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Article

A Model for Sustainable Humanitarian Engineering Projects

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Abstract: The engineering profession should embrace a new mission statement—to contribute to the building of a more sustainable, stable, and equitable world. Recently, engineering students and professionals in the United States have shown strong interest in directly addressing the needs of developing communities worldwide. That interest has taken the form of short-and medium-term international trips through Engineers Without Borders—USA and similar organizations. There are also several instances where this kind of outreach work has been integrated into engineering education at various US institutions such as the University of Colorado at Boulder. This paper addresses the challenges and opportunities associated with balancing two goals in engineering for humanitarian development projects: (i) effective sustainable community development, and (ii) meaningful education of engineers. Guiding principles necessary to meet those two goals are proposed.

Keywords: engineering education; interrelationships between people; resources; environment; and development; hands-on projects; humanitarian development

1. Introduction

At the start of the 21st century, humanity is facing the formidable challenge of securing basic quality of life for all people on our planet. According to the World Bank's Water Supply and Sanitation group [1], and independently reported by the World Health Organization [2], more than 1.1 billion people do not have access to safe water, 2.6 billion lack access to proper sanitation, and 1.6 billion do not have access to electricity. An estimated population growth of 1.5 billion people over the next two decades, 97% of it in developing regions, will exacerbate the already unprecedented demands for energy, food, land, water, transportation, materials, waste disposal, earth moving, public health care, environmental cleanup, telecommunication, and infrastructure [3]. The role of engineers will be critical in fulfilling these demands at various scales, ranging from small remote communities to large urban areas (megacities), mostly in the developing world.

Within the past decade, the growth of humanitarian-based development activities including students and working engineers has risen dramatically in the USA. Engineers Without Borders—USA (EWB-USA), founded by the first author in 2001, has quickly grown to include more than 12,000 professional and student members spread over 250 chapters in the USA and working on close to 400 projects in 47 countries [4]. In addition to extra-curricular service organizations like EWB-USA, several domestic universities have worked, often independently, to integrate service learning, civic engagement, and outreach into their curricula [5-8]. This trend reflects a growing consensus among some engineering faculty, practicing engineers, and university administrators that the current system of engineering education is not adequate to create global *citizen engineers* who have the skills to address complex geopolitical and economic problems. The traditional approach of the past two centuries that engineering and society are distinct does not hold anymore. As clearly emphasized in the proceedings of the 1990 meeting of the National Academy of Engineering on *Engineering as a Social Enterprise*, engineering is "an adaptive socio-technical subsystem functioning within the adaptive socio-technical system of society." Engineering functions inseparably from the society of which it is part of, and engineers need to be trained accordingly [9].

Today, concepts such as sustainable development or engineering for poverty reduction are becoming part of modern engineering education. Initiatives explicitly focused on creating global citizen engineers through international humanitarian engineering projects are already changing the landscape of engineering education and practice. Organizations that have integrated these concepts into academic programs within the USA include the Village Empowerment Program at the University of Massachusetts Lowell [5], the ETHOS Program at the University of Dayton [6], the Humanitarian Engineering Program at the Colorado School of Mines [7], and the Mortenson Center in Engineering for Developing Communities (MC-EDC) at the University of Colorado at Boulder (CU-Boulder), described below. A review of some initiatives in the areas of accreditation, service learning and hands-on experience, awareness building, and curriculum development can be found in a recent paper by Amadei and Sandekian [10].

This paper highlights the authors' experience with various engineering projects implemented by EWB and MC-EDC students at CU-Boulder over the past seven years. It originated after reading a paper entitled "A model for sustainable short-term international medical trips" by Suchdev *et al.* [11] and a paper by Heck *et al.* [12] on medical volunteerism. Both papers present several guiding principles for successful short-term medical trips in developing countries. This paper proposes similar guiding principles that should be applied to short- and medium-term engineering for humanitarian development projects in order to avoid pitfalls associated with expensive but inconsequential trips.

2. Challenges of Voluntary International Development Work

International development has traditionally been conducted by expert professionals in large, well-funded organizations (United Nations, World Bank, USAID) or volunteers working for non-governmental organizations (NGOs). The former group tends to focus on large projects with top-down management, and decisions are often made by western experts thousands of miles away from where the activities are located. On the other hand, the NGO approach focuses mostly on small projects often via a piecemeal approach lacking technical and systemic input. The projects are often narrowly focused and lack significant planning and accountability [13].

Engineers are not usually involved in international development projects that specifically focus on sustainable community development, especially with regard to policy issues [14]. As a result, non-technical people often address many technical problems related to development. The large-scale participation of engineering students and professionals in engineering for humanitarian international development is a relatively new phenomenon over the past ten years, as demonstrated by the vigorous growth of EWB organizations in the USA and abroad, including the EWB-International network [15]. Engineering for humanitarian development is a grassroots movement consisting of individuals who are willing to donate time and expertise to solving poverty issues. The projects are smaller in size and funding than traditional engineering projects and do not compete with those conducted by large engineering firms. EWB-USA's work falls into what Bugliarello [16] refers to as *engineering for* development, a new interdisciplinary thrust in engineering which "…responds to the global need for engineers who understand the problems of development and sustainability, can bring to bear on them their engineering knowledge, are motivated by a sense of the future, and are able to interact with other disciplines, with communities and with political leaders to design and implement solutions." Further, engineering for humanitarian development contributes in part to the implementation of the eight Millennium Development Goals [17] and represents an alternative to top-down development.

Today, the participation of engineering students and volunteers on real projects in the developing world takes limited forms ranging from short-term experiences, sometimes called volunteer tourism, or *voluntourism* [18], to long-term living situations including study abroad, internships, and Peace Corps service. Short-term and long-term activities demonstrate two extremes in a *continuum of engagement* that may range in weeks, months, or years. To be an effective educational tool, that engagement requires a set of guiding principles necessary to make those experiences a success for both the students and the participating organization or community hosting the students.

Experts in international development seem to have a wide range of opinions regarding the effectiveness of trips based on their duration. Some will argue that short trips accomplish nothing while others will argue that long trips create a culture of dependency. Suchdev *et al.* [11] discuss various arguments used by critics of short-term medical missions. Critics contend that these activities are self serving, ineffective with regards to identifying and solving root problems, burdensome on local communities and facilities, unable to meet community expectations, and lacking accountability.

In addition to this list, critics also suggest that grassroots efforts can have limited impact by virtue of demanding lengthy interaction and attention from highly experienced development professionals, or at worst, can have a negative impact on the community and be a waste of local and international resources while presenting the appearance of progress.

There are many instances where such arguments are valid for missions conducted by volunteers. This can apply to charity organizations which, despite good intentions, often do not have the range of expertise to address the breadth of community needs. But to generalize such criticisms to all types of international missions is not appropriate. Indeed, the aforementioned criticisms may not hold for short- and medium-term engineering for humanitarian development trips if proper guiding principles are followed and a multi-year commitment is established beforehand and is well maintained.

In the authors' opinions, the first goal of engineering project-based international development activities should be community development and capacity building. This is done by partnering with the community to address its problems and needs and then devising long-lasting, successful solutions that are respectful of the community itself, its people, and its environment. These solutions are not primarily technological, rather they should consist of education, training, empowerment and the integration of economic mechanisms to ensure long term success. The technology will only be successful if the capacity to adopt and maintain it is developed. The desired outcome is to create healthy and safe communities. The mindset necessary to reach this first goal can best be described by a quote attributed to E.F. Schumacher: "Find out what people do best and teach them to do it better" [19]. Through proper assessment of community needs and existing capital, a set of objectives can be outlined. The community first goal relates to what international development should be about whether it takes place over one long trip, several medium trips, or multiple short trips. In all cases, the commitment to collaboration with the community must be long-term even though the length of outsider presence in the community may vary. In short, successful development takes time and patience.

The second goal relates to the benefits gained by engineering volunteers. For students, the goal is educational in nature by allowing them to: (i) have an international experience; (ii) have an opportunity to work on a real project from concept through implementation and then on to evaluation/monitoring as part of a multidisciplinary team of experts in technical and non-technical fields; (iii) experience multicultural team work; and (iv) sense that they are contributing to making the world a better place. For engineering professionals the goal is more altruistic but, at the same time, it may allow professionals to share their expertise, mentor engineering students, and recruit student leaders who will later work in engineering firms. Engineering professionals may equally benefit from exposure to addressing engineering challenges with resources outside of their experience base. All those features closely match what is expected today of engineering education by the Accreditation Board for Engineering and Technology [20] and the recommendations by the American Society of Civil Engineering (ASCE) Body of Knowledge for the 21st Century [21].

We propose that guidelines for successful engineering project-based international development volunteer activities be developed. These guidelines should balance the two aforementioned goals while also acknowledging the complexity of international development, the characteristics of which can be described as follows:

- The field of international development is diverse, multidisciplinary, and not unified. It has had its share of successes and failure over the past 50 years [22]. Many best practices have been developed by various agencies, yet little effort has been made to develop a comprehensive database of such practices.
- No two development projects are alike, although similar issues may appear from one to another. The communities being addressed range in geographical scale (villages to megacities) and time scale (transient to permanent communities). Even within a single country or region, one size solutions do not fit all.
- There is no such thing as one model of international development or one model of intervention. During the lifetime of a project, there are points when short-term interventions are adequate and others when more long-term presence is necessary. After all, this variability exists in all projects irrelevant of location. The models of intervention must best fit the community's current phase of development whether that be emergency response, recovery, or planned development.

In engineering for humanitarian development, the challenge is to cultivate a repertoire of best practices (assessment, design, implementation, monitoring, evaluation, and follow-up) or *guiding principles* that could be used by the engineering profession. Ideally, those *principles* could be applied to different settings (developed vs. developing communities) rather than trying to duplicate *solutions* that claim universal applicability. The guiding principles can be derived from experience in industrialized country projects and in previous international development projects.

A review of the activities of the MC-EDC and the EWB chapter at CU Boulder are presented below, followed by a series of proposed guiding principles that the authors believe, based on their seven years of experience [10,23], balance effective sustainable community development with the education of engineers.

3. EWB-USA and EDC

The College of Engineering and Applied Science at CU-Boulder boasts both the founding chapter of EWB-USA (EWB-CU) and a well-established academic program called Engineering for Developing Communities (EDC) which started in 2004 and was recently renamed the Mortenson Center in Engineering for Developing Communities (MC-EDC) [10]. MC-EDC's mission is to educate globally responsible students who can offer sustainable, appropriate technology solutions to the endemic problems of developing communities worldwide. Whereas EWB-USA focuses on extracurricular outreach projects, MC-EDC places equal emphasis on education, research/ development, and service/outreach, and more importantly, considers the relationship between those three components within the context of engineering for humanitarian development [8,10].

The projects conducted by EWB-USA teams nationwide and by EWB-CU and MC-EDC students at CU-Boulder have proven that international engineering for humanitarian development activities including students and working engineers can be a positive experience for both the participants and for the partnering communities, as long as guiding principles are in place. Real-world development projects provide the students a much needed field experience; create teamwork, leadership, and global competency; and above all, give students a global outlook, a sense of belonging and engagement, and a societal context for their work. Ideally, the partnering communities receive much needed advice and assistance to build the internal capacity necessary to solve their own problems.

Despite these positive characteristics, significant questions arise surrounding the sustainability and appropriateness of activities undertaken in the name of humanitarian development. Common questions include: (i) Who benefits from the projects: Does the partner community receive as much benefit from the work as the participants do? (ii) Are the implemented solutions a direct response from the partner community or are they in response to an intermediary's view of what is needed? (iii) What is an appropriate time frame to maintain the relationship (and funding input) before exiting a community and expecting complete self-sufficiency? and (iv) Are short- and medium-term engineering field projects an appropriate use of funding designated to address humanitarian development [14,24]?

3.1. History

EWB-USA grew out of a single project run by the first author and a handful of undergraduate students in 2001. Now EWB-USA is an international non-governmental organization (NGO) whose mission is three-fold: (i) partner with disadvantaged communities to improve quality of life; (ii) implement environmentally and economically sustainable engineering projects; and (iii) develop internationally responsible engineers and engineering students. About 43% of all EWB-USA student and professional members are women, which is especially noteworthy considering that women comprise fewer than 11% of the engineering workforce in the USA [25]. Although the organization is currently expanding its educational component, its focus is on completing community development projects. EWB-USA welcomes volunteers from all disciplines and experiences, emphasizing commitment to the projects over previous or applicable experience.

In their working lifetimes, engineering students now attending college can expect to see a 50% increase in world population [26], major global warming phenomena, and major losses in biological and cultural diversity on Earth. Whether colleges and universities are doing enough proactively to teach students what they need to know to operate in a future environment is an open question [27]. The MC-EDC program at CU-Boulder addresses this concern through multidisciplinary studies. It addresses a wide range of issues such as water provisioning and purification, sanitation, public health, localized power production, shelter, site planning, infrastructure, food production and distribution, communication, jobs, and capital for developing communities including villages, refugee settlements, Native American reservations, *etc.*

The discussion below focuses on two types of field projects that involve engineering students, faculty, and professional mentors at CU–Boulder: EWB-USA service/outreach projects that must follow the guidelines set forth by EWB-USA and tend to be extracurricular; and MC-EDC projects that typically include a significant research and education focus.

3.2. EWB-USA Type Projects

Since 2001, nearly 100 CU-Boulder engineering students have participated in EWB-USA sponsored projects in Belize, Mali, Thailand, Senegal, Mauritania, Rwanda, Peru, and Nepal. Their work is usually done on a voluntary basis over the course of one or several academic years. Students go to the field once or twice a year and work on their respective projects between trips. They are responsible for the project assessment, design (which is reviewed by professional mentors), fundraising, project management, implementation, and follow up. As per the guidelines suggested by EWB-USA, the chapter must show a five year commitment to each community it is serving.

In general, EWB-USA projects benefit students by:

1. Giving them an opportunity to experience all aspects of engineering: problem identification, assessment, design, funding, implementation, and monitoring.
2. Giving them an opportunity to work with professionals and real clients, develop good contacts within industry, and learn by doing.
3. Providing a direct hands-on experience in a safe environment.
4. Giving the opportunity to work in multi-disciplinary teams on larger and more socially relevant projects than the traditional design competitions featuring concrete canoes (in Civil engineering) or the new flushing toilet (in Mechanical engineering).
5. Demonstrating that engineering problems can be complex and sometimes ill-defined, can be solved in more than one way, and often require working effectively with people who think differently (including engineers and non-engineers) and have different cultural backgrounds.
6. Teaching students how to interact with people of different cultures and thinking creatively with limited tools.
7. Developing awareness of professional ethics and the role that engineering plays in addressing community needs.

The projects conducted under the EWB-USA banner are voluntary and not usually integrated into the engineering curriculum. They often reveal critical issues (including water filtration, affordable shelter, or telecommunication needs, for instance) that might serve later as research ideas for undergraduate independent studies or master's degree research topics at CU-Boulder or elsewhere. In some cases, aspects of the projects can be integrated into engineering senior design classes.

3.3. EDC-Type Projects

Other projects unrelated to EWB-USA have been under way at CU-Boulder since 2004 [23]. These MC-EDC-sponsored projects all contain overlapping education, research, and outreach components. They tend to cut across disciplines such as engineering, business, and public health and are often funded through multi-year grants. As is the case with EWB-USA projects, the MC-EDC makes a long-term commitment to its partner communities. Project examples include:

- Design optimization and sale of fuel briquettes made from municipal waste for heating and cooking in Afghanistan.
- Tele-education and tele-medicine projects in the Amazon region of Peru.
- Sustainable economic development using compressed earth block production and earthen building methods for construction of single family homes project on the Crow Reservation in Montana.
- Expansion of the Casa de la Esperanza community center into a math and science hub for children of agricultural workers.

4. Guiding Principles

The aforementioned project activities have helped us derive guiding principles to balance effective sustainable community development with the education of engineers using humanitarian development projects as the framework. The guiding principles were adapted from those proposed by Suchdev *et al.* [11] and Heck *et al.* [12] for medical missions.

4.1. Shared Mission, Vision, Values and Approach

Field project effectiveness requires that all participants be willing to support the sponsoring organization's mission, vision, values, and approach to development. For EWB-USA and MC-EDC projects, the students, faculty, professional advisors, and community partners need to understand that their work includes both a community development goal and an educational goal, and that humanitarian engineering for development is not charity work or tourism, but is instead a discipline dedicated to implementing community-driven, sustainable solutions to community problems. For that reason, the participation of sociologists, economists, anthropologists, public health experts, and others has been strongly encouraged in EWB-USA and MC-EDC projects in order to address better the range of issues faced by communities. The ultimate goal is to help create a healthy and safe community that can manage its own future problems without additional outside assistance.

4.2. Quality Control and Ethics

The melding of education with volunteerism can lead to substandard results if quality control and technological appropriateness are not primary guiding principles. Instead of encouraging the idea that short-term projects are an appropriate substitute for painstaking intervention, volunteer-based organizations must ensure quality control on every project, putting quality above quantity, and reminding all participants that the main goal is to create something sustainable that can be maintained and reproduced by the community.

Volunteer participants must also understand that they are bound to a professional code of ethics with regard to behavior, accountability, quality control and quality assurance, and delivery of projects. Although this is not often emphasized strongly in engineering education, it is nevertheless a given at the professional level. Work in developing communities requires the same level of standards and ethics as in developed communities. EWB-USA has adopted the code of ethics set forth by the ASCE that provides fundamental canons, rules of practice, and professional obligations, which includes "sustainable development" as the first of its seven fundamental cannons [28]. Engineering professionals from countries outside the United States have equally rigorous codes, including the many listed on the Illinois Institute of Technology's Center for the Study of Ethics in the Professions website [29]. Non-engineering professions have their own codes of ethics, so it is important for team members to discuss the differences and similarities within these codes.

Engineering students who perform development work with varying levels of direct oversight sometimes face difficult ethical decisions with regards to the work they are doing and the limits of what they are fully-trained to be doing independently. To ensure project design quality, all EWB-USA projects follow a rigorous process of submission and review by professional engineers. Once a project has been submitted to EWB-USA by an outside group, that project is followed through by EWB-USA project coordinators, which is in many ways similar to the practice followed in traditional engineering firms within the USA.

4.3. Organizational Accountability

While most humanitarian development organizations are established with sincere altruistic motivations, their structure can sometimes conflict with true development ideals. Specifically, volunteer-based organizations are often driven by the motivations of their current volunteer labor force and those volunteers tend to want to experience an immediate return on their efforts. Trying to encourage volunteers to donate their time to painstaking and sometimes boring long-term projects is difficult so, often, a shotgun approach is used—focusing on the initiation of a variety of projects without regard for long-term sustainability of implemented solutions. This approach leads to varying levels of project completion and success. Even when the programs are based on long-term commitments to communities, volunteer turnover frequently results in the atrophy of many projects that are underway but not yet sustainably completed [13]. Instead of following this path, humanitarian engineering organizations should acknowledge these constraints and institute organizational accountability. This means that an organization's leaders are directly accountable for successes and failures within projects. This accountability remains regardless of management and engineer turnover, in the same way that traditional engineering firms are responsible for successful completion of their contracts.

For example, the EWB-CU team working in Rwanda for the past six years has spent considerable effort focusing on rainwater catchment systems. While rainwater catchments may appear to be simple, or even simplistic to engineering students, the challenges of ensuring a functioning system in a rural community are complex. The first installed rainwater catchment system failed within months, in part, because the team had significant volunteer turnover and the new members wanted to focus on other, more exciting projects. However, instead of abandoning the project, key team leaders ensured that focus remained on the existing installations which were repaired, improved, and then replicated.

4.4. Education

Education of both the volunteers and the community members is an integral part of humanitarian development projects. Students and working engineers need to acquire proper training before going on project trips. Ideally, this education component should be integrated into the engineering curriculum, as is the case with the Mortenson Center in Engineering for Developing Communities (MC-EDC). In time, an integrated curriculum would somewhat mitigate the need for additional training of professional engineers because they would all be knowledgeable about the requirements and considerations necessary for this type of work.

4.4.1. Undergraduate education

As discussed in another paper by Amadei and Sandekian [10], the MC-EDC brings together a wide range of courses in engineering, sustainability, appropriate technology, renewable energy, public health, international education and development, business, and various fields of humanities. It also provides an opportunity for undergraduate students in engineering to enroll in a traditional degree program in the College of Engineering and Applied Science at CU-Boulder and, at the same time, take some of their humanities and social sciences electives, technical electives, and independent study credits in courses emphasizing community service and sustainable community development.

An EDC track was created in the Civil Engineering undergraduate curriculum in 2007. The students complete the standard core courses in their concentration and enroll in elective courses focusing on topics relevant to developing communities. An undergraduate certificate program that will be available to any degree-seeking student whose major is housed in the College of Engineering and Applied Science is currently under development.

4.4.2. Graduate education

EDC graduate tracks are currently offered within three of the six focus areas programs leading to MS and PhD degrees in Civil Engineering (CE): Environmental Engineering (since 2004), Civil Systems (since 2008), and Construction Engineering and Management (since spring 2009). EDC tracks in the other CE programs (Building Systems, Water Resources, and Geotechnical Engineering) are under consideration by their respective faculty groups. The guiding principle behind the EDC tracks has been to integrate them into the current CE curriculum by leveraging existing courses offered by the Department, the College, and the rest of the campus. A graduate certificate program in EDC is under evaluation.

4.4.3. Skills training

Providing students with basic skills is equally critical as providing the technical theory they get in the classroom. As observed by the first author, excellent undergraduate or graduate students, despite extensive engineering knowledge, are sometimes completely inept at manual work or managing a field project. To remedy that problem, the EWB-CU chapter often sponsors hands-on workshops during the academic year such as concrete design, health assessment methods, photovoltaic design and installation, *etc.* The workshops are optional and give the students much needed supplementary hands-on skills that they do not get in the classroom. Professional members also benefit from these trainings. Additional prerequisite skills include language (at the proficiency level), local culture, first aid, fundraising, management and leadership, and risk analysis specifically with respect to evacuation and emergency response plans. Acquiring such skills has been strongly suggested by EWB-USA and several guidelines are available on their website in areas such as concrete, energy, health, community assessment, *etc.*

4.4.4. Community education and participation

Educating members of the partner community is a fundamental aspect of EWB-USA and MC-EDC projects. Concepts such as "train the trainers" or "teach the teachers" allow communities to be an integral part of the current development process while building capacity to solve their own problems. Methods of community education and participation are well documented in the literature. They include Participatory Action Research, Rapid Rural Appraisal, Rapid Assessment Methods, Behavior Change Communication, and others [30,31]. In the EDC program, those methods are presented in a six-credit, two-semester graduate-level core course entitled Sustainable Community Development [32]. During the first semester, the course emphasizes a public health perspective and participatory models, covering an overview of development and global health concepts and issues as they apply to developing communities. The second semester covers the principles, practices, and strategies of appropriate technology as part of an integrated and systems approach to community-based development.

However, education should not be used as a substitute for acknowledgement of, and accommodation for, development constraints in organizations and communities. Oftentimes when statistics about the number of people without clean water in the world are presented, audience members ask, "Is this not just a question of education? If you educate the people on the need to treat their water, will they not care enough to boil their water, or maintain the water treatment system you have installed?" The implications of these questions are two-fold: If community members do not change their behavior after an intervention, then either the community members are to blame for not caring about their own welfare or the development workers are to blame for not rigorously following community participatory development models. However, both of these conclusions conflict with human nature [13] and, in some cases, with the local culture [33]. For instance, most Rwandans have been well taught the dangers of contaminated drinking water and poor sanitation. They also typically understand appropriate technology and hygienic interventions. However, the adoption rate of these interventions is very low, which is shocking to many in the developed world who drink expensive bottled water simply because it tastes better than readily-available, inexpensive, purified tap water. Again, the assumption by people in resource abundant countries is that the people in resource poor countries have not been sufficiently empowered by the development programs. Any argument that average citizens simply do not choose to spend even a modest (but not negligible) amount of time and money on treating their water, and instead choose to run the risk of getting sick, is unspeakable in the idealistic model.

This kind of human behavior is similar around the world. For example, dentists have long advocated that people floss their teeth several times a day. Yet even though people know the reasons and have the resources to floss their teeth, many of them do not follow the recommendation. Instead, they knowingly run the risk of significantly more expensive and painful interventions later in life. One main reason for this is that many people simply can't be bothered to take that little bit of extra time every day to do something so mundane. In both cases, education and resources are not necessarily sufficient to ensure compliance with a public health recommendation, when the action would impose a burden on the individual. Longer term engagement, and recognition of these limitations, is needed to achieve a community wide change.

The guiding principle here is that education efforts must include all stakeholders, including students, professionals, and community partners, and must go beyond traditional (technical) topics to include skills training and behavioral change that are directly relevant to the project. Additionally, there needs to be an understanding that education alone will not ensure successful adoption of new systems. To be truly sustainable, communities must take ownership of the project and resulting systems. Without self-motivated behavior changes, implemented technologies will be ineffective.

4.5. Innovation and Technological Appropriateness

Engineering for humanitarian development is still unusual in mainstream engineering curricula. In addition to teaching good engineering practices and design, educational efforts should encourage innovation that expands the usefulness of proven designs for direct applicability in resource-poor communities. Again, the primary driver for engineering innovation must be the end user. Volunteers must be encouraged to consider only those technologies that are truly appropriate for partner communities [34]. Often that requires familiarization with existing and proven techniques. At the same time, volunteers should be discouraged from innovation simply for the sake of their own interest in the projects. A complicated new system design might be more exciting for volunteers, but a simple modification to an existing design is usually better for the partner community.

4.6. Fundraising

Humanitarian development projects require a steady state of funding over multiple years, yet fundraising is a significant challenge for most organizations involved in this type of work. Approximately $30,000 is needed per year for each project run by the EWB-CU chapter, so students seek private donations or university-based funding sources. Students often face special challenges finding money for travel because many funding agencies consider travel costs as overhead, not as a vital aspect of the education of engineering students.

Projects sponsored by the MC-EDC require a different approach to funding, in part, because they are integrated into an academic program. MC-EDC-associated faculty members apply for external grants that can be used to fund students who conduct research resulting in an independent study project, master’s thesis, or doctoral dissertation. MC-EDC faculty members also occasionally apply for, and receive, seed grants from on-campus resources. Typically, the seed grants provide early-stage project funding and are then leveraged to obtain external grants. The MC-EDC’s main funding challenge is finding the money to pay adjunct faculty to teach courses that are beyond the expertise of traditional engineering faculty including public health and interdisciplinary development topics. Since the MC-EDC courses are mainly at the graduate level, they have small enrollments and, therefore, are not self-sustained by the small percentage of tuition dollars returned from the campus to the host department.

The disclosure of dual goals, which include a balance between effective sustainable community development and the meaningful education of engineers, is critical for effective and honest fundraising and will put these projects in a separate category compared to those from many traditional charitable organizations. Unfortunately, the current funding structures for non-profit organizations encourage the constant development of "new" and "better" projects. Volunteers and donors are motivated by the news that greater numbers of people are impacted by new projects or those that have expanded to include additional communities. These structures are often counterproductive to sustainable development because there is little or no incentive for employees, volunteers, or donors to ensure the success of projects already in progress, especially if they are currently struggling.

4.7. Collaboration and Teamwork

Successful humanitarian development projects require collaboration with various internal and external stakeholders and effective teamwork. EWB-USA and the MC-EDC have advocated the need for creating a strong relationship with the community as well as with other partners such as government agencies, local NGOs, other local organizations including local EWB groups, for instance, and individuals who live in the country but not necessarily in the partner community including Peace Corps volunteers. Oftentimes several EWB-USA chapters collaborate on a project. However, collaboration must not be used as an excuse for lack of accountability. Lead organizations and individuals must guide any collaboration and acknowledge ultimate responsibility for all actions taken on behalf of the project. This occasionally becomes awkward when different teams working under the banner of a single project provide varying quality of work.

When dealing with student chapters, a critical issue is that of continuity. EWB-USA requires a five year commitment to each partner community which is slightly longer that the tenure of the average undergraduate engineering student. The project team must build on its members' skills and experiences, and continually assess its membership to ensure that new members are groomed to take over leadership roles as existing leaders graduate. Travel teams should include the smallest cadre of members that can cover all necessary specialties and not include extra (unnecessary) individuals simply because they have put in substantial effort on the project.

Volunteers may spend significant time learning and parroting sustainable community development models that call for extraordinary ambition and motivation on their part and the community's part, but often, only a small fraction of team members actively contribute. Even fewer volunteers have the opportunity to travel and participate in community education and project implementation. One of the most frustrating parts of this work is witnessing volunteers who have traveled thousands of miles to participate, only to appear apathetic or half-heartedly willing to follow through on the tasks required for motivating community participatory development. Instead of expending the significant and sometimes daunting effort necessary to use proven development models, they take the easy route and arrange a few meetings of handpicked residents, or give large community presentations. Volunteers who participate in engineering development work are, by their nature, motivated both by humanitarian ideals and the potential for adventure. Unfortunately, some individuals have the tendency to take humanitarian development project work less seriously if it is not tied to a grade or a performance review. Again, organizational leaders must accept and ensure that project and program quality control is not compromised by underperforming team members and volunteers must remember that the ultimate goal of their work is community self-sufficiency.

4.8. Duration of Intervention

The time that a project team spends in the partner community depends a great deal on the nature and the current phase of the project that is being addressed. Field visits are a must to collect data but it is much easier to evaluate alternatives and complete designs in a well-equipped office. During the academic year, students have limited time for field work. Therefore, most implementation trips take place during academic breaks, with durations varying between one or two weeks and a couple of months, depending on the project phase (assessment, implementation, or monitoring). Designing interventions that fit what the community needs and simultaneously match the visiting group's resources, involving several partners with each one visiting the community at a different time, and following well-established assessment methods such as participatory action research (PAR) can maximize the effectiveness of short-term interventions. The commitment to a partner community must be long-lasting and enduring, even if the duration of a project team's presence in the community is limited.

4.9. Sustainability

Project sustainability is one of the most difficult issues surrounding engineering for humanitarian development. People often ask, "How do teams ensure that what is implemented today will still be working six months, a year, 5 years, or 10 years from now?" The answer to that specific question is, "They cannot. Things change in the developed world, so how can anyone expect them not to change in the developing world?" With that in mind, the question should be, "How do teams ensure that what is implemented today can be modified and changed over time by the community without doing any harm or creating unnecessary burden to itself?" This implies a commitment to an ongoing collaborative relationship. Efforts can be augmented from trip to trip, and project scopes may change radically based on other development happening near the partner community. Requiring teams to make a commitment of at least five years provides a strong tool for sustainability. Ultimately, however, the volunteer group needs to devise an exit strategy. If the team's capacity building efforts have been successful, the community should have the skills and desire to maintain, and possibly even expand, implemented solutions and the knowledge needed to solve future problems that arise.

The drawbacks identified in the "Challenges of Voluntary International Development Work" section of this paper often lead to discussions on capacity building. More often than not, capacity building is presented in a nebulous fashion, where the implications are that sustainable development activities must simultaneously address education, training, revenue streams, policy, and motivation on a regional or national level. Most development organizations are ill-equipped to address this type of request. Even at the project level, there usually is not enough time, money, or motivation on the part of either side to touch on all aspects of sustainable development. In response to this challenge, the greatest publicized successes have been discrete, low-impact projects that affect relatively few people. Instead, sustainability should focus on tangible capacity building, wherein partnerships with communities are sufficiently defined, cohesive, and accountable so that discrete projects are designed as stepping stones to address long-term goals.

4.10. Evaluation

The concept of evaluation instills fear into the minds of many individuals and organizational leaders. However, without this key component, it is impossible to determine the true success of any project. Standard methodologies for evaluating civil engineering projects, which typically are large-scale, long-lived projects involving many economic, financial, social, and environmental factors may or may not be directly applicable to these types of projects. However, those traditional methods provide a framework for the development of appropriate metrics of success.

One potential need in the sustainable development field is an auditing and accreditation organization. While non-profits and government organizations report statistics such as overhead numbers, cost of materials, and number of people impacted per dollar spent, these statistics do not necessarily translate to positive changes in developing communities. Additionally, the humanitarian benefit numbers are predominately self-reported, and the only type of external auditing generally conducted is financial. Just like universities are accredited by an independent organization to verify their quality, a sustainable development accreditation organization may be appropriate to independently verify development claims, provide feedback to organizations and donors, and hold implementers accountable for the resources spent. By conducting periodic evaluation and receiving feedback throughout the various project phases, collaborators can help ensure that proposed solutions are appropriate—meaning that they are more likely to be acceptable to, and welcomed by, the partner community. Independent auditing could reinforce the concept of organizational responsibility and possibly expand fundraising success by instilling confidence in would-be donors.

The graduate-level curriculum developed as part of the Engineering for Developing Communities Program (recently named the Mortenson Center in Engineering for Developing Communities Program) has existed for more than five years. MC-EDC faculty and staff are designing a variety of assessment instruments to evaluate the impact of humanitarian development projects and interdisciplinary education on its students. Preliminary results have been presented at various conferences and published in proceedings [8]. Due to the small number of participants to date, statistically relevant data pools are not yet available. EWB-USA is also still working to implement an appropriate assessment scheme for the projects in which they have been involved.

5. Conclusions

As the number of volunteer organizations conducting engineering for humanitarian development projects expands, it becomes vital to have a set of guiding principles that help define successful efforts. Proposed principles for successful engineering for humanitarian development projects include:

1. Shared Vision—All project participants must buy-in to the sponsoring organization's mission, vision, values, and approach to development.
2. Quality Control—Humanitarian engineering projects must include quality control standards. Participants must be bound to a professional code of ethics with regard to behavior, accountability, quality control/quality assurance, and delivery of projects.

3. Organizational accountability must be accepted and ensured by organization leaders without allowing collaboration or their volunteer workforce to be used as excuses for falling short of success.
4. Participant education is an integral part of humanitarian development engineering projects. This includes traditional higher education supplemented with relevant skills training. In addition, education of partner community members is fundamental to the development process and to building the capacity necessary for the community to solve its own problems.
5. Innovation should be driven by the needs of the resource-limited end user. This often means that the most effective and appropriate solution could be a modification of an existing technology.
6. Fundraising efforts should clearly explain the dual purpose of this type of work: sustainable humanitarian development projects and the education of student and working engineers.
7. Successful projects require collaboration with various internal and external stakeholders and must ultimately respond to the community's self-identified needs. Teamwork in this context includes not only working with a culturally and intellectually diverse group, but also the need for continual mentoring of future leaders who can maintain a long-term collaboration through leadership turnover.
8. Interventions (time and tasks) need to be designed to maximize the direct response to community needs and desires, considering the resources available and the project phase. Volunteer presence in communities may be short-lived, but a long term commitment to the community is vital for sustained success.
9. Sustainability requires periods of external presence in the community, but not necessarily continuous presence. Groups must devise and discuss their exit strategy and timeline with project partners in order to ensure sufficient capacity building efforts.
10. Evaluation is the key to determining success. Organizations should embrace external critical evaluation, and respond to identified shortcomings.

This paper highlighted some of the work of the CU-Boulder student chapter of Engineers without Borders-USA and those involved in the Mortenson Center in Engineering for Developing Communities in an effort to identify guiding principles that balance the goals of effective sustainable community development and the meaningful education of engineers. The authors hope that presenting this list will initiate a conversation leading to refinements by others involved in similar efforts, eventually resulting in commonly accepted metrics for successful engineering for humanitarian development work.

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