, and renewable energy, as well as methods of teaching and learning.

Experiential Learning Opportunities through Collaborative Projects

In 2014, California State University Sacramento entered the SMUD 2016 Tiny House Competition. Sponsored by the local utility district, the competition was modeled after the US Department of Energy's Solar Decathlon [1]. Participating teams were required to design and build fully functional tiny houses that were evaluated across multiple criteria including energy use, innovation, and aesthetics. California State University Sacramento successfully completed the project and placed 5th overall. The Tiny House is now used as a research platform for engineering, construction management, and computer science students at California State University Sacramento. Among its many features are a home automation system which enables users to monitor and control all of the homes features. In order to give an occupant a real-time full energy profile of the house, data (including temperature profile, the energy required to maintain an indoor climate (heating & cooling), water flow rate, water temperature, light monitoring and control, and overall power consumption) is collected and displayed. The system is designed to promote energy-saving behaviors among occupants by providing instant user-feedback with regard to energy use and cost. For example, the house features a full kitchen and bath that can display how much energy and water is used. In 2017, two faculty members towed the home to Denver Colorado where it was on display at the state's capital, Coors field, and science museum to promote the upcoming US Department of Energy Solar Decathlon 2017. Fifteen thousand event attendees toured the tiny house during the exhibition. The experience, student engagement, and feedback on the behavioral energy automation system are discussed.

Project based learning (PBL) incorporating students into full-scale design build projects such as the 2016 Tiny House competition requires significant contributions of time and interdisciplinary collaboration to accomplish at the college level [2], [3]. A competition with real deadlines, budget constraints and the tangible deliverable of a net zero tiny house made keeping the project on track a necessity for faculty and students to accomplish the milestones along the project timeline [4]. The pedagogical approach involved integrating a real project into engineering and management curriculum to provide context to student's theoretical work. The result was a meaningful experiential learning opportunity. In order to accomplish the project goals, project faculty leads brought together students from the Mechanical Engineering, Construction Management and Interior Design departments. This approach allowed students from each department to collaborate as subject-matter experts in their respective areas. Design and construction decisions were discussed as a group in consultation with students and faculty within each discipline. Students in each department gained the perspective of the collaborators within the other technical fields. The final outcome was an interdisciplinary learning opportunity that resulted in the construction of a fully functional net-zero-energy tiny house.

The outcome of the experience was a fully functional tiny house that was taken to competition and then later used as a research platform and a promotional tool for the department of energy. Students learned construction techniques and building from specified plans that they participated in creating. Students experienced every aspect of home construction along with installing solar and converting DC power to AC. Many students have never had the opportunity to see how a solar panel or system are integrated into a home electrical system in practice. Student success

was measured based on direct feedback from students throughout the build as well as comments received after the project completion including student reports of successful job-interviews citing their involvement in the project. Further technical measures included evaluation of the energy performance characteristics of the home as well as trailering and towing dynamics. The methods of assessment were student feedback from interviews, competition judges' and general spectator feedback.

The Competition

In 2014 the Sacramento Municipal Utility District solicited proposals from collegiate teams to compete to design and build net zero energy tiny houses. Ten teams from northern California were selected. Teams then had two years to design, build, test and display their tiny homes. The competition culminated with four days of juried events, metered contests and public tours designed to evaluate the performance the homes in all aspects of daily living. The criteria requirements of the competition are summarized in TABLE 1. The homes were instrumented such that energy data, including production and consumption, could be monitored as each team simulated functions in the home related to energy and home life. The event was very well attended. Organizers had anticipated 3,000 attendees during the public day but over 20,000 attendees ultimately came to tour all ten of the faculty/student built tiny houses. As a part of the competition, each team prepared a 15 min tour to explain the features of their home and discuss the project with visitors.

TABLE 1. Guidelines were as follows Sacramento Utility District Competition Criteria [5]:

Architecture	Home must include a minimum living area, make use of space efficiently, provide detailed build plans, built on a trailer, comfortable living space and functionality for two occupants.
Energy	Home must be net-zero in energy during competition, lighting must reach 800 lumens, thermal comfort with ventilation, ten gallons of hot water for a shower twice a day, boil water in under five minutes, freeze a half pound of water, and charge small electrical devices.
Home life	A home-cooked meal was to be prepared in the house, capture all grey water to reuse, waste management system to be sustainable.
Communications	Provide 15 min tour of the home, website to promote the home, blueprints, signage around the home, document carbon footprint, video of the home 10 minutes long for promotional purposes.

Student Engagement, Design & Construction Methods

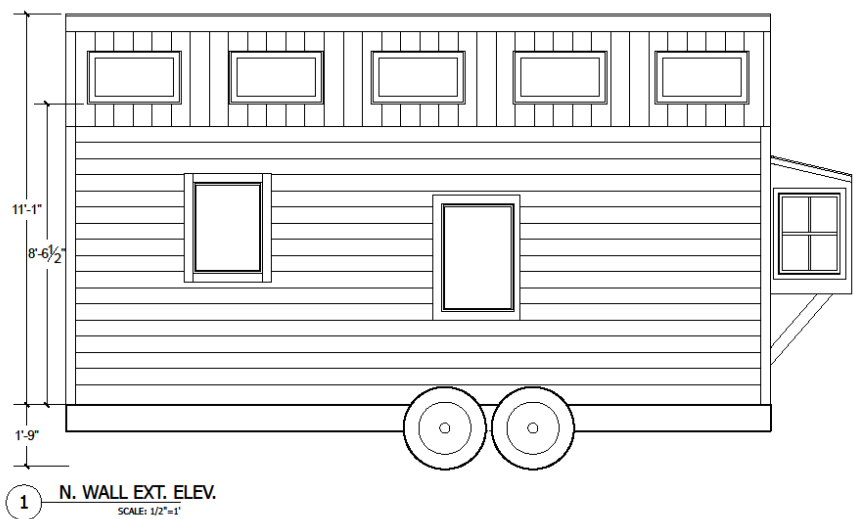
The project was divided into a design phase that lasted a year-and-a-half and a build phase that occurred over the course of five months. During the design phase a team of roughly 27 students met weekly to devise solutions to the various design challenges. The team consisted of ten civil engineering, one interior design student, fifteen mechanical engineering, and two construction management students. The work was divided amongst the students in a variety of ways. Some students worked in a purely volunteer capacity while others were able to incorporate portions of the project into their senior design class for course credit. For example, the exterior envelope of the home and the solar hot water heater were both designed and built by students in a senior design class. A few of the other subsystems of the house, such as the vacuum tube solar water heater and the thermal envelope were designed and built with two five-person mechanical engineering senior project teams. Of the remaining students, most were volunteers looking to learn more about tiny house design and construction.

In order to facilitate the design process, students used two primary computer aided design and drafting (CADD) programs. The overall architectural intent and interior design was communicated using Google Sketchup. Then the structural framing of the house was designed using Solidworks. Throughout the process, mechanical engineering students worked very closely with the interior design student lead. The student roles of the project were very well defined in that the interior design lead had full creative control of the architectural design while the mechanical and engineering students provided the engineering to bring the architectural design to physical existence. Construction Management students performed the material quantity take offs and developed final construction drawings that enabled the project to progress from design to reality.

An early design decision was made to construct the tiny house with standard building materials commonly used in the home-building industry. While better performing energy-efficient wall assemblies, HVAC systems, and building methods were available, the cost of such was significantly more than the project budget allowed for and, in some cases, would have required additional training time for the students [6]. Using standard construction techniques lessened the time required to teach students the basic principles of carpentry. Furthermore, selecting readily available “off-the-shelf” (OTS) equipment and fixtures reduced both cost and lead-time thereby ensuring timely completion of the project. While such decisions had a positive impact on factors such as budget and schedule, there were significant trade-offs. The use of common building materials and OTS equipment in favor of materials and equipment specifically designed for trailering resulted in a significantly heavier structure than anticipated. While just within [STATE] Department of Transportation (DOT) limits, the trailering dynamics were unstable at speed. Furthermore, the strategy of using DOT size and weight restrictions as baseline design criteria neglected to account for other practical trailering considerations. The height limit for a trailer in California is thirteen-and-a-half feet, however most fueling stations are not able to accommodate this max height (most were 12'). Additionally, the added height significantly added to trailer sway when pulled in a traditional bumper-tow configuration [7].

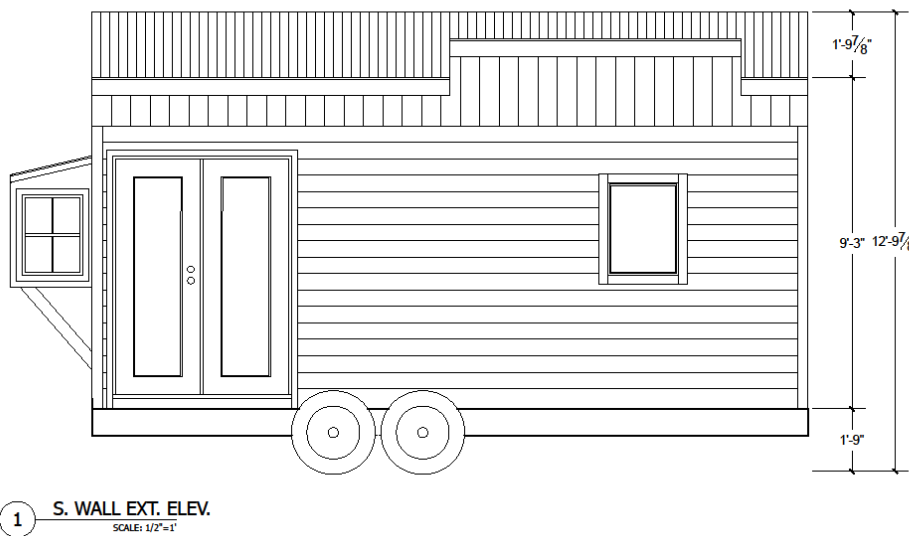
The submitted competition architectural layout and exterior elevations of the design are shown in FIGURES 1-4. The initial design was for a 7,000 lb gross vehicle weight. After completing the

project it neared 10,000lb requiring the addition of a third 3500lb capacity axle before transporting it.



TINY HOUSE	
CSUS TEAM SOL VESPIDE (SOLAR HORNET)	
TEAM: ADVISOR: RUSTIN VOGT STUDENT POSITIONS: ENGINEER: JOSE INGLEZ DESIGNER: MICHELLE FEARBY LIGHTING ENGINEER: DEVIN SWENICK CONSTRUCTION MANAGER: THOMAS JOHNSTON PROGRAM MANAGER: ISAAC SANCHEZ PLUMBING: MATT CURTIS	
SCALE: N/A	
SHEET SIZE: 11X17	
SHEET #	
A-200	
SHEET TITLE: NORTH WALL EXTERIOR ELEVATION	

Figure 1 North wall elevation view.



TINY HOUSE	
CSUS TEAM SOL VESPIDE (SOLAR HORNET)	
TEAM: ADVISOR: RUSTIN VOGT STUDENT POSITIONS: ENGINEER: JOSE INGLEZ DESIGNER: MICHELLE FEARBY LIGHTING ENGINEER: DEVIN SWENICK CONSTRUCTION MANAGER: THOMAS JOHNSTON PROGRAM MANAGER: ISAAC SANCHEZ PLUMBING: MATT CURTIS	
SCALE: 1/2"=1'	
SHEET SIZE: 11X17	
SHEET #	
A-202	
SHEET TITLE: SOUTH WALL EXTERIOR ELEVATION	

Figure 2 South wall elevation view.

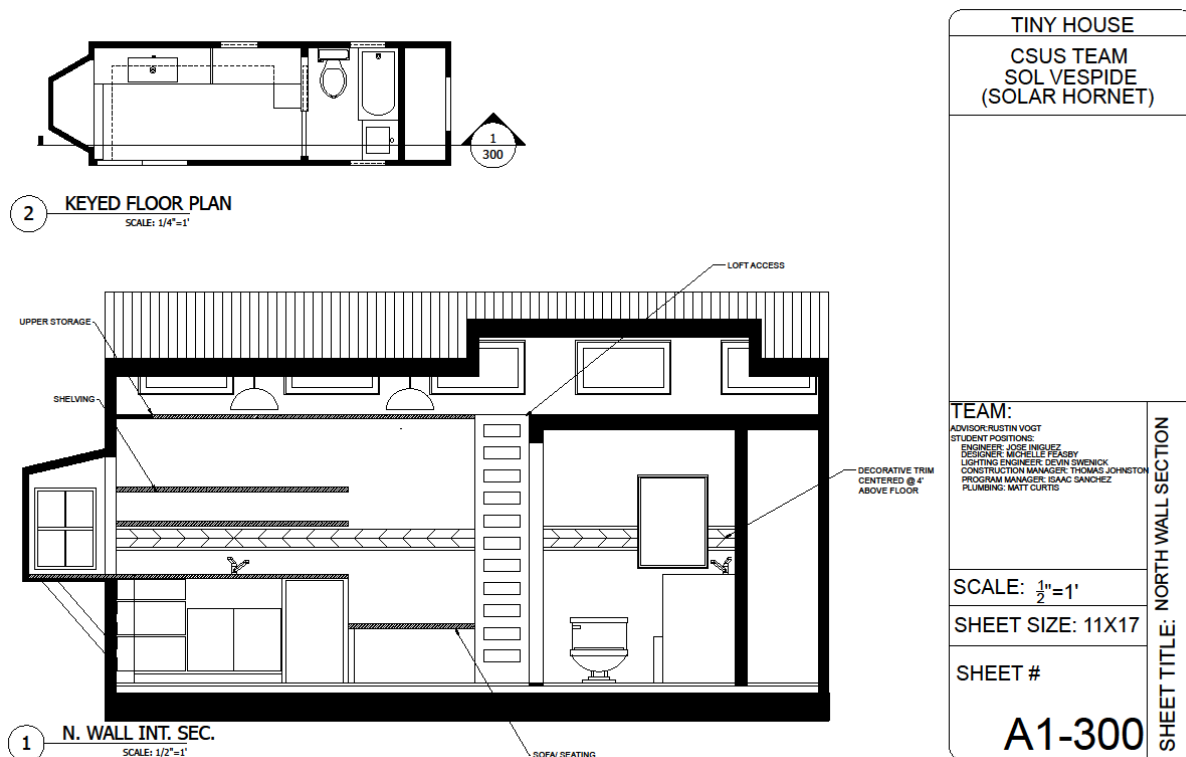


Figure 3 Floor plan and interior sectional view.

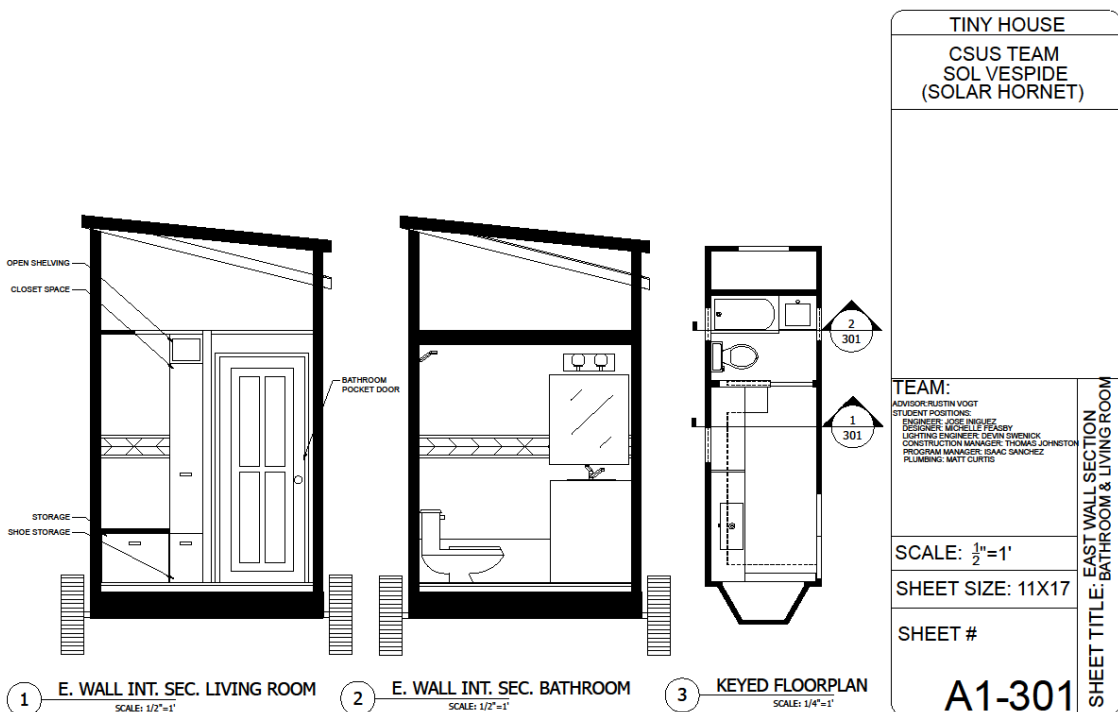


Figure 4. East wall elevation views and floorplan.

Build Phase

The finished house specifications are shown in TABLE 2. The trailer was built in the mechanical engineering lab where students learned to weld for the first time and assemble axle components and trailer brakes. The decision to manufacture our own trailer was made to save cost but ultimately took one month of available build time and only saved roughly \$1000 (about 4% of the total budget).

After the design was completed, Construction Management students performed material quantity take offs and taught the civil and mechanical engineering students how to frame the wall roof assemblies. The structure was built in an empty lot on campus that only had power. No outside trades were hired to do any of the work. The entire project was built by two faculty and a very devoted team of students. Successful completion of the project not only required significant resources and knowledge of all associated trades, (metal fabrication, framing, electrical, plumbing, and carpentry) but also a substantial time commitment from all those involved.

The faculty managing the project logged over 1000 hours to complete the project over the course of 1.5 years. Student attendance to meetings from the initial project kickoff through the end of the competition was very high. This was attributed to constant communication and engagement. The faculty lead, took the responsibility of coordinating the effort. An email was sent multiple times a week with project information including: meeting times, location, goals for that week, and also what skills the students will learn. During the design phase this was mainly teaching modeling software skills and basic residential construction principles. The build phase of the project included weekly emails of the tools the students would be trained to use and what aspects needed to be built. The communication step was one of the key responses from students at the end of the project that kept them engaged in the project from beginning to end. Strong communication and direction was needed daily.

TABLE 2 Tiny House Specifications:

Location	Sacramento State (38.5816° N, 121.4944° W)
Area	184 sq. ft (including 40 sq ft. loft)
Trailer materials	Steel 2x6" rectangular tube trailer 10,500 lb capacity triple 3500 lb capacity axles with electric brakes.
Wall Construction	2x4" wood studs 16" center and ½" sheeting
Wall Insulation	Fiberglass batten
Roof Construction	2x4" wood 24" on center ½" sheeting
Floor Construction	2x4" wood 24" on center 7/8" sheeting
Glazing	Jelwen Dual pane
Siding	Pine shiplap 7 ¼"
Heating	Solar Hot water system vacuum tube collectors (### Btu)
PV System	8 Bosch 240 watt panels, 36V, 3500KW inverter,
Battery Bank	8 Deep cycle lead acid batteries in series
Cooling System	GE 6,000 Btu wall unit with Infrared control
Construction Materials Cost	\$25,068.18

The premise of building net-zero is to reduce the carbon foot print and energy consumption [8]. Current building practices have evolved by implementing more energy-efficient sub systems and construction methods, but little is done to modify how energy is used in daily functions. Most residential homes are not equipped with an energy/resource-use feedback system that clearly shows how resource consumption for daily tasks [9], [10]. Actual measured electricity use, water consumption, water temperature, heating and cooling loads, interior climate (temperature, humidity) are key factors that, when communicated effectively to occupants, could influence human behavior. It was the research goal to be able to display information on how much energy was used (kWh) tied to a dollar value so a residential occupant can for example instantly see how much a typical function like a shower costs or the effects of keeping an interior climate warmer or colder relative to ambient temperature and the energy impact that decision. The automation system is shown in FIGURE 5. It was designed to be very simplistic and use basic electrical engineering hobby kits to highlight the fact that anyone with a modicum of technical capabilities could put together their own system inexpensively.

The features of the automation system measure temperature in real time of exterior walls, interior, solar panel temp, water temp, and roof shingle temp the give an overall temperature profile of the home. Humidity and CO2 are also monitored as high humidity could lead to issues of mold [11]. Lighting inside the house is the Philips Hue wireless system that is controlled via a raspberry pi touch screen. Communication is handled through a wireless router. One key aspect of tour feedback was water consumption tracking. Typically the only metric for water usage is emptying the hot water tank during normal use. In most scenarios a home occupant isn't aware of the gallons per minute a typical shower consumes.

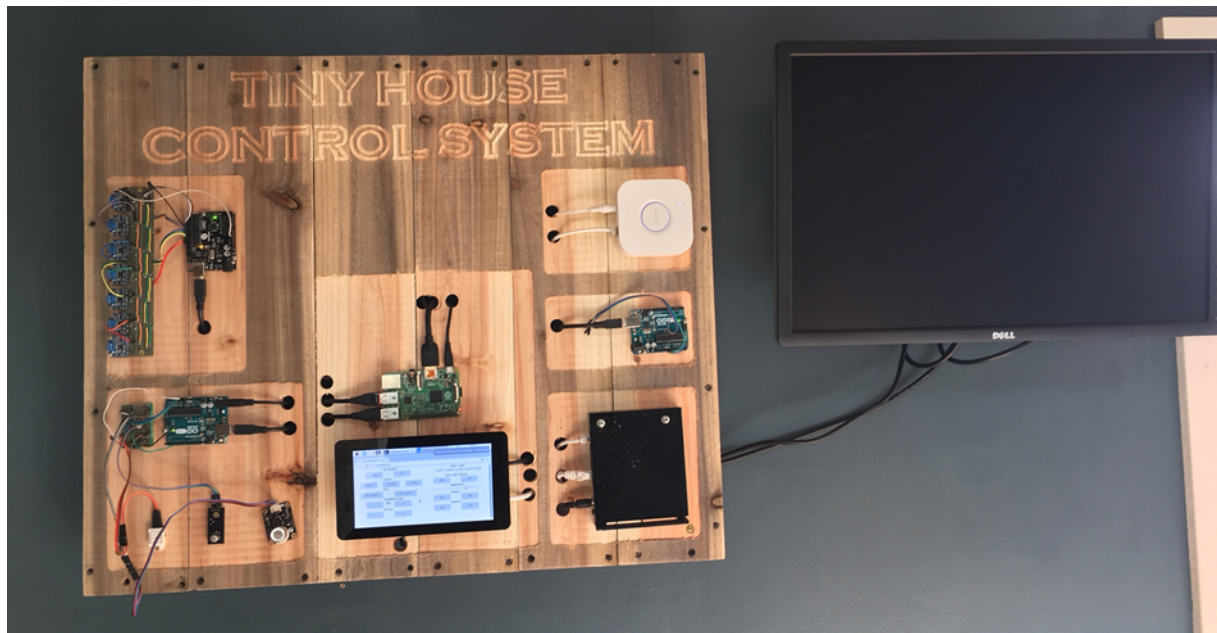


Figure 5. Tiny House Control and Automation System.

One month before the department of energy's Solar Decathlon 2017, the tiny house was towed from Sacramento CA to Denver Colorado. The purpose of towing the faculty and student built project was to promote the Solar Decathlon event around Denver. The house was staged at Colorado's Capital in Denver, the science museum and in front of Coors field with signage promoting event details. The home was also an exhibition where the purpose of the control system was to solicit spectator feedback at the solar decathlon event where 15,000 people toured the home over nine days. The response was overwhelming as most spectators weren't aware of their own energy consumption as function daily living tasks. The Solar Decathlon event is geared towards sustainability and energy efficiency and the feedback highlights a niche in human behavior in energy reporting that an in-situ system would dramatically make and impact in individual's carbon footprint [1].



Figure 6. The tiny house setup as an exhibition at the solar decathlon 2017 event in Denver Colorado.

Some of the outcomes of the tiny house project was the success that the team had after graduation as a result of the project indicated by the employers and experience when they hired the graduates. Namely, the lead mechanical designer and interior designer of the project began careers in aerospace and at a large architectural firm.



Figure 7. The tiny house staged in front of the Capital Building in Denver Colorado to promote the 2017 Department of Energy Solar Decathlon. It was estimated that over 100,000 people observed the house in this location the two weeks that it was parked here.

Interest in tiny homes is very high and initial engagement stems from a curiosity. Managing a team requires continually taking each task of the project, giving it context, meaning, a deadline and a very specific action item that students can work on was instrumental in being able to accomplish an overwhelming project. The time commitment required for faculty is significant. The lead faculty had to be present for all aspects of the project. Teaching students how to positively work through challenges was another take away from the project. This requires being in the computer lab working on the design with the students giving feedback. One of the largest components of time required preparing for a specific activity. Build days required preparing the site with tools and raw material to complete what needed to be done that day. During the build timeline of 3 months, this required 7 days a week 8-10 hours a day being on site and present.

A significant take away was that if a faculty member was present working on a task it motivated the students to engage. Providing opportunities for engagement included having a task for the day such as building decking for the entrance of the home. Showing a team of students the design, the raw materials, and then instructing them to use the tools/equipment enable them to figure out what needed to be done. Specific tasks during the design phase and build phase with boundaries for students to work in allowed for many learning opportunities for example; design process would have specific dimensional constraints and defined what the variables were the students could design to while always focusing on the function of what the design needed to address.

A communication structure is needed to ensure instruction to the project teams were very specific and had a structure of needed to be accomplished that day. There were daily emails of build times, locations and tasks that were to be completed that day. Also what was listed was the tools and learning opportunities available.

Future recommendations would be to build the tiny house on a goose neck or 5th wheel trailer for towing purposes. Tiny homes have a significant amount of weight and for the best transport and towing characteristics, a trailer that assists with issues of trailer sway make for a safer towing experience especially if the 10,000 lb Department of Transportation weight limit is being reached with a regular hitch towing and class A license. In a university setting using the home for STEM and research makes logical sense to continue to disseminate construction methods, energy usages etc.

References

1. US Department of Energy Solar Decathlon 2015 <https://www.solardecathlon.gov/2015/>
2. G. Figgess."Building Career-Ready Students through Multidisciplinary Project-Based Learning Opportunities – A Case Study". *ASEE Annual Conference & Exposition 2017*
3. B. Sharma, B. Steward, S.K. Ong, F.E. Miguez. "Evaluation of teaching approach and student learning in a multidisciplinary sustainable engineering course". *Journal of Cleaner Production* 142 (2017) 4032-4040
4. W. Wua, B.Hyattb. "Experiential and project-based learning in BIM for sustainable living with tiny solar houses". *Procedia Engineering* 145 (2016) 579-586.
5. Sacramento Municiple Utility District "Judging Criteria" www.smud.org
6. N. Mazhar, F. Arain, "Leveraging on Work Integrated Learning to Enhance Sustainable Design Practices in the Construction Industry" *Procedia Engineering* 118 (2015) 434 – 441.
7. <https://drivinglaws.aaa.com/category/us-motor-laws/california/>
8. S. Lynne, "Nowhere to Go But Lots to Love in a Tiny House" *The State Journal ; Charleston* Vol. 32, Iss. 16, (Apr 15-Apr 21, 2016): 29.
9. G. Woodz, M. Newborough. "Influencing user behaviour with energy information display systems for intelligent homes". *International Journal of Energy Research* 31 (2007) 56-78.
10. M. Hightower, "Energy Meets Water". *Mechanical Engineering* July 2011
11. D. Popa, "Study Concerning the Excessive Humidity on the Walls of a Residential Building and the Healthy Impact". *Journal Of Environmental Protection And Ecology*, 2016, Vol.17(4), pp.1345-1350