Material Testing as an Opportunity for International Collaboration and Undergraduate Research

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Abstract

This paper considers material testing of African wood species, performed by an engineering school in the U.S. on behalf of an international non-government organization (NGO), as research conducted partially by undergraduate students. The material testing program yielded useful information in itself, but the innovative method of international collaboration provides an example for educational institutions and NGOs of sharing resources for common benefits. Engineering Ministries International Uganda (EMI) provides design and construction management services to Christian charities throughout East Africa. Their structural engineers have been using North American timber standards to estimate the strength of similar African wood species, since little published information on the strength of locally-sourced African woods is available. Through the connection of the lead author's involvement with EMI during a recent sabbatical, EMI sent samples of cypress, eucalyptus, musizi and pine to the U.S. Air Force Academy's (USAFA) Department of Civil & Environmental Engineering for testing. Although the number of wood samples tested was small, the results provided EMI more confidence about the actual strength of these wood species used in East African construction, and are presented in this paper. The project also provided opportunities for undergraduate engineering students at USAFA and an EMI intern from Auburn University to participate in meaningful research. More collaboration is possible as Uganda Martyr's University (UMU) Faculty of the Built Environment considers involving its facilities and undergraduate students in continued testing. The testing results proved valuable to EMI, and the students involved gained experience setting up testing procedures and apparatus, conducting tests, recording data, and analyzing results. This unique approach of connecting North American and African universities, NGOs and undergraduate students required almost no funding and could be adopted by other similar organizations to simultaneously facilitate academic research and provide a valuable service not locally available. Many NGOs operating throughout the developing world would be grateful for such technical assistance. University engineering programs could provide this kind of testing and analysis as an opportunity for meaningful research. The level of complexity in such investigations can be appropriate for undergraduate participation with faculty guidance. Students are often drawn to engineering by a desire to benefit mankind. For example, faculty and undergraduate students at the Colorado School of Mines are helping EMI to evaluate the feasibility of small-scale solar-powered UV water disinfection systems. The authors assert that students are motivated to take part in research that helps people in developing countries improve the quality of their lives.

Introduction

Material science and testing is a fundamental component of undergraduate education for multiple engineering disciplines, including civil and mechanical. As undergraduate engineering students progress through their curricula, they gain the ability and the opportunity to participate in research. Many engineering programs encourage, if not require, a research experience as part of an undergraduate engineering education. Every engineering curriculum includes a culminating event, usually a senior design project. Most curricula include some opportunity for independent or small group research, even if it is only limited to a literature review on a specific topic. Another research opportunity available to most undergraduate engineering students is an independent study course. Research is also an important experience for undergraduate students considering going on to graduate school.

There is a great deal of literature describing the value of undergraduate research, especially for science and engineering students. The National Science Foundation (NSF), The National Institutes of Health (NIH), and the National Aeronautics and Space Administration (NASA), among many other institutions, sponsor research to include undergraduate students. Russell, Hancock and McCullough found that undergraduate research opportunities often increase a student's interest in STEM careers and higher degrees, with 68% saying their interest increased either "somewhat" or "a lot" (Russell, Hancock & McCullough, 2007).

One of the benefits of undergraduate participation in research is improved student retention. Nagda et al found that "faculty-undergraduate research partnerships are most effective in promoting the retention of students at greater risk for college attrition, African American students and students with low GPAs" (Nagda et al, 1998).

Accreditation of engineering programs is another reason to encourage undergraduate research opportunities, especially those with international content. In its criteria for evaluating undergraduate engineering programs for accreditation, ABET includes Criterion 3, Student Outcomes. Undergraduate participation in research directly supports at least three of the eleven outcomes (a-k):

- (b) design and conduct experiments
- (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- (i) engage in life-long learning

Additionally, ABET's Criterion 6, Faculty, states that one of the factors for evaluating faculty competence is "level of scholarship" (ABET, 2017).

In designing research experiences for undergraduates, a challenge is balancing the level of complexity with meaningful and interesting topics. One approach to this dilemma is looking to international projects. Research projects tied to the developing world can not only provide undergraduate students an opportunity to work on projects that are interesting and within the scope of their studies, but also contribute to improving people's lives. As described in the next section, materials testing served as a useful undergraduate research opportunity that answered a need for information in the developing world.

Material Testing – A Collaborative Example

For years, structural engineers with EMI Uganda have been designing timber structures by approximating African wood strength based on known properties of North American timber. Design values for "mixed southern pine" were used to conservatively estimate the strength of pine available in Uganda (AFPA/AWC, 2001 and CWC, 2005). Though a reasonable approach, the EMI engineers never quite knew how close these assumed values were to the actual strength of locally-sourced pine. Additionally, they had even less confidence in other species of wood used for construction in Uganda. While there exists limited information on the strength of these local wood species (Zziwa, Ziraba, & Mwakali, 2010), there were not enough references available to give the engineers great confidence in their assumptions. EMI's desire to increase confidence in material strengths they use for design prompted a collaboration opportunity with a U.S. academic institution for the limited testing of a variety of wood species. Through an academic contact, EMI partnered with a faculty member knowledgeable in materials testing at the U.S. Air Force Academy's (USAFA) Department of Civil and Environmental Engineering who was able to identify an undergraduate student interested in a conducting an independent study. Like most U.S. academic institutions with civil and/or mechanical engineering programs, USAFA has a laboratory that includes frames capable of basic material testing to support their programs, such as a course in construction materials.   Not only was EMI grateful for an opportunity to have some of these species tested at virtually no cost, they were able to avoid the cost of overseas shipping by sending the wood samples along with members travelling back to the U.S. in their luggage.   For USAFA, the cost of using existing equipment was negligible and outweighed by the advantages of a clearly defined and meaningful research project within the capability of an undergraduate engineering student.

Materials Testing Independent Study:

The materials testing independent study developed for this project took place over a single semester. The overall goal of the study was to test Ugandan wood samples in general accordance with ASTM procedures to derive strength values in bending, compression, and direct shear. The collaborators selected four wood species based on their use in Ugandan construction, and because they had been included in a study published in the International Wood Products Journal (Zziwa, Ziraba, & Mwakali, 2010). Testing gave structural engineers using these materials another data point with which to compare the reasonableness of their design assumptions. The four species selected were Caribbean Pine, Eucalyptus, Cypress and Musizi. USAFA received two batches of wood samples from EMI. To facilitate fitting into the luggage of individuals transporting them to the U.S. from Uganda, the size and number of samples were limited to those shown in Figure 1.

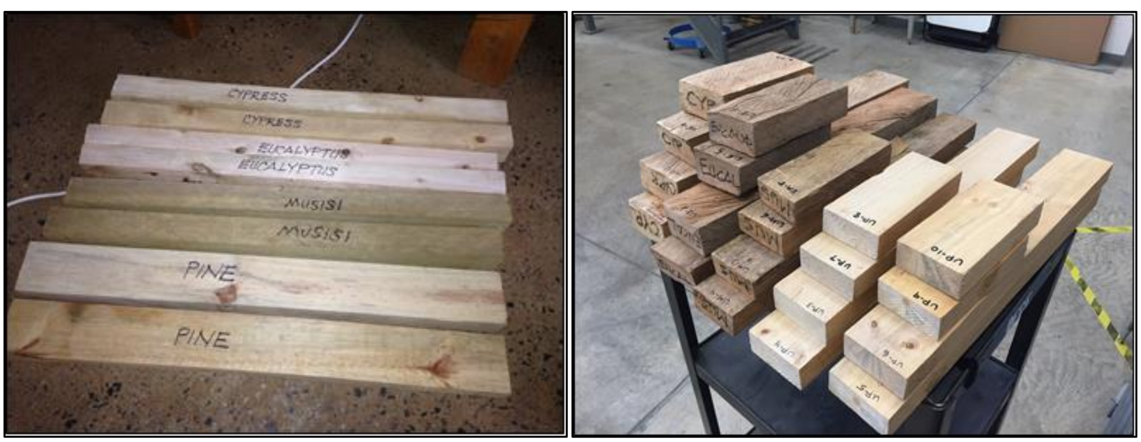


Figure 1: Wood Samples before Harvesting Specimens for Testing.

Specimen preparation and testing was conducted as closely as possible in accordance with ASTM D143 - Standard Test Methods for Small Clear Specimens of Timber (ASTM International, 2009). Three different tests were conducted on specimens prepared from the provided wood samples: Static Bending, Compression Parallel to the Grain, and Shear Parallel to the Grain. The limited number, size, and as-received conditions of the samples prompted deviations from the ASTM, most notably on the sizes of many test specimens. These deviations actually served as a valuable learning opportunity for the undergraduate researcher, as the student had to grapple with the constraints imposed by the available size, condition, and number of samples. In the end, it was decided that strict accordance with the ASTM, particularly in terms of prescribed size and clarity of the specimens, was less important than testing as much of the provided materials as possible. Over the course of the semester, the student tested and reported the results of 8 bending specimens, 74 compression specimens, and 49 shear specimens harvested from the wood samples. This materials testing project provided numerous learning experiences for the student researcher at each step in the process as outlined below.

ASTM Familiarity & Specimen Preparation:

The undergraduate researcher's initial task was to become very familiar with the specifics of the ASTM testing procedures. This included the guidance on prescribed specimen size, orientation during testing, testing configuration and load rate, and harvesting samples immediately after testing for determining moisture content at the time of testing. The student was also tasked with cutting all specimens to the appropriate size as well as developing a cataloguing system that assigned each specimen a unique identifier that could be traced back to its source sample and wood type. Many samples came in a roughhewn condition, requiring the student to become proficient in several pieces of woodworking equipment to plane and cut samples to the appropriate dimensions.

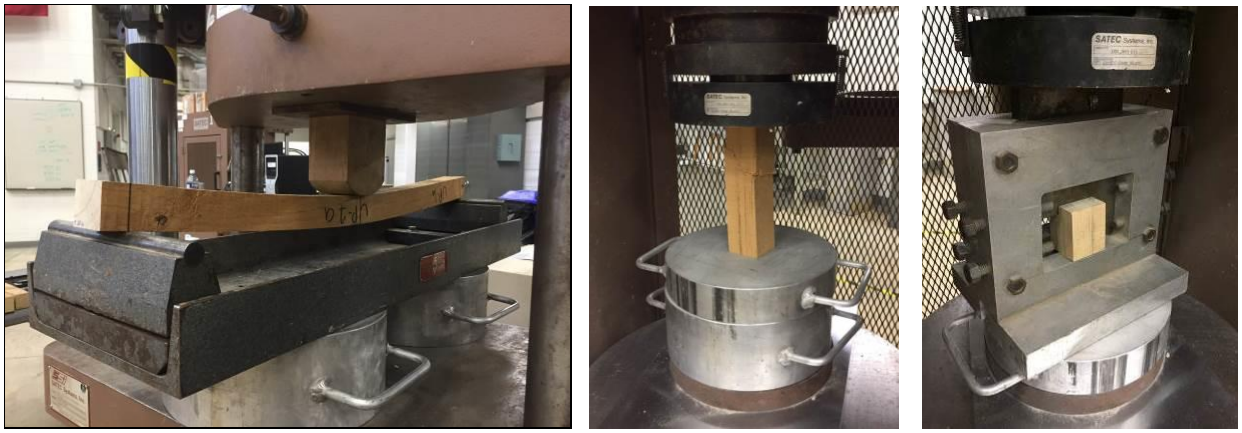
Data Collection:

In preparation for actual testing, the student developed a data collection concept that included both data sheets for recording immediate results as well as various spreadsheets to help automate some of the calculations and would be later used for analysis of key test results. Prior to testing, the student recorded each specimen's cross-sectional dimensions and length, which were used for both peak stress and unit weight calculations. Data collected from each test included peak load, peak stress, stress plots, and for bending and compression the estimated modulus for the initial linear portion of the testing plot. After testing, data was collected to determine moisture content of each sample. Data sheets were used early on, but the student soon realized the efficiencies of using a spreadsheet for a large number of samples, and developed a data collection spreadsheet to facilitate both collection and analysis.

Testing:

Testing was accomplished using existing SATEC/Instron fixed testing machines with capacities well exceeding what was needed for these tests. For the compression parallel to the grain test, which requires the greatest compressive force of all three types of tests in this study, the peak load did not exceed 25,000 pounds, which indicates the testing could have been accomplished on most test frames found at other institutions. Test apparatus, such as the static bending test load head and support platform and the direct shear device, were already available by their use in other courses in the civil engineering curriculum at USAFA. So no new equipment was required for this study. The ASTM provides detailed specifications for these apparatus, facilitating their purchase or fabrication if an institution does not have ready access to them. The instructor developed the testing algorithm in the test frame controller software in accordance with the

ASTM protocol and trained the student how to operate the machine for each of the three types of test as shown in Figure 2.



a) b) c)

Figure 2: Testing Ugandan Wood Samples per ASTM D143: a) Static Bending Test, b) Compression Parallel to the Grain Test, and c) Shear Parallel to the Grain Test.

The student was responsible for running all testing, including collecting the appropriate data from the test in the form of test printouts and conducting immediate post-test activities, such as annotating the failure type, taking photos, and harvesting samples from tested specimens to determine moisture content. Harvesting involved cutting one or more samples from tested specimens near the point of failure immediately after testing, obtaining the “wet” mass and placing them in an oven at the temperature prescribed by the ASTM for the time required to achieve “dry” mass. For this study, the oven used for determining moisture content was found in a soils lab, and it is assumed a similarly-suited oven could be found at institutions with any basic science or engineering labs. After approximately 24 hours the dry mass of the sample was measured, and with the wet mass, used to determine the moisture content at the time of testing. With 8 bending and 74 compression specimens tested, and often more than one moisture sample harvested from each after testing, the student came to appreciate the importance of developing an appropriate cataloguing and data collection process for later analysis.

Data Analysis & Summary:

For each specimen, the test frame controller software prompted input of the specimen dimensions for automated computations of stress, strain, and in some cases, modulus. The student was responsible for understanding the automated computations and checking the test results for reasonableness, particularly the automated estimate of flexural tangent modulus in the static bending tests. For compression parallel to the grain tests, the student manually computed the modulus by selecting two reasonable points of stress and strain representing the initial straight-line portion of the plot. The student input all test data into his data collection spreadsheet for comparison and analysis. In some cases, the student recognized errors/anomalies that required culling certain specimens. To summarize the data, the student averaged key test results across the various samples, such as peak stress, modulus, unit weight, and moisture content, and incorporated them into tables for inclusion in submittals throughout the semester. Unfortunately, the restrictions on transport of test material to the USAFA limited the number of tests that could be performed, meaning that a detailed statistical analysis of the results was not conducted.

Deliverables:

The student researcher was tasked with preparing several deliverables, culminating in a final report at the end of the semester. Upon receipt of each batch of wood, the student prepared a characteristics report that included all as-received wood sample dimensions, initial weights, and photos of all sides of each sample. These deliverables provided a mechanism for feedback on submittal expectations, and more practically, helped in determining how many of each type of specimen could realistically be harvested from the sample given the dimensions and location of flaws. After running each of the three types of tests throughout the semester, the student prepared a test summary report, which included the summarized results tables, and also included photos of each sample before and after testing in addition to the test plots and other relevant data. Each of the previous submittals was incorporated into a final report by the end of the semester, which served as the testing report provided to EMI as the customer.

Test Results:

Tables 1 through 3 present the unit weight and primary strength parameters from this materials testing study for each of the three types of tests conducted on the four species of Ugandan wood. The values reported from this study are also compared with those published by other sources, where available.

Table 1: Static Bending Test Results.

	Tested Values			*Published Values*		
Species	*Unit Weight (lb/ft^3)*	*Flexural Strength (psi)*		*Published Source*	*Unit Weight (lb/ft^3)*	*Flexural Strength (psi)*
Cypress	30.2	6,260		(1)	26.2 to 28.7	6,600 to 10,600
Eucalyptus	37.4	11,399		(2)	25 to 30	10,550
Musizi	33.8	11,747		(3)	25.4	4,047
Pine	31.6	9,575		(3)	23.9	3,902

(1) Forest Products Laboratory, 2010.
(2) Windsorplywood.com, accessed Aug 2016.
(3) Zziwa, Ziraba & Mwakali, 2010.

Table 2: Compression Parallel to the Grain Test Results.

	Tested Values			*Published Values*		
Species	*Unit Weight (lb/ft^3)*	*Compressive Strength (psi)*		*Published Source*	*Unit Weight (lb/ft^3)*	*Compressive Strength (psi)*
Cypress	20.9	4,723		(1)	26.2 to 28.7	3,580 to 6,360
Eucalyptus	31.8	8,473		(2)	25 to 30	5,650
Musizi	23.5	6,566		(3)	25.4	3,907
Pine	21.3	5,099		(3)	23.9	3,819

(1) Forest Products Laboratory, 2010.
(2) Windsorplywood.com, accessed Aug 2016.
(3) Zziwa, Ziraba & Mwakali, 2010.

Table 3: Shear Parallel to the Grain Test Results.

	Tested Values		*Published Values*	
Species	*Shear Strength (psi)*		*Published Source*	*Shear Strength (psi)*
Cypress	1,072		(1)	810 to 1,000
Eucalyptus	946		---	---
Musizi	945		(3)	1,130
Pine	1,051		(3)	1,403

(1) Forest Products Laboratory, 2010.
(3) Zziwa, Ziraba & Mwakali, 2010.

As shown in the tables above, the tested strengths of the wood samples were generally in good agreement with published values, with some tested values exceeding published by a considerable margin. For the static bending tests, only cypress did not exceed the published range of values, though only two beam specimens were tested and each failed near knots that were present within the center third of the members. The compressive strengths of the wood samples were within range or exceeded published values. Though some of the tested shear strengths were below published values, they were in general agreement, especially considering the limitations on the number, size, and clarity of the specimens. The comparison of tested and published values was valuable to the student researcher by instilling confidence in the results in cases where there was reasonable agreement or prompting reflection where there was not agreement.

Typical wood strength values used in structural design are much lower than published clear strength values. Clear strength values typically represent the mean as-tested values of clear specimens (without knots, cracks or other defects), whereas design values are often two standard deviations below the mean to ensure a 95% probability of the wood not failing. To conservatively estimate the strength of pine in Uganda, EMI would typically use design values for "mixed southern pine" from U.S. standards, which are shown in Table 4 below. Though this study did not include enough clear specimens of each species of Ugandan wood to establish a statistical basis for design values, a simple comparison provided greater confidence in using comparable published design values.

Table 4: Reference U.S. Design Values for Mixed Southern Pine (AFPA/AWC, 2001).

NDS Supplement Design Values – Mixed Southern Pine (2" to 4" Wide Size Classification)				
Commercial Grade	*Unit Weight (lb/ft^3)*	*Flexural Strength (psi)*	*Compressive Strength (psi)*	*Shear Strength (psi)*
Select Structural	31.8	2,050	1,800	175
No. 1		1,450	1,650	
No. 2		1,300	1,650	
No. 3 and Stud		750	950	

Supporting ABET Student Outcomes and Program Criteria
In addition to undergraduate research's value to ABET student outcomes mentioned above, this course and testing program directly satisfied many of the ABET student outcomes. In fact, nine of the eleven student outcomes were satisfied through the student's research, lab work, testing, analysis, writing and interaction with the instructor, except (c) "an ability to design a system…" and (d) "an ability to function on multidisciplinary teams" (ABET, 2017).

Even though the student's independent study experience was conducted within a civil engineering curriculum, it also supported the program criteria for materials engineering programs.

- To apply science to computational techniques and engineering principles to materials systems implied by the program modifier, e.g. biomaterials
- To integrate the understanding of the scientific and engineering principles underlying the four major elements of the field: structure, properties, processing, and performance related to material systems appropriate to the field
- To apply and integrate knowledge from each of the above four elements of the field using experimental, computational, and statistical methods to solve materials problems including selection and design consistent with the program educational objectives (ABET, 2017).

Even though educational methods and levels of instructor guidance to students vary among institutions, this example demonstrates that undergraduate international research can support ABET student outcomes and materials engineering program criteria.

Additional Impacts
As a result of the materials testing, EMI structural engineers in Uganda are now able to design for these four wood species with greater confidence. This project also led to a research connection between EMI and Uganda Martyr's University (UMU) Faculty of the Built Environment. UMU has a material testing lab (Figure 3), but would like to expand its capabilities and eventually add an architectural engineering degree to their program. They have offered to test materials for EMI including masonry, giving UMU undergraduates the opportunity to participate in research. EMI has now established other research collaborations with multiple U.S. and Ugandan universities.

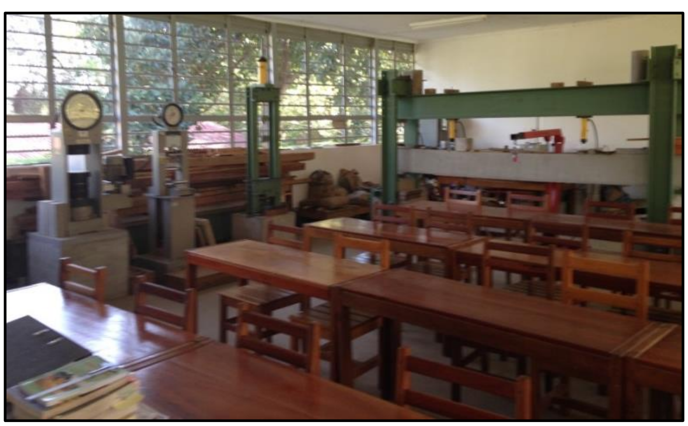


Figure 3: Material Testing Lab at Uganda Martyr's University.

Collaborators and Mutual Benefits

Research as part of an undergraduate curriculum has been advocated as far back as the 1960's. Jenkins and Healy trace the development of undergraduate research from its origins in U.S. practice to a growing international movement. "Undergraduate research has resonated internationally with those who wish to hold on to the Humboldtian ideal of a university where teaching and research are intertwined, but who must adapt that ideal to the realities of a mass higher education system" (Jenkins and Healy, 2010).

Beddoes, Jesiek, and Borrego trace the spread of project based learning (PBL) in engineering programs around the world and as a field for international collaboration. Yet they point out that "international research collaborations on PBL remain scarce" and encourage the global engineering education community to "consider partnering with their international colleagues" (Beddoes, Jesiek, & Borrego, 2010). Altbach and Knight found that developing countries are motivated toward internationalization "to improve the quality and cultural composition of the student body, gain prestige, and earn income" (Altbach & Knight, 2007).

Laboratory facilities in the west, even at the undergraduate level, tend to be much better than those available at most universities in developing countries. Standard lab equipment for an ABET-accredited program in the U.S. is often beyond the reach of many universities in other parts of the world. This creates an opportunity for U.S. universities to involve their undergraduate students in research for NGOs, possibly in cooperation with international universities, using existing facilities at little or no additional cost.

Africa as an Example of Educational Needs in the Developing World

Understanding educational needs in the developing world might best begin with Africa. Its population of over 1.2 billion people is spread throughout more than 50 countries on a continent larger than China, India, the United States and most of Europe combined (Turvill, 2013). The "State of Education in Africa Report 2015" provides an introduction to the challenges of education there with some key facts:

- Africa is the world's most youthful continent with nearly 50 percent of the population under age 15.
- Between 1990 and 2012, the number of children enrolled in primary schools more than doubled, from 62 million to 149 million children (AAI, 2015).

The same document also describes the state of higher education in Africa:

- Between 2000 and 2010, higher education enrollment more than doubled, increasing from 2.3 million to 5.2 million.
- In 2008, about 223,000 students from sub-Saharan Africa were enrolled in higher education outside of their home countries, representing 7.5 percent of the total global number of students who study outside of their home country.
- Private higher education is one of the fastest growing education sectors in Africa. In 2009, there were around 200 public universities and 468 private higher education institutions on the African continent (AAI, 2015).

African universities have an uphill struggle. Starting in an environment that is economically poor and where higher education is only available to a small fraction of the population, they don't enjoy the sort of financial backing from the state, private industry, research grants or alumni giving that are common in the U.S. While labs and other facilities in African universities might be lacking by western standards, one resource they do have is the internet, even if it is only via smart phones (Napoli & Obar, 2014). That connectivity helps enable international collaboration at low cost.

Engineering Needs of NGOs

Non-government Organizations throughout the developing world are involved in a wide range of refugee assistance, disaster recovery, food aid, healthcare, agriculture and development work. Their work on the "front lines" often involves needs such as safe drinking water, medical care, structurally sound buildings, improved roads, power supplies and other infrastructure. While NGOs are directly involved in identifying needs and even funding such projects, they do not always have the necessary engineering expertise to carry out research, design or construction themselves. There is often a gap between a project need and the engineering resources to carry it forward. For example, Engineers Without Borders actively recruits volunteers for its Engineering Service Corps to assist international NGOs with their engineering expertise. Examples of needs recently posted include an energy adviser in Jordan, electrical and mechanical engineers in Kosovo and water resource management in Morocco (EWB USA, 2017). Large NGOs usually have the budget, network and experience to find and hire the engineering support they need. But smaller organizations in the developing world, affiliated with schools, hospitals, training programs or orphanages, may need engineering support less often and don't know where to turn for assistance. Even EMI, with its in-house civil and structural engineers, does not have its own material testing equipment or lab. If engineering schools in the developed world partner with international NGOs and universities they could help meet these needs.

International Collaboration Opportunities for Engineering Programs and their Students

From the point of view of Western universities, these types of research opportunities have multiple benefits. First, they provide opportunities for faculty and students to work on meaningful projects appropriate for undergraduates. Second, these opportunities can be incorporated into project-based learning, senior design projects or independent study projects. Finally, they also provide opportunities to form research partnerships with indigenous universities and their students. Such relationships can lead to faculty sabbaticals, joint grant proposals, recruiting international graduate students, service learning projects for western students, semester exchange programs and more. They also allow U.S. universities to take advantage of unique capabilities of indigenous universities, such as their intimate understanding of local building materials, techniques, practices and culture.

The modest wood materials testing program described above is an example of how these partnerships could be established and function. In this particular case, an NGO in Africa leveraged a contact with an engineering school in the U.S. that led to the opportunity for material testing. The collaboration proved beneficial to both organizations, as testing provided an enriching undergraduate research opportunity at the school and useful results for the NGO. That effort also helped foster a relationship between the NGO and a local university that is developing the laboratory facilities to continue the material testing program that will give research opportunities to African students.

There are important benefits for universities in developing countries as well. Research projects with colleagues in the developed world can also include collaboration with NGOs in the same country or region on areas of mutual interest. There are many topics such as water treatment and sanitation, engineering applications for disaster response, sustainable & low cost housing, etc., needing further work. These sorts of collaborations can result in funding and donated equipment. Even modest contributions to programs in developing countries can go a long way toward improving their capacity for research and have a big impact on program quality.

Research cooperation with western universities can also establish international partnerships between faculty and students working in the same disciplines and on the same topics. Universities in developing countries can benefit from hosting visiting professors, Fulbright scholars and western graduate students. These sorts or collaboration can lead to increased capacity for more students and better educational experiences.

Obviously, NGOs can benefit from universities conducting research on their behalf. International collaboration might better enable such research. Returning to the example of EMI, since the initial wood testing that led to this paper, the EMI Uganda office has expanded its work with universities on undergraduate research projects to include:

- Small-scale solar powered UV water purification with the Colorado School of Mines
- Large-scale sand filter water treatment for disaster response with George Fox University
- Further research collaboration with three Ugandan Universities

Conclusion

What began as a small-scale material test of African wood species for an international NGO led to the realization that there are great opportunities for international research collaborations. These relationships can be mutually beneficial to all parties, most importantly students and the people supported by these NGOs. Many NGOs throughout the world could benefit from even modest engineering assistance. This assistance could be provided by universities in both the developed and developing world, ideally in cooperation with each other. Such cooperative projects do not have to be expensive to have major impacts. The authors hope that the examples provided in this paper will lead to more similar cooperation around the world.

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