Lessons from Africa – Sustainable Design and Engineering

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Sustainability

We discuss current undergraduate engineering projects that address the issues of energy, water and shelter within the context of engineering for those in very poor, remote, rural communities. The projects, originally conceived in Africa, now span the USA, Ghana, Rwanda, Kenya and Burundi. Through this inter-relationship, students in all countries are brought into contact with the core requirements for true sustainable engineering and design. In particular, students in the USA, through exposure to engineering in the less developed countries, learn much about design when access to resources is limited. They learn how to deconstruct engineering problems to provide minimalist solutions and in so doing, how to do more with less. Students in Africa learn that the solutions to many of the problems they address are available by using what's at hand in terms of both material resources and traditional environmental knowledge.

Introduction

There is general acknowledgement that humankind is facing a complex set of inter-related problems associated with the future availability of, and access to, potable water, food, material resources and environmentally benign sources of energy – humankind is effectively looking at the requirements for its own survival. Past engineers have contributed to this situation – future engineers will play a key role in providing solutions to these questions. The engineering challenges are formidable – almost incomprehensible – yet it is likely that simple processes that emulate nature will provide truly sustainable pathways to ensure our survival. Shirley Strum Kenny, President of Stony Brook University, quoted recently in the New York Times [1], stated "Sustainability is going to be the defining issue of the 21st century". It is essential that undergraduate engineering education stress the need for truly radical changes in design philosophy and engineering practice that extend the viability of the commons. Engineers create the resources that enable us to customize our environment and so must assume responsibility for its state: true "Renaissance" engineers embrace the societal and environmental consequences of their solutions with as much rigor as they do the scientific and technological issues.

By adopting a minimalist approach to design and working on themes that address the basic needs for human survival, students learn that nature is the ultimate resource for all human endeavors. Through this, they begin to understand that we must live in harmony with the planet, rather than exploit what it has to offer, in a manner that dramatically alters the intrinsic intricate balance of the landscape and its inhabitants. These engineering problems introduce students to the complex issues that govern the sources, delivery and usage of water, energy and materials, and the consequences of such usage and their related impact upon the environment. They begin to appreciate the infrastructure necessary to support human life and learn that we can utilize more efficiently the resources that we have to hand. Firsthand exposure of an engineering student to the mercy of the commons may well be invaluable to their incorporation of more responsible, ethical practices in the future, whether it is in design work or policy formation.

Engineering for the poor often comprises the adaptation of well-established solutions from the developed world to satisfy a perceived demand in the developing world; this approach takes into account neither the real needs of the intended user nor the operating environment in which the solution is implemented. Such errors are further compounded by the distribution of these solutions in the form of "aid" into which the issues of sustainability are rarely incorporated – and that are usually devoid of the principles of socially, economically and environmentally responsible entrepreneurship. The net result, so perfectly described by Ian Smillie in Mastering the Machine Revisited: Poverty, Aid and Technology [2] is that ".. too many failures in the 'development business' have been ignored or covered up, condemning poor people to suffer the re-invention of too many wheels that never worked in the first place". William Easterly, in The White Man's Burden [3], forcefully argues that the developed world can help Africa emerge from poverty by providing the poor with the means to establish their own self-reliance and, through this, gain their own self-determination. To do so reliably means that we need to work with the poor to develop sustainable, geographically and culturally appropriate engineering solutions to address their real needs and, through this, we can acquire the skills necessary to change our own engineering paradigm.

Bringing the Mud Hut into the 21st Century

The traditional adobe house, common throughout much of the world, provides a perfect conduit through which to introduce the principles of minimalist design that embody the constructs of true sustainability. The combination of indigenous materials, traditional construction techniques and xeriscaping constitute a synergistic relationship that produces a habitat of exceptional aesthetic appeal, perfectly suited to the climate and the environment [4, 5]. Our approach to an updated design is centered upon the means by which naturally available materials and techniques can be selectively, and carefully, combined with their modern, synthetic, more durable equivalents to design a shelter that combines architectural and engineering innovation and practicality. The core design enhances and improves upon the attributes displayed by the traditional adobe house and so brings the mud-hut into the 21st Century. Our intention is to further elaborate upon the techniques of water collection, thermal efficiency, smart site planning, and the innovative use of naturally available materials. A successful, and natural, outcome of this dialog is a reconnection to the art of the adobe dwelling, its superior architecture and technological performance – the reemergence of a habitat ideally suited to the occupants, the environment and the economy of sub-Saharan Africa.

This research started in the rural areas of Northern Ghana where we investigated the different types of, and approaches to, traditional building and construction methods. Our research focused on the *roof problem*: traditional flat roof designs require an excessive amount of cut wood to support the thick mud roof itself and to provide vertical support for these cross members. We have developed an alternate earthen roof design that eliminates the use of wood for structural support – thereby addressing one of the factors responsible for the acute deforestation evident throughout much of sub-Saharan Africa. In 2008, using bamboo for lateral support of the flat roof in conjunction with vertical columns, comprising mud blocks containing 10% cement built into the mud wall, we built a traditional house that uses no wood and yet incorporates only a small quantity of materials with a high embodied energy content. Where appropriate, traditional methods were intentionally incorporated into the construction to demonstrate the symbiotic combination of old and new; as, for example, in the use of cow dung for plastering the external walls. At the time of writing, this structure has successfully withstood its environment for the past eight months.

Future work will concentrate on incorporating water collection facilities, a composting toilet and the installation of solar powered lighting into the existing building. A thermal analysis of the building will be used to provide a comfortable internal environment, independent of the time of day or year, through the optimization of low-cost passive heating and cooling systems.

RAGS – Reuse of Available Garbage for Shelter

RAGS is an attempt to design a template for a modular shelter that can be tessellated to provide a sustainable urban environment for the millions of families who live in self-built houses within the self-organized communities that comprise the shanty towns throughout the world. To make the design available to those with extremely limited resources, and to permit the greatest flexibility of location, the shelter does not require access to sources of power or water.

The generation and disposal of waste represents a terrible misuse of resources by our society, ultimately caused by poor design and engineering. Large conurbations generate huge quantities of low-level waste such as plastic bags and bottles, glass bottles, newspaper and cardboard that is generally condemned to landfills or incineration. Generating a route for the reuse of these materials for construction extends their useful life whilst addressing the needs of shelter for the world's poor. The intent of the design procedure is to generate a template for the construction of an aesthetic, durable house that can be easily adapted for fabrication throughout the world using the low quality waste at hand. The structure must be able to withstand the extremes of the local climate with heating and cooling systems, implemented through passive heat transfer techniques, used to provide a comfortable internal environment – best suited to the location and ambient temperature. Amongst other roles, the roof is used to collect water which is then purified using a simple sand filtration system for on site storage. A water-free process for the collection and disposal of human waste is considered an essential ingredient of a healthy neighborhood; the facility may be a family or shared resource.

By incorporating the means for internal temperature control, water collection, and sanitation into the core design, a controlled-regulation of the surroundings becomes an integral outcome of the shelter design. We argue that a combination of a house with aesthetic appearance with less-polluted surroundings will contribute significantly to a more visually appealing environment – and thus lead to the formation of a community with more self-respect and greater control over its destiny. This is in contrast to the more normal situation in which those with very limited material and financial resources are often condemned to live in squalor in closely spaced shacks that lack aesthetic appeal. The problems arising from this environment are usually compounded by inadequate sanitation facilities and limited access to potable water – the result being a habitat that does little to encourage hope or promote public health.

Meeting each week throughout their first semester, twenty-five first year students were presented with the challenge of designing and constructing a shelter from trash. Within the framework discussed, the class addressed the concepts of sustainable engineering; minimalist design; reuse of materials; and design for the urban poor. From a consideration of water and energy needs, they began to appreciate the fundamental resources required to support human life.

Whilst the use of garbage for shelter is not new [6], the class demonstrated that a combination of low level waste comprising plastic bottles, newspaper, plastic bags, cardboard and plasticized cardboard containers, generally available throughout the world, can be used to construct a shelter in New York City – potentially suitable for occupation throughout the year. During the Fall 2009 semester, a section of the incoming first year class will refine the existing design and build a single story house ready for habitation by the end of the semester.

Self-Assembled Solar Lighting Systems for Remote Rural Communities

There is a desperate need for an economic lighting system that can be assembled, installed and maintained by the millions of rural poor who live in the remote regions of the developing world. Matching this, there is immense interest in providing solar lighting for remote rural communities: the potential demand – and, consequently, the potential global market – is almost limitless. However, to be successful, the lighting system must be designed and developed with reference to its place of intended use, be sought after, affordable, locally implemented, and be financially, technologically and operationally self-sustaining. Currently, many rural families rely upon simple oil lamps made from cans or bottles with cotton cloth wicks, or the more modern kerosene lanterns. These traditional light sources are expensive to run due to the cost and limited availability of fuel and replacement wicks. They provide poor quality illumination, consume fossil fuel, generate carbon dioxide, and create health hazards not only from fire risks but also degradation of indoor air quality in the enclosed spaces in which they are used.

A major contributing factor to rural depopulation in countries close to the equator is the restriction of activities after nightfall. Truly sustainable sources of artificial light can "extend the day" – ultimately acting as an agent to reduce depopulation of the rural areas, foster education and advancement of the community. Equally, the widespread introduction of such light sources may inevitably cause seismic changes in the social structures of the individual communities and the region as a whole. Whilst it is not possible to predict social outcomes, we have to believe that the economic and health impacts of this change will be to the net benefit of the individuals and communities: indeed, as we have observed directly through our existing installations in Northern Ghana, solar powered lighting systems are coveted and greatly enhance community-wide activities after sunset.

To date, we have designed, constructed, installed and tested a solar lighting system that is amenable to fabrication in rural regions; it does not require specialized tools or highly skilled labor. It has been designed to utilize locally available components where possible, is robust, easy to maintain and repair. The existing multiunit charging station comprises an 85W solar panel and a 75Ah car battery that has the capability of supporting up to 50 lanterns whilst accommodating up to six consecutive cloudy days. The rechargeable lantern comprises: one sealed lead-acid battery; one white light emitting diode (LED); circuitry to supply the LED with current pulses of variable duration at fixed frequency to control the brightness and utilize the battery charge efficiently; and, circuitry to disconnect the battery when a predetermined level of discharge has been reached – thereby maximizing the life of the battery. By supplying the components in kit form for self-assembly, we believe that a solar powered lighting system comprising a charging station and fifty lanterns can ultimately be installed for less 1500USD. If this were to replace its kerosene equivalent, the system could pay for itself in a year.

The ultimate goal is to provide an interested entrepreneur with a *system in a suitcase* – that is everything required to establish a complete solar lighting enterprise *under a tree*. In brief, this encompasses all the necessary documentation, tools, test procedures and sources of components to open up shop. As crazy as it may sound to bypass all the standard procedures and routes normally adopted for the introduction of a new technology to the developing world, we believe that this approach has the necessary ingredients to succeed. By importing the raw materials directly to their place of intended use, the local communities have a much greater appreciation of the fabrication procedure. Instead of being presented with a sealed lantern with a molded plastic housing through the auspices of a donor, they see that the electronics comprises a few components they can assemble. Furthermore, with assistance, they are asked to supply their own lantern housing from materials that are available to hand.

This past summer, we took some lantern kits to Baazing – a small village beyond the end of the dirt road in Northern Ghana – and asked the community to help us assemble lantern circuits. We taught them how to solder, what the different components looked like and so on. The outcome was truly inspiring – a community that had no electricity, no light, no solar panels was able to construct its own solar lighting system. We believe that this was a seminal event and fully supports our assertion that it is possible to establish assembly lines for "high-tech" products within remote, rural communities. Experience with existing installations has also demonstrated that a community is well capable of maintaining a solar lighting system – although it should not be inferred that everything went smoothly!

Our financial model, still in the early stages of development, anticipates the establishment of "social businesses" as described by Mohammed Yunus [7] and Paul Polak [8]. We envisage that these ventures have the potential to play a major role in capacity building – through the development of an infrastructure run by local entrepreneurs that comprises enterprises to assemble, install and repair these lighting systems; and, through the training of local communities to maintain and operate these systems. Contingent to the success of these ventures is the establishment of a robust, self-sustaining microfinance strategy to provide assistance with the initial purchase of the lanterns by the end-user and the charging station by an entrepreneur. We are working to maximize direct, hands-on involvement by the local community at all levels.

In this project we will establish four lighting systems in remote, rural communities in Northern Ghana to gather feedback about the ways in which this technology is used and the robustness of the design; and to gather community input to the design, operation and maintenance of these systems. The experience gained from our two existing systems has provided critical input to development and made us aware of factors that we would not otherwise have considered. Incorporating the communities directly into the development process gives them ownership of, and buy-in to, the product – thereby releasing expectations of aid and handouts from Western donors.

We have just installed two prototype lighting system assembly lines in Ghana – one at the Kwame Nkrumah University of Science and Technology in Kumasi, the other at the Polytechnic in Wa. We have also installed another complete assembly line at the National University of Rwanda in Butare and have a partial assembly line shared between the Jomo Kenyatta University of Agriculture and Technology and the Kenya Polytechnic University College, both in Nairobi. Working with students and faculty at these institutions, the prototype lines will provide critical feedback and enable joint development, with our African colleagues, of a turnkey lighting system. Using a combination of diagrams, sketches, audio and video, we are in the process of developing documentation for the fabrication of a rechargeable lantern, the base station charging circuitry, system installation, operation and maintenance. Lighting kits are en route to interested entrepreneurs and faculty in Burundi and Peru and we hope to deliver the first systems on a commercial basis by the end of 2009.

A Sustainable Water Defluoridation Filter

The World Health Organization deems water non-potable if it contains fluoride ions with a concentration greater than 1.5ppm. The objective of this research has been to develop a truly sustainable filter for the removal of fluoride ions from groundwater that can, in principle, be used worldwide. Principal requirements for the filter are that, where possible, it uses indigenous materials for both the housing and filter media, and that the design be potentially accessible by all. It is our intent that neither skilled labor nor specialized components be required for construction of the filter housing, and that the design of the filter be available through a set of simple drawings and instructions for construction. Since the most important component of any filter is the material used to remove the undesired chemicals or particulate matter, the adsorption media should be indigenous, freely available and not require special preparation in the form of chemical treatment or high temperature processing.

In the short-term, the objective was to design a filter for the removal of excess fluoride ions from contaminated groundwater found in the Bongo District in the Upper Eastern Region of Ghana. A successful filter prototype will reduce the fluoride concentration from a maximum of about 5ppm to below 1.5ppm. Longer-term objectives include adapting the design for use throughout the developing world, especially by remote rural communities with very low income, and, of course, the urban poor.

Given that an essential component of the design is that it can be adapted for use throughout the world, the potential media investigated must be those available in the regions containing fluoride contaminated groundwater. From the literature, wood charcoal, bone char, laterite and Moringa oleifera seeds were identified as potential media. Bone char was excluded from this stage of the investigation since the communities in Northern Ghana, for whom the filter is currently being designed, consume little meat: furthermore, longer term considerations strongly suggest that the consumption of meat should be discouraged. We have found that laterite and Moringa satisfy the requirements that potential adsorption media be indigenous and economic, and that these materials do not require special preparation prior to use. Our work to date with Moringa has proved less successful than that with laterite – we have therefore chosen to concentrate on the latter. As suggested in the literature, laterite removes fluoride ions from solution through a physio-chemical adsorption process – the magnitude of the reduction in concentration increases with decreasing particle size.

To test the efficacy of these materials, it is self-evident that the most important procedure in this research is the accurate measurement of the concentration of fluoride ions in aqueous solution. For use in rural areas, the method needs to be portable, require a minimum calibration procedure and ideally provide data under conditions of constant flow. This aspect of the project has proved to be troublesome – our work with ion-selective electrodes with inbuilt reference junctions has proved inconclusive. Whilst it has been easy to obtain consistent, reproducible results in the laboratory, measurements in the field have proved more elusive. Research into the determination of aqueous fluoride continues.

Working with faculty and students from KNUST and a community in North Eastern Ghana, we have been able to learn something of the ways in which people in very poor, remote rural communities actually use water. They are teaching us about the technology gap that exists between them and us; we are learning about their preferred requirements for a water filter, their preferred procedure for recharging the filter media and have been able to observe at first hand, their usage of water.

Our procedure to date entails mixing crushed laterite with the contaminated water, stirring it at intervals over a ten-minute period and then passing this mixture through a simple column sand filter or clay pot to remove the laterite powder. The crystal clear water emerges with a fluoride concentration well within the WHO guidelines. We currently estimate the fluoride capacity of the laterite to be 12 – 15 times its volume and are working towards regenerating the laterite by heating the spent material in a simple crop dryer – within which the ambient temperature will reach about 80˚C. Prototypes of these units have been installed in communities in North Eastern Ghana – their full adoption awaiting tests for the presence of pathogens introduced through the laterite or sand. Alternatively, the use of a "clay-pot" filter to remove the pathogens represents a more straightforward solution although the pot currently has to be imported. We believe that the laterite/sand-filter procedure represents a truly sustainable solution to the problem of contaminated water. It requires no external input and uses indigenous materials for the housing and the filter media.

Dramatic Improvements in the Efficiency of Wood Stoves

The combustion of wood in a traditional African three-stone stove is a very inefficient use of fuel. In Northern Ghana, the local beer, pito, is consumed in significant quantities on market days and during family occasions such as weddings and funerals. A typical "brew" using a three-stone stove, in which the metal pot is built into a clay structure that surrounds about 75% of the pot, consumes about six "head-loads" of wood. Simple adjustments to the existing design, using exactly the same materials increased the efficiency of the stove by 100%. A gap was introduced between the clay wall and the pot, enabling the combustion gasses to transfer their energy to the sides of the pot prior to exit to the surroundings. Additionally, the size of the firebox was reduced as was the size, and control, of the air intake ports. Whilst this result in no way resolves the problem of cutting down trees for firewood, it does suggest that straightforward engineering improvements to the most basic amenities can have significant consequences with regard to the health of the environment.

Conclusion

Working with, and learning from our African partners, these examples of engineering practice provide wonderful examples for the teaching of a sustainable engineering process whilst simultaneously being of benefit to the local communities and, ultimately, humankind as a whole. Potential improvements to many of the traditional practices and traditions encountered can be derived from a rigorous analysis of the existing procedure or apparatus. From these analyses, engineering solutions can be developed that make more efficient use of local resources and simultaneously increase the efficiency of the tasks in hand. With this approach, the solutions developed are in partnership with the end-user – ensuring tact and cultural sensitivity. The outcome being a radical change to the outlook of the students involved who take these projects back to the United States to so ensure a maximum dissemination of the material and lessons learned in the developing world.

It is also worthwhile noting that there are more "modern" lessons to be learned from Africa. Use of the ubiquitous plastic bag has been banned in Rwanda. Coupled with a nationally mandated neighborhood clean up on the last Saturday of each month, this leads to a litter free environment that puts much of the United States to shame. Particularly noticeable is the pristine state of Kigali, the capital city, and Butare, home to the National University of Rwanda. Burundi, although not as far advanced in nationally mandated directives, boasts a capital city, Bujumbura, in which children are able to wash in the water in the storm drains without getting sick.

Humankind started in the Rift Valley in the Great Lakes region of East Africa. As the developed world struggles to find sustainable solutions to its engineering problems, it may behoove us to look to Africa, where engineering problems are approached from the perspective of limited resources, for sustainable answers that ensure the continuance of homo sapiens.

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