

Involving Construction Students in Research through Collaboration and a National Sustainability Competition

Matthew D. Reyes, MSCM, Lisa M. Holliday, PhD, PE,
and Daniel J. Butko, AIA, NCARB, LEED AP, ASA
University of Oklahoma
Norman, Oklahoma

While it is common for engineering students to be involved in research, construction student involvement in less prevalent. Professors at the University of Oklahoma (OU) used the EPA-P3 Competition as a way to involve students in a multidisciplinary research project. The EPA-P3 Competition is an annual national competition among student research teams to address the three Ps – People, Prosperity, and the Planet. The multi-disciplinary team of students was formed with the purpose of designing, field-testing, constructing, and then monitoring the performance of a house built of compressed earth blocks (CEB) for Cleveland County Habitat for Humanity. The objective of this multi-phase research project is to produce new knowledge and develop best practices for CEB construction. The authors believe compressed earth blocks are inherently sustainable, economical, and energy efficient; they require little energy to produce, conserve natural resources, virtually eliminate landfill waste, and reduce energy consumption required for residential heating and cooling. With appropriate reinforcement, earthen walls have been shown structurally sound even in earthquake prone areas. An earthen design and construction course was created to research CEB resulting in students presenting their analyses and test results at the National Sustainable Design Expo in Washington D.C.

Key Words: Construction Student Research, Compressed Earth Block**,** EPA P3 Competition

Background

There are inherent benefits to exposing undergraduate students to research. Involving students in research initiates a quest for knowledge and exposes students to methods of discovery and dissemination. Exposing students to research also helps to build future researchers; specifically targeting undergraduate students to participate creates a path for more graduate researchers. Engineering disciplines have a long tradition of being heavily involved in research and this research trickles down to undergraduate research. Construction management lacks this long tradition in research and the construction industry is generally not a research-heavy industry. Varma stated that "evidence of undergraduate research in construction programs is limited" (Varma, 2001). Some programs, such as the Del E. Webb School of Construction at Arizona State University have used the Research Experience of Undergraduates (REU) program to bring research to undergraduate students (Peten, 2002).

The faculty at the University of Oklahoma College of Architecture used the P3 competition sponsored by the Environmental Protection Agency (EPA) as a way to introduce construction management students and students from other disciplines to undergraduate research. The "EPA's P3 – People, Prosperity, and the Planet – Program is a unique [student] competition for designing solutions for a sustainable future" (EPA, 2012). Sustainability is an area of research with a need for construction management skills. The students in the EPA-P3 competition explore sustainable solutions and compete for grant money at the National Sustainability Conference. The competition consists of two distinct phases. During the first phase of the competition, teams submit proposals for a $15,000 grant to develop their idea. If awarded, the teams then take their project to the National Sustainable Design Expo in Washington D.C. to compete for the P3 Award and a grant of $90,000 to further develop their project for real world application (EPA, 2012). Sustainability is an important concept in construction management and the EPA-P3 competition provided an opportunity to use sustainability education to solve real world problems. Projects based on the idea of sustainability also lead to an increase in student interest and learning (Bormann, 2012).

The project had two primary goals beyond the content of research related to sustainability. One of those goals was to establish an environment that would foster collaboration across disciplines. The collaboration was accomplished by involving students from multiple divisions within the College of Architecture and the College of Engineering in the earthen design and construction course and the subsequent research project. The other goal was to encourage the involvement of undergraduate students, particularly construction students, in a large scale research project. The mix of students with various backgrounds as well as both graduate and undergraduate students provided an ideal learning environment for the students. The undergraduate students were able to learn about the philosophy and methods of research while being guided by graduate students and professors.

Student Research Project

As a response to the need to involve construction students (particularly undergraduates) in research projects, a multi-disciplinary team of students at the University of Oklahoma was formed with the purpose of designing, field-testing, constructing, and then monitoring the performance of a house built of Compressed Earth Blocks (CEB) for Cleveland County Habitat for Humanity (CCHFH). CCHFH is the local Habitat for Humanity affiliate serving all of Cleveland County, Oklahoma. While the course was available for all OU students, particular effort was made to include students with an interest in experimentation and research as it relates to design, construction, and sustainability. The graduate and undergraduate students were expected to heavily contribute to the production of new knowledge and the development of best practices for the CEB construction process. With the connection to the EPA-P3 competition, the students had a national platform on which to share their research with a wider audience.

CEB are made by mechanically compacting soil with high pressure into forms to create blocks, similar to traditional masonry units. The blocks are then utilized as the main structural system in the house instead of lumber, concrete, or brick masonry. CEB are inherently sustainable, economical, and energy efficient; they require little energy to produce, conserve natural resources, virtually eliminate landfill waste, and reduce energy consumption required for residential heating and cooling. With appropriate reinforcement, earthen walls have been shown to be structurally sound even in earthquake prone areas. Additionally, the CEB construction methods are relatively simple for individuals and social organizations that rely on volunteer labor and other community efforts.

Figure 1: Left – CEB Block Machine Producing Blocks, Right – CEB Production Site

The research team wishes to examine the hypothesis that CEB construction is a better alternative to traditional wood framing by providing stronger walls, more thermally comfortable spaces, and a more environmentally friendly solution for design, construction, occupancy, and maintenance. The team has partnered with CCHFH to build a single-family residence using CEB as both the exterior and interior walls (with the exception of some plumbing walls). Simultaneously, there will be a house constructed of traditional wood framing on the lot immediately adjacent to the CEB house. This wood-framed house will serve as the control house and will be built according to high standards for sustainability as required to meet National Green Building Standards (NGBS). Both houses will be rigorously evaluated by the research team and an outside agency to compare sustainable features and to determine an NGBS score before construction begins. Once construction is complete, both houses will be instrumented and monitored so that evaluations and analyses can be made on structural performance, energy consumption, thermal properties, indoor air quality, and acoustical attributes.

Since the state of Oklahoma does not have a prescriptive earth building code, the building system must be engineered and tested for municipal approval. The students in the class were tasked with investigating multiple aspects of CEB design and construction to provide the data needed to complete the design. The student findings were presented to a licensed engineer for review and recommendations.

Student Findings, Data, and Outcomes

To cover the large area of research for this project, the faculty investigators enlisted students from various colleges and departments across the University of Oklahoma. Two departments within the College of Architecture as well as the Department of Civil Engineering were represented. The Fall 2011 upper division Earthen Design and Construction course consisted of students from the disciplines of Architecture, Construction Science, Civil Engineering, Environmental Engineering, Geotechnical Engineering, and Structural Engineering. The documentation and construction of the CEB CCHFH residence will be conducted by a select group of students from the course and other student and community volunteers.

The diversity among classmates ensured students approached problems from various viewpoints and continuously examined different methods of problem solving. Each topic was integral to the whole of the design and construction process and many topics were dependent or interrelated with one or more other topics which necessitated a large degree of collaboration among the students, often across disciplines. The topics of research were just as varied as students' interests including the following:

- Kyle, a civil engineering graduate student, tested how CEB walls resist in-plane shear.
- Travis, a civil engineering graduate student, tested how CEB walls resist out-of-plane shear.
- Paul, a civil engineering graduate student, calculated and checked the structural system for gravity loads.
- Katy, a civil engineering undergraduate student, calculated building code prescribed wind and seismic loads.
- Jesse, a civil engineering graduate student, teamed with Lang, a construction management student, to study soil and slurry mix designs and interior plasters.
- Estefania, a civil engineering graduate student, developed a device for field-testing strength of CEB.
- Aaron and Hervé, architecture undergraduate students, worked together on architectural drawings and details.
- Benja, an environmental engineering undergraduate student, studied carbon footprint and material sustainability.
- Molly, a construction science undergraduate student, created an energy model that compares the control house to the CEB house.
- Adam, a construction science undergraduate student, created a cost estimate based on local subcontractors.
- Matt, a construction science graduate student, studied the logistics and schedule of block production.
- Mitch, a construction science graduate student, researched mechanical, electrical, and plumbing coordination.
- Ryan, a construction science undergraduate student, determined the anticipated achievable points for NGBS certification.
- Peter, a civil engineering undergraduate student, studied CEB wall assembly moisture control and drainage.
- Tim, a construction science graduate student, coordinated data collection and testing requirements.

While working independently and collaboratively, students were encouraged to go outside their academic comfort zones and think critically about their classmates' research. This ultimately led to a better comprehension of project goals and a richer understanding of the current body of knowledge. Selected student work is summarized as follows.

Sustainability Data, Energy Studies, and Carbon Footprint Analysis

Using the energy-modeling program E-10 V1.8, Molly modeled both the existing low energy control house and the CEB house design. Using the data provided, the software created a model to project overall energy consumption, average hourly heating and cooling use, annual energy costs, and annual carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxide (NOx) emissions. The model predicted that the CEB house will use less energy and result in fewer emissions. Earthen walls are more thermally stable than conventionally framed walls, regardless of heating and cooling system efficiency.

The energy model estimated emissions for SO_2, NOx, and CO_2 based on the amount of electricity and natural gas consumed. SO_2 and NOx are both components of acid rain and CO_2 emissions trap heat in the earth's atmosphere. Emission levels of all three compounds were estimated to significantly lower for the proposed CEB house.

The control house was also projected to use more energy than the proposed CEB house. For annual energy use, the CEB house will use 36% less energy to heat and 34% less energy to cool than the control house. Overall, there will be a reduction of 28% in energy use, demonstrating the inherent energy saving properties of CEB and reduction in homeowner's energy consumption and costs.

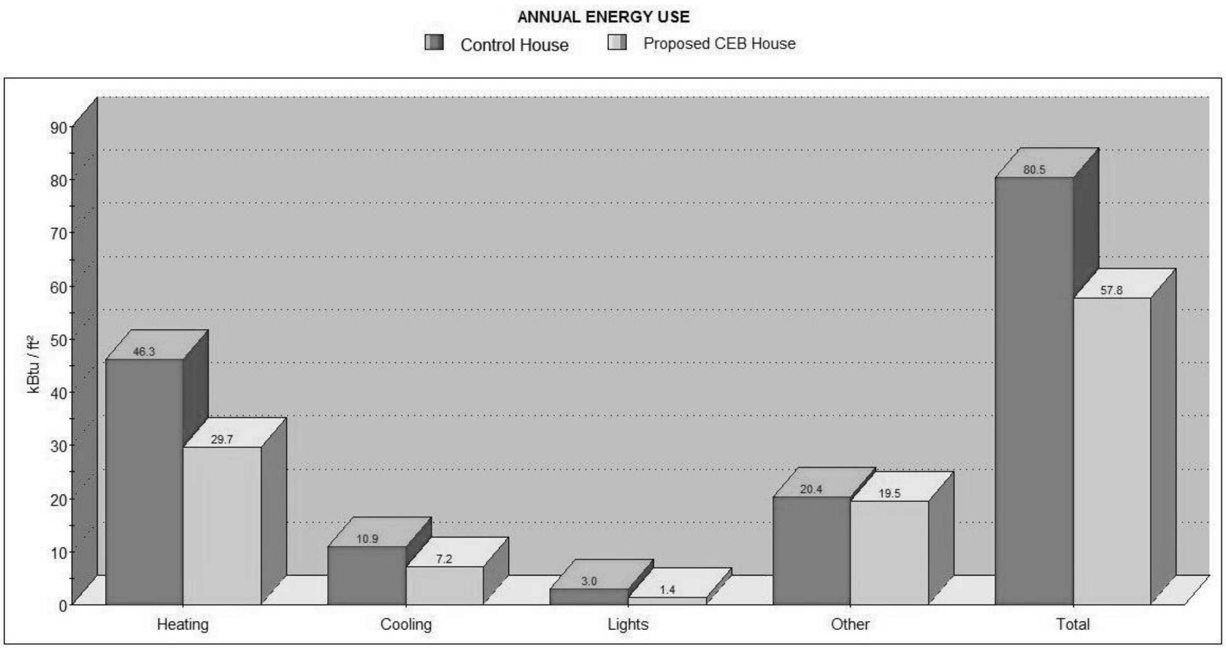

Figure 2: Model comparing energy use of CEB house to a traditionally wood framed house

To begin an understanding of the sustainable features inherent to CEB construction, Benja studied the carbon footprint of the material selections. The student team tested various soil additives, commonly referred to as stabilizers, to create CEB capable of structural capacity similar to conventional masonry units and uniform stability when exposed to moisture. Each additive is borne of an industrial process that releases heat and debris into the atmosphere. Stabilizers can be lime, portland cement, cement kiln dust (CKD), or fly ash. Benja helped find an additive that stabilized the soil mix and had a minimal carbon footprint. While CKD is an industrial byproduct and produced good results, it is only available in truckload quantities and therefore was not a viable stabilizer during the initial materials testing phase. After comparing the different attributes of various stabilizers, the team decided to use portland cement for this project because it produced the most dependable results and is only being used in small amounts, minimizing the environmental impact. Further research will provide more options for stabilizers in the future. Through a computer model, Benja found that the CEB house will have a significantly lower carbon footprint than the traditionally framed house

Using a report on a recently completed wood-framed house built by CCHFH as a baseline, Ryan used the National Green Building Standard (NGBS) ANSI ICC 700 to quantify the sustainability of the CEB house and control house.

The point system is based on six criteria: Lot Design, Resource Efficiency, Energy Efficiency, Water Efficiency, Indoor Environmental Quality, and Education. With each criterion, points were assigned based on the performance level of the project that meets the requirements to achieve the Bronze, Silver, Gold, or Emerald status. Combining data from various student research, it was determined that the CEB house will qualify for at least Silver rating.

Construction Cost Estimate and Schedule

After studying sustainability, the students' next big concern was the budget. Having never built anything like this before, the students researched this topic extensively to learn reaction of local subcontractors and to determine feasibility of scheduled CEB production. Students collected bids from local subcontractors (using the CEB house construction documents developed and drawn by students) for comparison to the conventionally framed house. Some costs will be reduced such as less wood framing, exterior sheathing, gypsum board, and insulation. Other costs will be increased such as additional concrete at bond beams, window and door headers, and footings. While more labor and a degree of a learning curve is anticipated during construction, these costs are expected to be offset by and far outweighed by energy savings in the future.

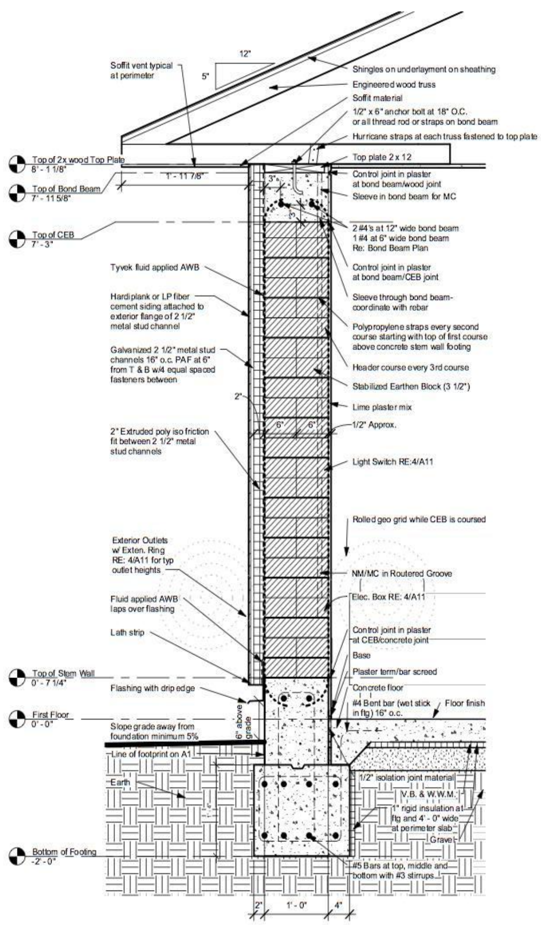

Figure 3: Section of proposed CEB wall

Floor Plans and Details

Aaron and Hervé were tasked with designing the CEB house to match the control house as closely as possible, making all necessary modifications to accommodate the differing wall system. Aside from developing details, they also had to coordinate the footprint and wall locations so that the interior volume of the two houses would match after accounting for different wall thicknesses thus enabling an accurate comparison of the two houses. Much of the information that Aaron and Hervé put into the design was gathered through architectural and structural mockups that were built by the class as a whole.

Mix Designs

Jesse and Lang experimented with mix designs, particularly comparing the performance of CEB manufactured with different stabilizers. The blocks were tested in two ways, using compressive strength and modulus of rupture tests. The CKD and cement stabilized CEB yielded the most promising results. Jesse and Lang made recommendations based on their experimental research and on test results from previous non-affiliated studies on rammed earth buildings. The conclusion was that 6% portland cement by weight was optimal for stabilization, yielding CEB that exceed strength requirements and exhibit resistance to deterioration in water.

The compressive strength test yielded a maximum strength of 1,899 psi and an average strength of 1,291 psi. The modulus of rupture test showed a maximum of 660 psi and an average of 620 psi. These values exceed the design and New Mexico building code strengths criteria.

Structural Testing

In addition to the traditional strength tests performed in at Fears Structural Engineering Laboratory, Estefania developed a field-testing device that measures flexural strength by three-point bending which can be correlated to compressive strength. Her device provides a practical way to perform quality control tests in the field that accurately reflect CEB strength.

In addition to testing the individual blocks for strength, the wall assembly also had to be tested as a system. Kyle and Travis ran two sets of shear tests on walls: in-plane and out-of-plane. These tests were closely monitored by two licensed professional engineers. Wind and earthquake loads as prescribed by the building code applicable to this house were calculated by Katy. Her lateral load calculations were meant to mimic an earthquake or wind event. By following the American Society of Civil Engineers (ASCE) guidelines on lateral loads, she determined that the seismic loads are greater than the wind loads, thus leading design of the walls to meet seismic requirements. Katy's results were referred to during subsequent structural tests.

Walls must have sufficient in-plane strength brace against loads and must also be able to resist loads out-of-plane to ensure that a wall never collapses or tips over. Kyle was tasked with determining whether a CEB wall system had sufficient shear strength to resist these loads. Kyle's results indicated that reinforcement is required to resist lateral loads. Travis tested wall systems to determine if they have sufficient out-of-plane strength to ensure occupant safety. His results showed that a reinforcing system will also be required to resist out-of-plane loads.

Paul analyzed the design for gravity loads and, collectively, the students determined the compressive load capacity of the wall far exceeds the maximum compressive load. The headers were also checked for shear and bending. Finally, the students calculated the foundation design and found that the foundation, specifically the footings, would have to be enlarged for the CEB house due to the additional mass of the walls.

Figure 4: Setting up test walls to determine in-plane shear strength of CEB wall assemblies

MEP Openings and Details

Using a lintel schedule found in the New Mexico Earth Building Code, Mitch determined the appropriate size and length of the lintels. It was decided that he framing for the doors and windows will be done in a similar manner to the traditionally wood-framed home with slight modifications to anchor into the different material. Mitch also studied integration of electrical and plumbing within the CEB walls, determining the CEB walls will require channels for conduit and piping. The electrical outlet and switch boxes for the CEB house will be installed in the same manner with the addition of masonry anchor screws.

Logistics of Block Production

Through observations and trial-and-error efforts, some vital items were identified as critical to the block manufacturing process. Matt identified some key items related to the arrangement of the site, the management of crews, and quality control measures that lead to more efficient CEB production.

An analysis of crew production was also evaluated. Matt worked with the student teams to study the output of different crews and crew sizes and by analyzing the capacity and efficiency of the machines used. The data collected was used to calculate consumption of fuel, stabilizer, and labor on a per CEB basis. This information was used in planning project milestones and also for the CEB house cost estimate.

Benefits of Interdisciplinary Collaboration

All of the engineering students involved in the class are accustomed to working and studying in an atmosphere where research is common. Some of the students had previously been involved in other research projects. However, engineering students rarely take part in the hands-on construction of projects.

Construction students typically have the opposite experience. They are accustomed to an environment where working on projects is common. Many of the students had worked on construction projects either as interns or volunteers or as part of a school activity. However, active involvement in a research project, particularly one that requires the collection of data, is a much less common experience for the construction students.

This class provided benefits for both types of students. The engineering students were able to work on a construction project and the construction students were able to work on research. The engineering students gained knowledge of what it is like to coordinate a construction project as it relates to both people and material. The construction students were exposed to the rigors of research, both theoretical and hands-on testing. Both groups of students gained insight into what the other more commonly does. Beyond just providing exposure to what the other group does, the course gave students essential experience in working with someone from a different part of the project team. All the engineers gained experience in working with constructors on a project and were able to see what they deal with on a daily basis. The construction students were able to work with engineers and gain more of an understanding of the challenges they face in the design phase of a project. Overall, communication across disciplines was essential to the class and to the project, resulting in valuable experiences for all involved.

Figure 5: Students competing at the EPA-P3 Competition

Results

The results of the 22 student multidisciplinary course yielded research results to complete the design, predict performance, and create a cost estimate for construction of the proposed CEB house. Along with this completed design, a proposal was developed that detailed the research results and the plan of action for the future of the project. This proposal was submitted to the EPA as part of Phase II of the competition. Two faculty members accompanied four students from the class on a trip to Washington, D.C. to participate in the P3 Expo competition located on the National Mall in April 2012. The Expo gave the students opportunities to interact with teams from other universities around the nation, EPA personnel, and with the public, explaining the research project and the plans going forward. Upon completion of the three-day expo, the OU CEB research team was selected as one of the few teams awarded Phase II grant in the amount of $90,000 to fund continuation of the research.

Figure 6: Award presented by the EPA to the student team

Outside the content of research effort, the primary goal of this endeavor was to address the lack of involvement in research by construction science students, particularly undergraduate students. The authors demonstrated a successful project in which construction students were involved and effectively collaborated with students from other disciplines. The class allowed students the opportunity to collaborate across disciplines and to take part in research which was a foreign activity to many of them. We believe that interdisciplinary experience orients students for success in their careers where they will have to interact with varied disciplines on a daily basis. The experience certainly proved to prepare the students well for the competition as each student that participated was able to clearly explain the entire process even if it was not their own research topic or even a topic within their discipline. Beyond the competition, the benefits were evident. Undergraduate students that had never previously gone through the rigor of defining a problem, investigating the literature, gathering data, and then analyzing and sharing the results were in the end able to do all of these things in producing effective research. It was through the active engagement in a research project, learning from more experienced peers, that the students were able to realize and achieve success.

References

Bormann, N., et al. (2001). Understanding the system: Sustainability projects increase student interest and learning. *Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition*.

College of Architecture: The University of Oklahoma. (2013). *Compressed earth block*. [WWW document]. URL http://ceb.ou.edu

Environmental Protection Agency. (2012). *P3: People, prosperity and the planet student design competition for sustainability* [WWW document]. URL http://www.epa.gov/P3/

Peten, G., Sawhney, A., & Badger, W. (2002). Overview of summer research program for undergraduate students in construction. *Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition*.

Varma, V. (2001). Undergraduate student research in construction engineering: The current status. *Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition.*