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Jump into STEM: A Case Study in Student Research

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Jump into STEM is a Department of Energy Challenge for undergraduate and graduate college students. The challenge focuses on innovate technologies for energy resources for the future. Similar to the Solar Decathlon, there are opportunities for construction students to participate in a national level competition while providing opportunities for a variety of research pathways. The Challenge encourages a diverse team, allowing students to find research funding through existing programs at the university through non-traditional sources like the Louis Stokes Alliance for Minority Participation program. Applicable coursework and pedagogy are discussed. Students applied a variety of construction skills during the project. Examples of research frameworks and an overview of how the project was completed are provided. The case study is a success story in interdisciplinary research across multiple education levels where the construction program does not have a graduate student program.

Key words: Undergraduate Research Funding, Jump into STEM, Louis Stokes Alliance for Minority Participation, Interdisciplinary Construction Student Research

Introduction and Literature Review

Students from within the Oklahoma State University Construction Engineering Technology undergraduate and Civil Engineering graduate programs were recruited to participate in the Department of Energy (DOE) (DOE 2020) Jump into STEM Challenge (2022). The challenge is not funded during the student research phase. However, the winning teams receive a 10-week paid summer internship at the National Renewable Energy Laboratory, the Oak Ridge National Laboratory, or the Pacific Northwest National Laboratory (Jump into STEM 2022).

As this project is unfunded during the research phase, some of the students were performing this research in conjunction with non-traditional funding sources. One such source is the Oklahoma Louis Stokes Alliance for Minority Participation (LSAMP) Program which services which is a consortium of universities within the state and supports minority students interested in research. The LSAMP program is funded through the NSF but does not require a specific STEM research area for the students (NSF 2022), so interdisciplinary or multi-disciplinary research can be supported. Unfunded research projects and competitions are frequently seen in undergraduate education for students who are motivated for extra-curricular work. The CET program is a regular participant in the Associated Schools of Construction regional estimating competition. Similar programs are found nationwide including the American Society of Civil Engineers Concrete Canoe competition or the Solar

Decathlon (Schuster et al. 2006). Group participation projects align with an active learning pedagogy (Pantoya et al. 2013).

The CET degree at Oklahoma State University include requirements for engineering economics and technical writing. Engineering economics included benefit- cost analysis, as do other courses in the degree program. However, for a technologist or a graduate of an engineering technology program, it more likely to be focused on broad based problem solving, versus problem definition and solutions (Floyd 2019). The English Department, and its technical writing faculty, understand the need for identifying a problem and presenting research, which is supported by research (Hepworth 2009). Undergraduates seek literature as part of research projects, frequently through library services. Providing seminars about library services has been found to increase student knowledge of materials outside of the traditional books and periodicals (Hallman and Chang 2020). Information Literacy (IL) describes the ability to find, understand and communicate information. While IL has been focused on the library in the past with online resources, IL now includes the ability to find, understand and communicate information found through the computer (Pinto et al. 2022). However, students may still find a literature review difficult due to the amount and availability of information and sources (Pinto et al. 2022).

Problem-based learning (PBL), an active learning pedagogy, requires the student to create a problem statement which can be difficult for a student (Schaub et al. 1999 and Pantoya et al. 2013). The fishbone diagram can be utilized to help students relate cause and effect to develop the cause of an unsolved problem (Priyadi and Suyanto 2019). Construction students frequently favor an active learning approach over traditional lectures (Abraham 2020) or an online learning environment (Kirkmann and Mosier 2022). An active learning approach aligns with the use of internships in Construction Management majors (Siddiqi and Ozcan 2004 and Moore and Plugge 2008). Internships can provide summer pay and are also considered to be a stepping-stone into long-term construction employment and higher starting salaries (Siddiqi and Ozcan 2004).

This case study includes discussion of three issues which were overcome. Unfunded students who do not need a research project for graduation may lack motivation to complete difficult projects (Schuster and Birdsong 2006). An additional concern with undergraduate students, is the need for longevity in a project (Schuster and Birdsong 2006). A third, unexpected issue was having students self-motivate for research during an ever-changing response to Covid (Pinto et al. 2022). The case study also describes the work product of the research teams and the final result.

Background

The "Jump into STEM" challenge is a student-centered research program supported by the Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) with annual topics under the Buildings Energy Efficiency Frontiers & Innovation Technologies (BENEFIT) – 2020 funding opportunity. In 2020, these topics were 1) Building Technology Research, Development and Field Validation and 2) Advanced Building Construction. Under Topic 2, Advanced Building Construction, subtopics were Advanced Building Construction. Under this subtopic was "Advanced Robotics, Tools, and Methods for Retrofits," which was chosen by the student team as an area of interest. The DOE additionally required, as written (2020):

> *All applications to Advanced Robotics, Tools, and Methods for Retrofits should define the "next best alternative" technology or practice (e.g. the baseline or state of the art) and describe how their solution significantly improves over this baseline in terms of cost reductions, invasiveness, installation time, and installation safety. Applications must address and quantify the following:*
> *• Energy savings, affordability, demand flexibility, and occupant comfort*

- *Description of the manner and extent by which their approach advances the state of the art*
- *Relevant metrics (links provided)*

The Construction Engineering Technology (CET) program at Oklahoma State University has been an undergraduate program only since its inception. The program began a partnership with the School of Civil Engineering in 2015 to support of graduate students in the construction research area. Previously the CET program only had access to undergraduate students for research. CET faculty relied on the LSAMP (NSF 2022) for minority students seeking financial support as research scholars. With the new partnership, graduate students seeking research opportunities in construction have been funded via teaching or research assistantships, as is traditional for many universities.

When considering that the CET faculty were teaching focused until 2014, there is not an established research program. New faculty are expected to create their own research program where there was no existing research funding. Likewise, there is not a graduate degree offered in CET which means that undergraduate students are much more available. These challenges to create a research program are not insurmountable but have been identified at other universities (Schuster and Birdsong 2006).

The Challenge

The challenge identified by the DOE, Advanced Building Construction Methods required,

> "…*an innovative solution incorporating substantial changes in building materials or construction methods, leading to benefits such as increased productivity and worker safety though reduced construction time, reduced cost and was, improvements to occupant comfort and health, and reduced energy use."* (Jump into STEM 2020)

The DOE "Jump into STEM" (JUMP) challenge is open to teams of 2-4 students. Although all of the team must be current students, there is not a limitation to their major or degree level. JUMP does take into factor the diversity of the team as well as the challenge submission (Jump into STEM 2022). Our student-researchers represented a variety of ethnicities, genders, nationalities, and majors, both undergraduate and graduate students. Two teams of four students worked on the Jump into STEM challenge, one team in 2020-21 and another in 2021-22. The 2020-21 team was made up of two undergraduate CET students, an undergraduate Mechanical Engineering student and one civil engineering doctoral student. They were funded by LSAMP stipends and Research or Teaching Assistantship salary respectively. The 2021-22 team was made up of two undergraduate CET students, a civil engineering master's student and civil engineering doctoral student. The undergraduate students on this team were not funded through any mechanism, while the graduate students received Research or Teaching Assistantship salary. An overview of the demographics is provided in Table 1. *Note the doctoral student participated in both years.

Table 1

Demographics of Student Researchers

Major	Degree	Ethnicity	Gender	Funded
CET - 4	Baccalaureate - 5	Asian - 1	Female - 1	Yes – 5
Civil Eng. - 2	Master -1	Hispanic - 3	Male - 6	No - 2
Mech. Eng. -1	Doctoral -1*	White - 3		

A proposed research methodology flow was created which consisting of four phases: Phase 1: Dimension Development, Phase 2: Multi-Criteria Decision Making, Phase 3: Life Cycle Cost Analysis, and Phase 4: Benefit-Cost Analysis (BCA) (see figure 1). Phase 1 Dimension Development included identifying Key Performance Index (KPI) dimensions (including economic), construction, technology, social/environmental, energy, and mechanical criteria as identified in the fishbone diagram. Phase 2 Multi-Criteria Decision Making (MCDM) included Choosing by Advantages (CBA), which was conducted to determine the best option by comparing alternatives. CBA weights options based on importance and can support collaborative group-based decision making (Kpamma et al. 2016). Phase 3 Life Cycle Cost Analysis (LCCA) was conducted for financial analysis. Phase 4 Incremental Modeling, a BCA technique, was performed to evaluate and to provide a graphical representation of the more beneficial options among the robotics selected for review.

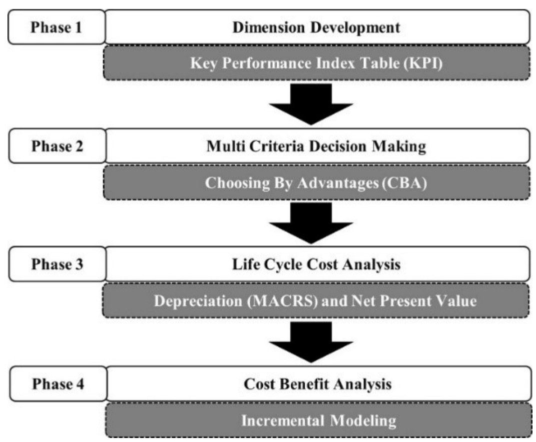

Figure 1. Proposed Research Methodology

In 2020-21, our team responded to the challenge with a submission titled "Sustainability Performance Analysis in Robotics of Construction." During initial meetings to define the problem, the faculty and students created a fishbone diagram (see figure 2). During this time, students identified their own areas of interest for the literature review and a cause-and-effect relationship within the research project (Clary and Wandersee 2010).

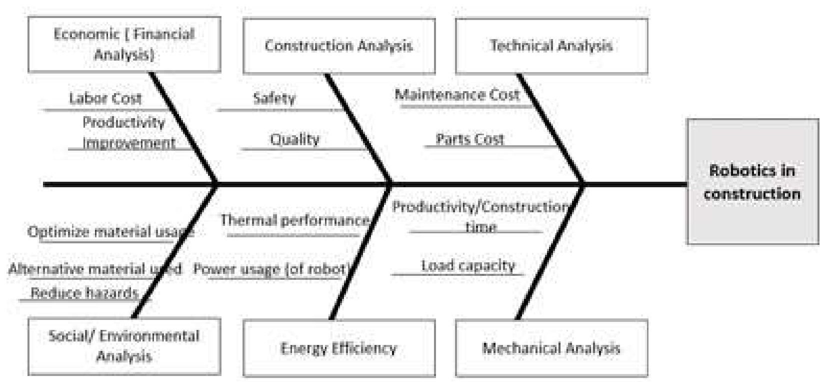

Figure 2. Student Research Fishbone Diagram

The team proposed a comparison of conventional construction methods with the use of robotics in the construction industry, and to evaluate construction impacts, social impacts, environmental impacts, energy impacts utilizing a life cycle cost analysis based on the leading robotics in the construction industry. Using the relationships identified in the fishbone, the students developed the following research statement; “as artificial intelligence and advanced robotics have pushed to the forefront of the world's attention; many companies have made great strides in applying more robotics in the construction industry.” Based on their initial literature review, the student team selected three emerging technologies from available construction robotics: rebar tying robot (TyBot), a GPS skid steer (GPS3), and a 3D concrete printer (3DCP) to evaluate the sustainability performance in robotics in construction based on a variety of robotic types and categories.

One of the student research findings from the BCA was although TyBot had the highest costs, better benefits were predicted for the sustainability performance. Based on the MCDM, productivity was identified as the most important Key Performance Index (KPI). Based on our analysis, TyBot was rated better not only in productivity, but also in the durability and technical dimension, while having the lowest environmental impact. Meanwhile, the comparison between the GPS3 and 3DCP indicated the GPS3 was more beneficial based on the BCA. The selection of the construction robots was determined using an innovative “sustainability performance analysis” approach, utilizing construction schedules and budgets to minimize project cost while satisfying long-term performance goals of the project. Additionally, the proposed sustainability performance analysis was not limited to the robotics in construction. The “sustainability performance analysis” approach can be applied to any emerging technology for evaluation. The emerging technologies, which included robotics, will not only increase production, but also increase efficiency, quality, and safety, reduce waste, aid in quick-response scenarios, and create a platform for even greater future growth of robotics and innovation in the construction industry.

In 2021-22, our team responded to the challenge with a submission titled “R3ER (Resilient, Equitable, Environmental, Energy efficiency, Rapid) Shelter Design.” One student returned to the research team with requisite knowledge and interest in the project. The second research team expanded on the knowledge of emerging technology robotics from the previous year. The research design methodology is presented as a schematic diagram with emphases in Construction, Design, Energy and Case Study (see figure 3).

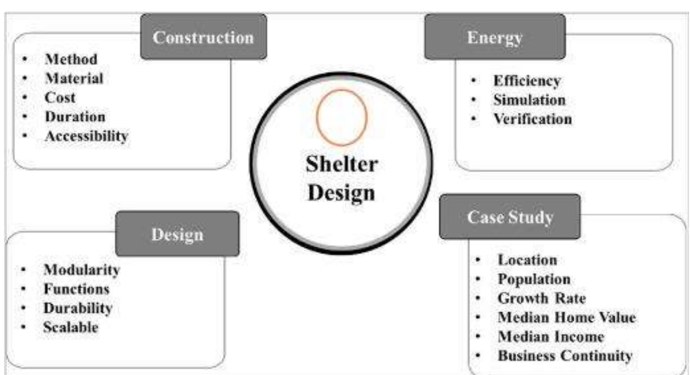

Figure 3. Schematic diagram for Shelter Design

From these overarching emphases, the team extended the research and R3ER Shelter Design to include 1) a 3D printing based construction method, 2) multiple design functions of the shelter design, 3) energy efficiency, and 4) an economic analysis to indicate market readiness, which included a case study. The case study was a holistic real-world scenario for the project to be modeled around and ensure implementation of the four emphases. The R3ER Shelter was designed not only as a disaster resistant shelter but also for multi-purpose uses including a hotel, office, or hospital pre- or post-disaster. Additionally, R3ER Shelter design team analyzed energy efficiency using Energy Plus. The Energy Use Intensity (EUI) is compared with the benchmark EUI approved by ASHRAE Standards Committee. The R3ER Shelter energy consumption is established below the targeted energy, which suggests the energy consumption of the model is below any permissible limit. Accordingly, the proposed shelter design optimized all aspects of building construction, including the structure, enclosure, and energy systems. The R3ER Shelter will provide any future stakeholders such as emergency planning commissions, third party organizations, and construction managers/engineers a resource to maximize both monetary and non-monetary benefits of using the R3ER Shelter. Communities would not only be less exposed to disaster damage or less vulnerable to disaster impacts, but also ensured of the maximum response based on limited resources to serve the largest number of persons affected by a disaster.

Methodology

In 2020-21, the team had different semester schedules and were not on campus due to Covid-19 precautions. The team utilized video conferencing 1) to meet two times per week, which encouraged members to collaborate as a team under the Covid-19 precautions, and 2) to communicate and check each task in detail, while supporting all members in performance of their tasks. The related coursework, i.e. Technical Writing, Engineering Economics, and internship experiences at Oklahoma State University. The collaboration provided a background for comprehensive understanding of the research methods, which included BCA, MCDM and CBA techniques. This diverse team, with their wide range of knowledge, developed the innovative methodology to evaluate the novel sustainability performance analysis" in Robotics of Construction utilizing construction schedules and budgets to minimize project cost while satisfying long-term performance goals of the project.

In 2021-22, there was a change in team membership and Covid-19 precautions changed. The only returning member, a doctoral student, acted as the overall project lead, managing data input, scheduling meetings, designing the shelter structure, designing the research structure, and developing the structure of the report. The graduate students were responsible for the background and methodology, providing a list of major design elements, analysis of the current state of 3D printing, and the energy efficiency analysis. The energy simulation was conducted to determine energy consumption of the R3ER shelter with the help of software Sketchup and Openstudio. A few considerations are set for the simulation such as Large Hotel building type, ANSI/ASHRAE/IES standard 90.1-2010 template, and ASHARE 169-2006-3A climate zone. They performed a whole building energy simulation for the structure of the R3ER Shelter for heating, cooling, ventilation, lighting use in the shelter. Undergraduate student responsibilities included assist in literature review, gathering 3D printer information, shelter designs, and existing statistics to aid the case study. Since most of the team members have a construction background, the case study compliments their existing knowledge while using problem solving techniques in all feasible aspects: construction method, shelter design, energy efficiency, economic analysis, and funding model.

Results

Our team utilized video conferencing 1) to meet twice weekly, to encourage collaboration as a team, 2) to facilitate communication, and 3) check each task in detail, which creates an active learning mode. By explaining results, students are completing a PBL process of writing a problems statement, performing a solution and illustrating mastery of the problem. The schedule and agenda for 2021-22 team meetings are shown in Table 2. Weekly meetings were scheduled with a second optional for questions.

Table 2

Meeting schedule and agenda

Week	Meeting agenda
1	Team member greeting, Positioning
2	Idea development meeting
3	Framework meeting
4	Grad. Student1: Leading the team and idea development Student1 & Student 2: Literature review Grad. Student 2: Studying Energy Efficiency simulation
5	Grad. Student1: Leading the team and idea development Student1 & Student 2: Creating tables based on literature review Grad. Student 2: Finding simulation program for energy efficiency
6	Grad. Student1: Leading the team and idea development Student1: Existing buildings to resist to natural disasters Student2: Current Shelters in the US Grad. Student 2: Studying Energy Efficiency simulation
7	Grad. Student1: Leading the team and conducting shelter design Student1 & Student 2: Create Presentations on options Grad. Student 2: Conducting Open studio for the Energy Efficiency
8	Grad. Student1: Leading the team and creating case study Student 1: Searching for feasible locations for the case study Student2: Searching statistical results for Case Study Location Grad. Student2: Conducting Open studio for the Energy Efficiency
9	Grad. Student1: Creating Table of Contents for the technical report Student1: Presentation for the feasible locations of the case study Student2: Presentation for the statistical results for Case Study Location Grad. Student2: Result presentation for the Energy Efficiency
10	Grad. Student1: Case study presentation and correct the case study Student1 and Student2: Writing literature review Grad. Student2: Writing Energy Efficiency for the case study All: Writing the submission and appendix All: Submission

Based on the students major and career aspirations, only the graduate students submitted applications for internships at the Oak Ridge National Laboratory. The undergraduate students were all seniors and expected to graduate and accept full time employment. None of the undergraduate CET students expressed an interest in a research internship or moving into a research or academic role. The

Mechanical Engineering student had a research interest and continued into a graduate program in Civil Engineering (See table 3).

Table 3

The current status for Jump Into STEM students

Student Major	Status
CIVE, Ph.D. Student	Internship at Oak Ridge National Laboratory
CIVE, Master Student 2021-22	Internship at Oak Ridge National Laboratory
MAE Senior 2020-21 & CIVE Master Student 2021-22	Full Time Employment
CET, Senior 2020-21	Full Time Employment
CET, Senior 2020-21	Full Time Employment
CET, Senior 2021-22	Full Time Employment
CET, Senior 2021-22	Full Time Employment

Conclusions

This was the first time the Oklahoma State University (OSU) CET program competed in the DOE Jump into STEM challenge. The CET program engages graduate students from the School of Civil Engineering, as the CET program is an undergraduate only curriculum. Faculty sought funding sources for the student research activities, which included LSAMP and Assistantships, to encourage continuing participation. The various experiences in learning, internships and team collaborations provided the student team with a comprehensive understanding of the research development. Using a problem-based learning approach, the faculty team was able to encourage undergraduate researchers to participate in the interdisciplinary project. The diversity of team members' comprehensive knowledge and performance, as a result, resulted in the development of the innovation added to the design and functionality of the R3ER Shelter project. An innovative approach to existing analyses, Sustainability Performance Analysis, was created and utilized to determine best options for the proposed shelters.

Although the initial faculty team did not know what to expect and intended for the team to include multiple disciplines and be interdisciplinary, the project changed over time. The initial team started their work in the fall of 2020, which coincided with the large-scale response to the Covid-19 pandemic. Team meetings were held online or with university social distancing requirements. However, the team found motivation to work on the challenge. Using their individual interests, the team identified an interdisciplinary response to the challenge. The following year, the returning team member with new members, used the DOE feedback and refocused the challenge response. In this case, the team were Final Event Winners, with two members accepting the DOE internships.

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