Changing Course

Global Engineering Education Conference Proceedings 2012

ENGINEERS AGAINST POVERTY

engineers without borders uk

A Global Dimension FOR ENGINEERING EDUCATION

Strengthening the global dimension in engineering education to address the world's most pressing needs

Conference Agenda

Time	Item	Speaker
09:30 - 10:00	**Registration**	
10:00 – 10:10	**Welcome and introduction**	Professor Anthony Finkelstein (Executive Dean UCL Engineering)
10:10 – 11:35	**Defining the Challenge**	Petter Matthews (Engineers Against Poverty) Professor Paul Ivey (Dean of Engineering - Coventry University) Michael Ramage (Eco House Initiative & Cambridge Environmental Initiatives – University of Cambridge) Alexa Bruce (President of EWB UCL)
11:35 – 11:40	**Explanation of the Workshop sessions**	
11:40 – 12:00	**Tea & coffee break**	
12:00 – 13:00	**Morning Workshop sessions**	
	Morning Research panel	
13:00 – 14:00	**Buffet Lunch**	
14:00 – 13:00	**Afternoon Workshop sessions**	
	Afternoon Research panel	
15:00 – 15:15	**Tea & coffee break**	
15:15 – 15:30	**Workshop Feedback**	
15:30 – 16:15	**Keynote Speech**	Jonathon Porritt (Founder & Director of Forum for the Future)
16:15 – 16:30	**Closing remarks**	Dr Doug Bourn (Director of Development Education Research Centre – IOE) Alexa Bruce (President of EWB UCL)
16:30 – 18:30	**Drinks reception**	

Welcome to the Engineers Without Borders UK & Engineers Against Poverty Education Conference 2012

Changing Course

The Global Dimension in Engineering Education

On behalf of Engineers Without Borders UK and Engineers Against Poverty, we are very pleased to welcome you to this event. The organisers, speakers, presenters, facilitators and participants come from diverse institutional and geographical backgrounds, but we are all united by one thing: a commitment to ensuring that the next generation of engineers are equipped with the skills, knowledge and attitudes that are needed to help them fight poverty and build a better life for all people.

We have developed a programme that will help us to understand better both the scale of the challenges and the practical measures needed to overcome them. We hope that if you are an academic staff member or a student, a policy-maker or a practitioner, that you will be inspired by this event and encouraged to back to your workplace with renewed energy and commitment.

Today would not have been possible without the support and generosity of numerous individuals and organisations. We are particularly indebted to Professor Anthony Finkelstein and his colleagues at University College London who have made their facilities available to us today at no cost. We are also grateful to those who have helped to organise the event and contribute on the day including our keynote speaker Jonathon Porritt.

The most important factor in determining the success of this event is the energy and ideas of the participants. We urge you to engage critically with what you see and hear above all to have your say on the things that are important to you. It is only through listening to each other and sharing our knowledge that we can develop solutions that will make a difference

Wishing you all the best in your future endeavours,

Petter Matthews

Executive Director - Engineers Against Poverty

Andrew Lamb

Chief Executive - Engineers Without Borders UK

Nina Neeteson (Policy and Research Advisor – Engineers Against Poverty)

Alistair Cook (Research and Education Manager – Engineers Without Borders UK)

Hayley Howard (Education Coordinator – Engineers Without Borders UK)

Alexa Bruce (President – EWB-University College London)

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About the EWB-UK Research & Education Programmes

Engineers Without Borders UK

'To facilitate human development through engineering'

www.ewb-uk.org

Engineers Without Borders UK (EWB-UK) is an international development organisation that **removes barriers to** development through engineering. Our programmes provide opportunities for young people in the UK to learn about **engineering's role in poverty reduction**. We support partner organisations by providing young engineers to help them with their projects. We have a vital network of branches at universities across the UK, where volunteers run events and activities for their members and communities. Professional engineers get involved to lend their expertise to our work. By taking part in our activities, our members are **making a difference** to people's lives around the world.

The EWB-UK Research Programme

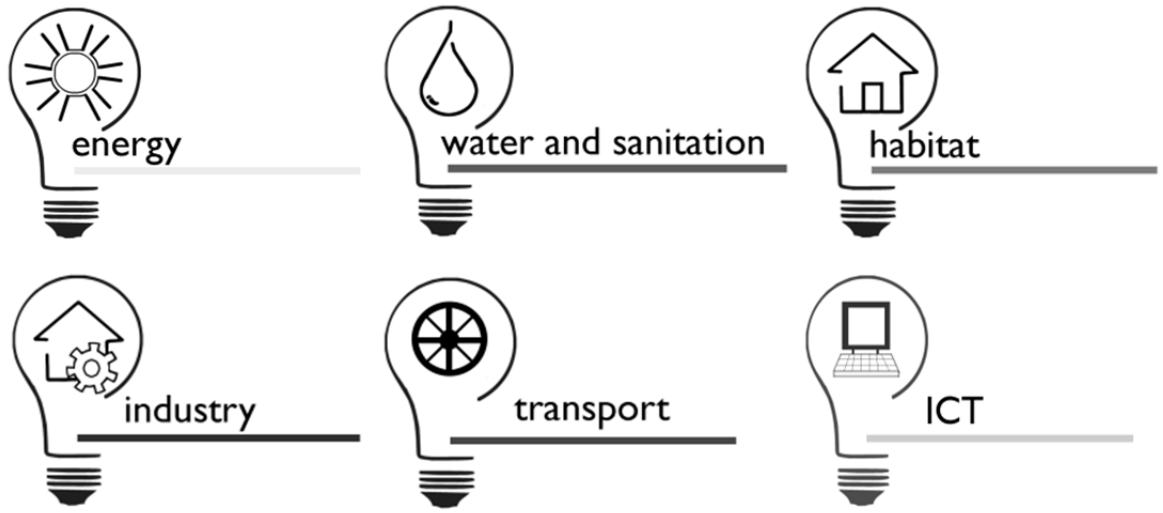
'Linking Students and Academic Institutions with Development and Humanitarian Organisations through Research Projects'

www.ewb-uk.org/programmes/research

In brief, the EWB-UK Research Programme **provides the research skills** of our volunteers – and hence the facilities of the institutions they study at – as a resource for development organisations. By working with them to turn identified technical issues into research briefs, we can offer research projects that are useful, exciting and relevant and that fit into the engineering degrees.

Once the research is complete, we ensure that the findings are communicated back to our partners and also disseminated through the knowledge section of our website. We are able to provide research bursaries to our researchers to help them purchase resources and materials, help towards the cost of field work study or implementation after the research is complete – this greatly increases the effectiveness of the research so that it can make a practical difference where it is needed most. At present, we have 41 such projects under way.

All EWB-UK activities are split into 'communities of practice' to enable ease of navigation - whether you are a potential researcher looking for our available research projects (**www.ewb-uk.org/programmes/research/researchbriefs**) or a partner organisation wanting to access completed research (**www.ewb-uk.org/knowledge**).



Communities of Practice

The EWB-UK Education Programme

'Expanding coverage of global issues in undergraduate engineering curricula'

www.ewb-uk.org/programmes/education

In brief, the EWB-UK Education Programme **supports academics and students** to embed global issues into university engineering curricula. We provide advice on course and module content, example lectures delivered through our university branches, access to our central library of development engineering resources and grants of up to £200 to help set up specialist libraries at your university.

The Education Programme also provides extra-curricular educational opportunities for students such as bi-annual courses with the Centre for Science and Environment in New Delhi and workshops with the Royal Academy of Engineering.

How do I become involved?

If the EWB-UK Research & Education Programmes sound of interest to you – whether you are from an organisation working in the development sector, a potential researcher, academic or professional – please visit our web pages for more information or send your enquiry to **research@ewb-uk.org** or **education@ewb-uk.org**.

About the Engineers Against Poverty Research and Education Programmes

Engineers Against Poverty

www.engineersagainstpoverty.org

Engineers Against Poverty (EAP) is a specialist NGO working in the nexus between engineering and international development.

EAP's development perspective is shaped by a firm belief in the critical role of Science, Engineering, Technology and Innovation (SETI) in meeting the challenges of poverty and inequality. It works with partners in industry, government and civil society to identify innovative ways to enhance the contribution of SETI policy and practice to addressing these global challenges.

EAP has developed a reputation for producing cutting edge action research and it is regularly consulted by leading international agencies. It demonstrates a high level of innovation both in terms of its programme content and in the range of partners it has mobilised in support of its efforts.

Engineering Education

Engineering education must develop to keep pace with challenging global issues such as poverty, conflict, climate change and sustainability. Forward-thinking higher education institutions (HEIs) are already adapting courses to equip graduates with the skills, knowledge and attitudes that are necessary to maximise the positive and far-reaching impact of engineering on society.

But constraints exist that must be overcome if these improvements are to be scaled-up and maintained over time. Importantly, there is often a lack of knowledge of global issues amongst teaching staff and resistance to what is seen by some as a 'dilution' of core engineering content.

EAP's Programme

EAP works with UK based HEIs, regulatory bodies and specialist research institutes to strengthen the commitment and capacity of engineering faculties and staff members to embed global issues within the learning of engineering undergraduates. It does this through a range of activities including research, advocacy, policy analysis, and supporting professional development.

The cornerstone of EAP's engineering education work is the Global Dimension for Engineering Education programme funded by DFID's Development Awareness Fund. This project brought together for the first time the leading organisations in the UK responsible for curriculum review, professional development and accreditation in engineering education to focus on global issues. They include the Engineering Council, Engineering Subject Centre, Engineering Professors' Council, Engineers Without Borders UK and the Development Education Research Centre of the Institute of Education.

The purpose of the project was to build the knowledge and understanding of the challenges and prospects for development amongst academic staff and enable them, through embedding global issues in the curriculum, to impart this knowledge and understanding to engineering undergraduates. Key is helping undergraduates to understand that for engineering knowledge to be effective, it must be integrated into the social, economic and institutional aspects of development and that they must join their knowledge with that of other specialists through interdisciplinary approaches. The Global Dimension for Engineering Education programme is nearing completion, but the stakeholders involved will remain in action as advocates of change in the higher education sector. This conference marks a welcome opportunity to look back on the programme's achievements in the last three years, as well as focusing on the future.

Publications

An evidence base was required to inform the Global Dimension for Engineering Education programme, so a report was prepared in partnership with the Development Education Research Centre at the Institute of Education. It was based on the knowledge generated through a series of workshops and stakeholder dialogues to better understand the current practice and thinking within engineering higher education about 'global skills'. Global skills equip engineering graduates to negotiate major issues shaping the profession e.g. globalisation, rapid technology advances, climate change and poverty. The publication presents a framework of approaches for embedding global skills into the engineering curriculum and highlights examples from current practice to illustrate these approaches in action. You will find a complimentary reprinted copy of the report included in your delegate conference pack – we hope that it provides a useful reference.

Speakers for the day

Host

Professor Anthony Finkelstein		University College London

Keynote

Professor Paul Ivey	Engineering Education UK – it is really not good enough?	Coventry University
Alexa Bruce	Global Learning – A students perspective	University College London
Jonathon Porritt	Engineering Education and Global Challenges: Critical Reflections	Forum for the Future

Speakers

Petter Matthews	Barriers and Opportunities for the Global Dimension	Engineers Against Poverty
Michael Ramage	Eco House Initiative: Postgraduate research in partnership with NGO's	University of Cambridge

Morning Research Panel

Mohammed Qasim Riaz Raja	Improving NGO-Government Relations During Post Disaster Relief Work	University of Birmingham
Amber Claughton	Researching temporary sanitation: a case study of a UK MEng thesis	Loughborough University
Doug White & Chris Hutchens	Is Bottled Water affordable for the Poorest in Rural Cambodia?	University of Edinburgh
Sam Williamson	Concepts, Simulation and Testing for Pico Hydro Networks'	University of Bristol

Afternoon Research Panel

Maryam Lamere	The problem of lack of access to electricity and Flywheel Energy Storage system as an appropriate technology'	City University London
Jon Leary	Locally Manufactured Wind Power Technology for Sustainable Rural Electrification'	University of Sheffield
Samina Azreen Islam	The Glowstar Project: Developing the next generation of solar lantern	University of Manchester
Johannes Whittam	Transitional Tents: Technical Milestone Report'	University of Cambridge

Speaker Biographies

Keynote Speakers

Jonathon Porritt
Founder Director – Forum for the Future

Jonathon, Co-Founder of Forum for the Future, is an eminent writer, broadcaster and commentator on sustainable development. Established in 1996, Forum for the Future is now the UK's leading sustainable development charity, with 70 staff and over 100 partner organisations including some of the world's leading companies.

In addition, he is Co-Director of The Prince of Wales's Business and Sustainability Programme which runs Seminars for senior executives around the world. He is a Trustee of the Ashden Awards for Sustainable Energy, and is involved in the work of many NGOs and charities as Patron, Chair or Special Adviser and was recently appointed Chancellor of Keele University

He was formerly Director of Friends of the Earth (1984-90); co-chair of the Green Party (1980-83) of which he is still a member; chairman of UNED-UK (1993-96); chairman of Sustainability South West, the South West Round Table for Sustainable Development (1999-2001); a Trustee of WWF UK (1991-2005), a member of the Board of the South West Regional Development Agency (1999-2008).

Jonathon received a CBE in January 2000 for services to environmental protection.

Paul Ivey
Dean of Engineering - Coventry University

Paul Ivey is Professor of aerospace engineering and Dean of faculty for engineering and computing (E&C) at Coventry University. He has around 100 publications including four book contributions and three patents, has supervised over twenty research studies and earned in excess of £13M of research income. He is a visiting Professor to the Emirates Aviation College, Emirates Airline. The E&C faculty has a turnover of £40M and 3800 u/g, 580 p/g, and 120 doctoral research students, another 5400 students educated overseas via twelve educational partnerships on four continents and comprises a High Performance Computing Facility, a Design Institute, the award winning SIGMA maths support centre (winner 2011 Times Higher Education Award for Outstanding Support for Students) and six departments: Civil Engineering Architecture and Building, Mechanical and Automotive Engineering, Computing, Engineering Management, Aerospace and Electrical / Electronic Engineering and Mathematics and Control Engineering. The faculty has worked with the Royal Academy of Engineering and MIT on two successive reviews of educational practice for Engineers and Technologists, and supports a Royal Academy of Engineering Academic Champion, two Royal Academy of Engineering Visiting Teaching Fellows and a Royal Academy of Engineering Visiting Professor.

Alexa Bruce
President – EWB-University College London

Alexa spent the first four years of her life in Dominican Republic before moving to Brighton, England. She attended Varndean Secondary School and then Brighton, Hove and Sussex Sixth form College for her A-levels. She is a second year undergraduate student at University College London, undertaking the four year Environmental Engineering MEng course. Through her Dominican father she had exposure to a very different culture which, allied with the influence of her mother's work in fair and ethical trade, have led to a prominent global dimension to her outlook on life from an early age. Since beginning her studies at UCL she has embraced her passion for international development, starting volunteering with EWB-UCL as events officer and the Project Leader for the societies Peru Project (which was completed in the summer of 2011). As a second year, she is currently President of EWB-UCL and one of five members of the branches EWB-UK bursary panel. She has recently accepted an offer to spend her third year studying abroad in Perth, Australia and is looking forward to continuing her involvement with Engineers Without Borders in Australia.

Morning Workshop Sessions

Is there more to development than engineering?

Dr Alison Parker *(Fellow in International Water and Sanitation – Cranfield University)*

Dr Heather Smith *(Research Fellow in Water Governance - Cranfield University)*

We would be surprised if anyone denied the fact that there is more to development than engineering, however, this workshop will explore how we teach these "soft" skills to engineers and scientists. It will draw on the experiences of recent graduates and explore what skills need to be taught, how they can be taught and indeed whether academic programmes are the place for this.

What does Humanitarian Engineering mean to you?

Simon Hill *(PhD Student – Coventry University)*

A workshop to understand the differing perspectives of Humanitarian Engineering and it's meaning, from a variety of engineering backgrounds; as well as compared to non-engineering points of view.

The EWB Challenge

Katie Cresswell-Maynard *(Engineer – Arup)*

An exploration of the newly initiated EWB Challenge UK, its origins as an idea and expected outcomes, preliminary findings on the impact it has had on the engaged students and looking to the future.

Constructing the Future of Engineering Education.

Vincent Danoher *(Dean of Civil Engineering – Nelson Mandela Metropolitan University)*

An interactive session during which we will use the power of visual metaphors as a tool to stimulate debate around the issues characterising the current and desired states of engineering education.

Engineering in Development - Planning the EWBook

Samina Islam *(University of Manchester)*

Jon Leary *(University of Sheffield)*

We are excited to announce that EWB are planning their very first book and this is your chance to contribute to it. As an analogue to RedR's popular Engineering in Emergencies, it hopes to bring together the mountain of knowledge that EWB has built up over the past 10 years to provide practical advice for those working on engineering projects in international development. The session will focus on brainstorming ideas for the energy and water and sanitation chapters, but we welcome anybody who feels able to contribute to the book.

Have a real impact now! Appropriate technology transfer

Jose Bermeo *(Eco House Initiative – University of Cambridge)*

Abi Bush *(Eco House Initiative – University of Cambridge)*

An interactive workshop demonstrating our experience in students and academics working together in a way which rarely occurs in engineering projects/standard education. This interactive workshop on how to include into student programmes industry, NGO's and local governments to get things to create rapid, scalable change. Looking at the skills an engineer working in international development requires such as an awareness of context, practicality, economics, social factors, and some basic soft skills as well as the academic grounding students gain from universities. These are the strengths of the Eco-House Initiative, both in terms of its outputs and also to produce engineers suited to a global career.

Failing to Learn & Learning to Fail

Divindy Grant *(Water Engineer - Mott MacDonald International Water Department)*

Emily Mattiussi *(University of Edinburgh – EWB Canada)*

Exploring the role of education in understanding failure, how do we learn to embrace failure and ensure we don't repeat engineering and development mistakes. What do we understand by the concept of 'failing forward' or 'successful failures', are these valuable learning tools?

Afternoon Workshop Sessions

Global engineers, are they entrepreneurial engineers?

Dr Liz Miles *(Senior Lecturer and Educational Consultant –Coventry University)*

Brain storming session around definitions with a presentation on some understood and researched definitions followed by participants discussing and charting their own experience and entrepreneurial traits

Developing global text books for global engineers

Brian Reed *(Lecturer, WEDC – Loughborough University)*

There is not much teaching material that lecturers can use in their courses and many textbooks are expensive, difficult to get hold of and often out of date. This is true for both UK and overseas universities. Some textbooks are available electronically but these are often large and printing them off or reading on the screen is not ideal as they were designed to be printed by a publisher not a standard printer. A series of smaller text-booklets and factsheets is being written by staff at the Water, Engineering and Development Centre (WEDC) at Loughborough University. We would like you to look at one or two of these – and (importantly) print one of them off so see how easy it is for you.

Co-ordination and hierarchies of responsibility

Rob Lawlor *(Centre Excellence Teaching and Learning – University of Leeds)*

Engineering firms may be willing, for example, to reduce carbon emissions. However, they may not be willing to act unilaterally if this will put them at a disadvantage in competition with other firms. Thus, to a large extent, this is a co-ordination problem. Similar issues relate to risk, exploitation and to duties to developing countries.

Given the individual focus of ethics teaching, an obvious response may be for the student to write these issues off as things they needn't think about. This workshop will consider some tentative solutions, as well as opening discussion for other suggestions.

The Global Engineer

Dr Doug Bourn *(Director of Development Education Research Centre- Institute of Education)*

Discussion on how staff and students perceive the concept of the 'global engineer' and its relevance to future professional needs of graduates. It will make reference to the EAP project and other research undertaken by IOE on how engineering students perceive the importance and value of learning about global issues.

To make money or not: are sustainability-driven careers inherently unsustainable?

Adam Rysanek *PhD Student–Energy Efficient Cities initiative, University of Cambridge)*

Those of us committed to leadership careers in sustainability or humanitarian engineering have been taught (or have volunteered) to willingly expect low earnings. This workshop aims to create an open discussion into whether this outlook is either realistic or beneficial in the long-run.

For better or worse: student volunteering in development work

Jonny Gutteridge *(Head of International Partnerships – EWB-UK)*

Understanding Engineers Without Borders UK's experience of facilitating the involvement of students in development projects in Africa, Asia and South and Central America, examining the highs and lows and asking whether the doctrine of "do no harm" means we should all be seeking to limit student volunteering or just do it better.

Co-creation and participatory design

Ashley Thomas *(MIT D-Lab Graduate & Harewelle International Limited)*

This workshop will be highly interactive and its goal is to explore the relationships among stakeholders working on product design projects in developing countries. Participants in the workshop will be given a design challenge which they must build and test within the workshop. At the end,there will be a mini-competiton to see whose design is the most successful (and further discussion on who defines that "success")

Poster Presentations & Exhibitors

Brian Reed	Developing global text books for global engineers	Loughborough University
Fazriz Sani Fadzil	The Fetishism of Microalgae species in High-Organic Industrial Wastewater	University of Oxford
Hayley Sharp	Incorporating Disaster Risk Reduction into Development Projects in Bangladesh	University of Cambridge
Mohammed Qasim Riaz Raja	Improving NGO-Government Relations During Post Disaster Relief Work	University of Birmingham
George Smart	Can bamboo be a suitable replacement for steel in the use of gabions?	Coventry University
Jack Barrie	Hand pump Failure – Investigating the socio-technical failure modes of hand pumps in post conflict Sierra Leone using case-based reasoning	University of Edinburgh
John Kings	Developing the Next Generation of Solar Lanterns	University of Glasgow & Glasgow School of Art
Jose Bermeo	Eco House Initiative	Eco House Initiative
	Branch Projects	EWB-UCL
Jack Barrie	Taste the Water & Shelter Centre Library	Taste the Water
	Completed Research Project Display	Loughborough University
	Development Case Studies	EWB-UK

Research Panel Papers

The Glowstar Project: Developing the next generation of solar lantern

Samina Azreen Islam

University of Manchester

Abstract

In the early 2000s the Glowstar Lantern was developed to meet the need for low cost, robustly designed off-grid lighting solutions in Kenya. Despite meeting the criteria for a well manufactured product, the lantern failed to reach its target market due to its high cost. Researchers in previous years have worked on both the technical and business sides of the lantern, reducing the costs considerably, however the lantern still remains just outside the price range deemed the most affordable for Kenyan off grid communities. This project seeks to continue the technical development of the Lantern, taking the approach of looking into more innovative areas such as organic electronics as means to drive down the cost and widen the applications for the lantern.

Keywords: Solar, glowstar, lantern, Kenya, off-grid lighting

Introduction

As of 2011, almost 3 Billion people [1] in the world- almost half of humanity- currently live without electricity, [2] the consequences of which are a life lived in poverty with little to no access to other basic rights such as medical care and education. [3]

In 1997 a World Bank report stated that 90% of Kenya's population were off grid and owing to the geographical nature of the country identified a significant need for and gap in the market for solar technology solutions for off-grid applications [4].

In the early 2000s, Practical Action Consulting (PAC), the consulting arm of Practical Action known then as the Intermediate Technology Development Group (IDTG) responded to this need by creating The Glowstar Lantern (GSL) in partnership with Sollatek Ltd, a small manufacturing company specialising in solar products.

Figure 1: The Glowstar Lantern

The GSL was developed as a short term, "my first" technology solution to Kenya and Africa's complex energy needs, enabling people to build capacity and economic growth for themselves through studying or working for longer hours in the evening, eventually putting them in a position where they could afford to join the grid or invest in more sophisticated technologies. It was also developed to be the major alternative to the current use of kerosene lanterns and candles, the former of which pose serious health risks due to inhalation of noxious fumes.

Figure 2: The GSL allows for children to study in the evening

While solar lanterns are not wholly innovative, the GSL was considered a market leader product, with its overall unique selling point being it's high quality, robust and reliable design and low cost, making it highly adaptable to the uncompromising, rural environmental conditions of Kenya, compared to other lanterns on the market at the time of which diverge from being low cost and badly made to well designed and far too expensive for the market.

However, the GSL did not meet the market demand as expected and feedback from test communities during field trials for the product stated that at the original price of $150 the GSL was too expensive, particularly as GSL market analysis conducted prior to the GSL's conception postulated a projected price of $50 being the price most of the target market would be able to afford. To date, previous researchers have worked on the Glowstar Lantern both on the technical and economic side to substantially drive down the cost, which now currently stands at $55 for the GS5 model and $85 for the newer model. [5]

Project Specification

The project brief stipulated by the project partners' places emphasis on dropping the cost of the entire system by over 10% via re-engineering the solar lantern, (specifically the newest model GS7) to improve market uptake of the product and to improve the overall functionality and usability of the Lantern.

Aims of the Project

- Drive down the cost of the solar Lantern to meet and maintain market demand.
- Broaden the applications and number of uses for the lantern.
- Maintain the high quality design work and other unique attributes to the lantern that differentiate it from the other products on the market.

Objectives of the project

- Investigating the feasibility of using innovative organic and inorganic photovoltaic panels as an alternative to the thin film panels currently used, as much of the cost of the lantern is due to the expense of the panel.
- Perform a technology review of LED technologies and batteries and subsequently update the technology of the lantern.

Solar panel

According to the cost breakdown provided by previous researcher Chris White, the solar panel was found to be the most expensive aspect of the entire system. At a budget cost of £18.152 for a batch order of over 1000 including DC connectors, the solar panel contributes 51% of the entire budget cost of the GSL which stands at £35.577 [6].

The GS7 is charged by a thin film amorphous silicon (a-Si) solar module rated at 12V nominal and available at 10W, 20W and 30W dependant on the wattage of the lamp that is purchased. Although mainly mono-crystalline silicon is considered the base material used in the design of the most widely recognised solar cells from the perspective of the consumer market, it is expensive with its high cost hidden in its complex manufacturing process negated by an approximately 17% efficiency trade off.

Many other materials and technologies exist within the solar technology markets that are competitive to silicon based cells; combinations of other inorganic materials such as cadmium telluride (CdTe) and Copper Gallium Indium Selenide (CIGS) are amongst the most established within the market. The advent of organic electronics has given rise to the use of conductive organic polymers to develop photo-voltaic cells like the dye sensitised solar cell. However, the question of efficiency, chemical and environmental stability of such new technologies compared to cost needs to be investigated.

Testing plan for PV panels:

- Halogen light has been found to have similar luminescence properties as sunlight.
- Expose solar panel, which has been connected to a resistance box (at fixed resistance), to light emissions from Halogen lamps.
- Tilt panel to required longitude (01°17'S) and latitude (36°48'E) co-ordinates [7] to emulate the specific angle at which sunlight hits the panel in Nairobi, Kenya and find the voltage output (Voc), calculating the short circuit current (Ioc) using the fixed resistance value.
- Characterise each type of solar panel in terms of its I-V curve, subsequently identify the Maximum Power point of the panel as shown in figure 3:

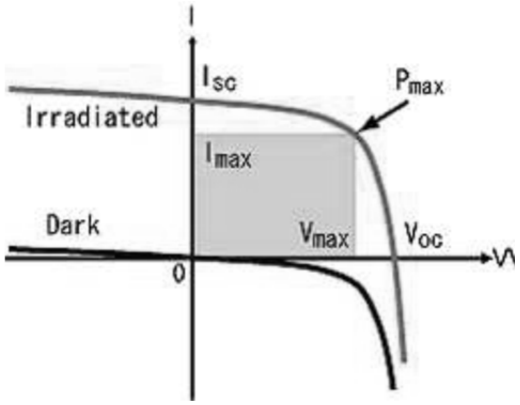


Figure 3: I-V curve characteristic of a solar panel

- Calculate the overall efficiency of the panel.
- Carry out comparative analysis on panels' suitability for the lantern, without losing the lantern's present level of efficiency.

At present, discrepancies have been noted in the repeatability of this experimental method; this was discovered to be due to the non-uniform distribution of light emanating from the halogen lamps and the resistance and resistivity properties of the panel increasing due to the heat radiation from the halogen light.

Batteries

The original design of the GSL utilised lead-acid AA batteries mainly for their low cost and abundant availability. Previous research recommended the use of Nickel-Cadmium batteries due to their superior energy storage properties. While this is true, this project contests the suggestion of such batteries as cadmium is a highly toxic metal and its usage is highly restricted in Europe by the REACH regulation. [8]

The graph in figure 4 shows that the energy densities and battery storage capacity of Lead-Acid batteries compared to other established technologies is low. Nickel–Metal Hydride (NiMH) batteries are considered to be the most practical alternative, offering higher storage capacities; leading to longer battery life and exhibiting no memory effect, which has limited their usability in previous years. This would subsequently allow for the lantern to be charged less often, maintain a low cost and is a widely available technology.

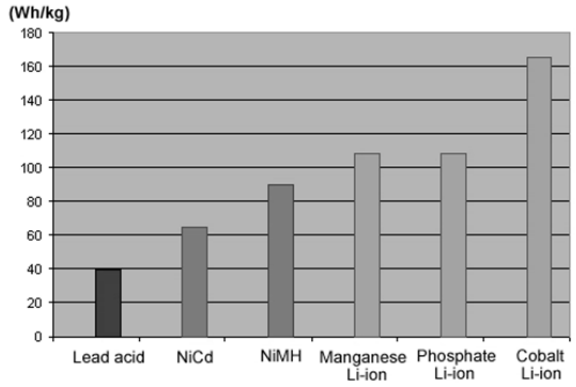


Figure 4: The energy densities in Wh/kg of various types of battery technologies

Light Technologies

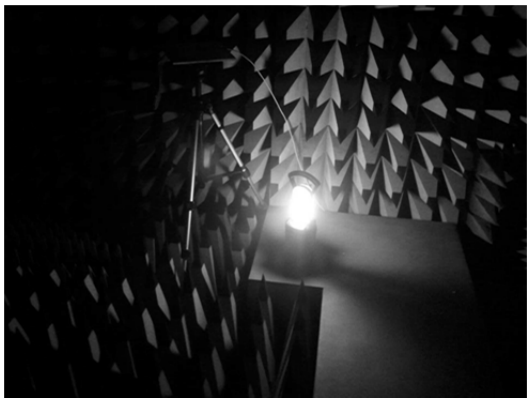


Figure 5: Testing the luminescence and light distribution of the lamp in an anechoic chamber

The GS7 currently employs a Compact Fluorescent Lamp (CFL; essentially an energy saving light bulb). Phosopher or white LEDs are a key technology that has been considered so far as an alternative as initial "blackout" tests performed showed that they offer a higher intensity of luminosity, high levels of light distribution due to the availability of 15, 30 and 70 degree distributions and abundant presence in simple, widely used products such as torches and bike lights. Induction of White LEDS into the GS7 would also remove the additional circuitry present that is required to increase the voltage output for the CFL. The Lantern due to the low light distribution is commonly used as a table lamp, mainly by children to study. Previous researchers have attempted various LED configurations and insertion of reflective materials to increase the light distribution to a full 360 degree spread. This has so far been unsuccessful, although finding a solution would mean that the lantern could also be used outside for people who work in agriculture (a major industry in Kenya) to work for longer hours.

Further Work

The lantern so far has been assessed and critiqued in terms of its individual components and it has yet to be understood what sort of results a cohesive re-design would yield. There is another researcher undertaking the Glowstar Project concurrently, who is assessing the lantern predominantly in terms of its product design, which also gives rise to how to final design could actually be realised.

This project presents the capacity of advanced technology research into the field of organic electronics to be applied in developing appropriate technology, eloquently demonstrating the trade off that exists between innovative research and product development. The implementation of such technologies in Kenya and other developing countries exhibits unique and distinct environmental and economic constraints which will be examined more in depth when concluding recommendations for the lantern.

Acknowledgements

Professor Andrew Gibson, Dr. Arthur Haigh, Dr. Vladmir Markevich & John Kings

References

[1] http://www.humanitycampaign.org/global-poverty-facts/

[2] http://www.undp.org/energy/

[3] http://practicalaction.org/energy

[4]http://rru.worldbank.org/Documents/PapersLinks/27.pdf
[5]http://www.glowstar.net/index.asp
[6]'Developing the next generation of Glowstar Solar Lantern' Chris White, University of Cambridge, 2010
[7]http://www.mapsofworld.com/lat_long/kenya-lat-long.html
[8] http://www.reach-cadmium.eu/

Figures

Figure 1: http://adjei.co.uk/images/lantern_offa.jpg

Figure 2: http://practicalaction.org/images/solar-lantern-37005.jpg

Figure 3: http://solarcellcentral.com/images

Figure 4: http://metaefficient.zippykidcdn.com/wp-content/uploads/lifepo4-energy-weight-comparison-of-different-battery-types.gif

Figure 5: Photo taken by author during experimental work

Is Bottled Water affordable for the Poorest in Rural Cambodia?

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Abstract

The rural population of Cambodia suffers from a widespread lack of access to safe drinking water. To combat this, the government of Cambodia seeks to achieve the global Millennium Development targets by halving the number of people without sustainable access to safe drinking water by 2015. Several international Non-Governmental Organisations (NGOs) and private entrepreneurs have already established bottled water programs in rural communities; however the suitability of this service as a low-cost means of supplying the poorest households has not yet been assessed. This paper investigates whether this solution is within the means of the lowest-wealth rural households.

The paper analyses data collected from 240 household surveys, situated in three rural Cambodian communities served by bottled water NGO Teuk Saat 1001 (TS1001). Families were surveyed regarding their income, expenditure on drinking water, and their opinion of how costly the service was. Households that bought bottled water were compared with a control group to establish key financial differences. The survey results were evaluated using an odds ratio analysis, an assessment of weekly expenditure on drinking water, and a comparison of household statements about how expensive they believed their system to be.

The results of the survey suggest that TS1001 bottled water is not reaching the poorest families in the community. Current uptake of the system shows sales trending towards the middle- and high-wealth members of the community, with a high proportion of the lower-income households stating that the bottled water was 'too expensive' in comparison to their existing methods.

Keywords: Bottled water; drinking water supply; Cambodia

Introduction

The rural population of Cambodia suffers from a disproportionately low level of access to safe water in comparison with its neighbours. As of 2008, only 56% of the rural population had access to an improved water source - this still leaves almost 5 million residents vulnerable to poor health from consumption and use of contaminated water. This is very poor in comparison to Thailand (98%), Vietnam (92%) and China (82%) (WHO and UNICEF, 2010). To combat this problem, the National Government of Cambodia has set itself challenging development targets, which fall in line with the international millennium development goals. The government seeks to: (i) by 2015 ensure 50% of the rural population has access to an improved water source; and (ii) by 2025 ensure 100% of the rural population has access to an improved water source.

The capacity for Cambodian communities to provide their own safe water solutions is severely impaired by the nation's financial situation (Irvine *et al*., 2006). Nearly half of the population earn less than $1.25 per day, which is defined as the international poverty line (Ravallion *et al*., 2009). This has resulted in widespread poverty in many rural areas around the country, and the lack of capital prevents villages from maintaining even the current level of service for water and sanitation (UNDP and UNCF, 2007). The situation is made more difficult to solve by the patterns of community distribution across the country. In Cambodia, 82% of the population live in low-density rural areas (ADB, 2007), rendering it prohibitively expensive to overcome the problem by installing large-scale centralised treatment systems.

Bottled water distribution is a relatively new and rapidly expanding sector in the provision of safe water to developing world communities (Hystra, 2011). There are few in-depth studies investigating bottled water in the developing world, and a very limited number have commented on the associated costs to the poor (Friedrich *et al*., 2009; Hystra, 2011). None have specifically considered bottled water provision to the poorest in Cambodia. At present in Cambodia, Teuk Saat 1001 (TS1001) is the largest foreign NGO provider of bottled water. In operation since 2004, the organisation has piloted a unique model for bottled water distribution in rural communities across the West and Central regions of the country. The organisation has rapidly expanded since its inception, and has ambitious plans for future growth. Currently, the Non-Governmental Organisation (NGO) has just over 50 stations in operation; this number is intended to reach 250 within the next six years. By 2018 TS1001 aim to be in a position to provide safe drinking water to over 1 million beneficiaries, while reducing the dependence on foreign donations by becoming financially self-sufficient (Chay, 2012).

The goal of the research was to assess the affordability of TS1001 bottled water for poor households in rural Cambodia. This paper details the methods of data collection and statistical analysis, presents the results of the survey, and discusses them in the context of bottled water as an appropriate provision method for the rural poor.

Method

Ethics Statement

This research study was implemented in rural houses that gave prior consent and with the knowledge that private information would be confidential. It was made clear that the household was in the position to withhold any information they wished.

Sample Group

Stratified random sampling was conducted in three rural communities within the Battambang province, Cambodia. Communities were selected where a TS1001 bottle water distribution station had been running for over one year and was considered financially stable by the NGO. The communities were all situated at least 10km from the city of Battambang, with populations between 1,000-3,000 households. For this study, 240 households were surveyed between 26th December 2011 and 13th January 2012. The sample was divided equally with a control group consisting of 120 households not using TS1001 and the remaining households currently using the system.

Data Collection

Data was collected for analysis through a survey comprising of formal questions and surveyor observations. A series of questions established data on the household wealth and included: (i) the family daily income; (ii) ownership of transport; (iii) ownership of a television; (iv)supply of mains electricity and (v) access to credit. Observations were also made about: (i) the house type, which was categorised as low, medium and high wealth households: (ii) the quality of road access to the household and (iii) access to toilet facilities. Information on household weekly expenditure on drinking water was also collected and for the control households included the cost for supply and any associated treatment costs including fuel costs, where relevant. TS1001 customer expenditure was based on the number of bottled water deliveries made per week. Opinions of the whole sample group were investigated in relation to bottled water and current treatment methods, and quantitatively assigned to allow analysis.

Data Analysis

Data analysis was carried out in three sub categories: (i) an odds ratio correlation to investigate the uptake of the system given the various wealth factors; (ii) linear regression analysis investigating the weekly expenditure on water given the income of the household and (iii) reasons cited for not buying TS1001. A number of controlling wealth factors were hypothesised and included in the survey as aforementioned. The data was collected and quantified, and the TS1001 and Non-TS1001 groups compared to establish patterns of behaviour. Odds ratios were generated to establish factors that controlled the likelihood of an individual household buying bottled water from TS 1001. An odds ratio of >1 suggested a positive correlation between this factor and participating in the bottled water scheme. Similarly, an odds ratio of <1 suggested a negative correlation. Factors were considered statistically significant if the 95%ile confidence interval was consistently above or below zero. A factor was considered to be positively significant if both the confidence interval values were >1. This was true of the opposite, a factor was considered negatively significant if both confidence interval values were <1. A linear regression plot on average weekly expenditure within each income group investigated the general trend on drinking water spending within the households. The fit of this data was evaluated through the coefficient of determination, variance and the standard deviation. Household opinion on a variety of drinking water aspects was investigated and analysis on the responses was undertaken.

Results

The survey results were evaluated using an odds ratio analysis, a linear regression analysis of weekly expenditure on drinking water and a comparison of household statements about how expensive they believed their system to be.

Direct wealth comparison

A number of controlling wealth factors were hypothesised and included in the survey, and these were compared using an odds ratio analysis. Correlation of the factors that influenced the uptake, negatively or positively, have been identified with positive correlation indicating that a household is more likely to uptake bottled water. The calculated odds ratios are displayed in; results considered statistically significant are shown in bold.

	Teuk Saat User		Control Household		Odds Ratio (95% CI)
	Respondents	%	Respondents	%	
Daily Income ($):					
0 - 2	15	13.04%	31	26.96%	**0.41 (0.21 - 0.80)**
2 - 5	36	31.30%	51	44.35%	**0.57 (0.33 - 0.98)**
5 - 10	29	25.22%	25	21.74%	1.21 (0.66 - 2.24)
10+	35	30.43%	8	6.96%	**5.85 (2.57 - 13.30)**
House Type:					
High Wealth	23	19.17%	19	15.83%	1.26 (0.65 - 2.46)
Medium Wealth	65	54.17%	65	54.17%	1.00 (0.6 - 1.66)
Low Wealth	32	26.67%	36	30.00%	0.85 (0.48 - 1.49)
Road Type:					
Paved	32	26.67%	32	26.67%	1.00 (0.56 - 1.77)
Good Dirt	56	46.67%	38	31.67%	**1.89 (1.12 - 3.19)**
Poor Dirt	25	20.83%	39	32.50%	**0.55 (0.31 - 0.98)**
Path	4	3.33%	11	9.17%	**0.34 (0.11 - 1.11)**
Access to Credit:					
Yes	47	39.17%	51	42.50%	0.87 (0.52 - 1.46)
No	77	64.17%	69	57.50%	1.32 (0.79 - 2.23)
Toilet Facilities:					
Flushing Toilet	77	65.81%	63	52.94%	**1.71 (1.01 - 2.89)**
Latrine Pit	6	5.13%	9	7.56%	0.66 (0.23 - 1.92)
Communal Facilities	7	5.98%	0	0.00%	INF
None	27	23.08%	47	39.50%	**0.46 (0.26 - 0.81)**
Transport Ownership:					
Car	8	6.72%	5	4.17%	1.66 (0.53 - 5.22)
Motobike	88	73.95%	77	64.17%	1.59 (0.91 - 2.76)
Tractor	35	29.41%	37	30.83%	0.93 (0.54 - 1.62)
Bicycle	59	49.58%	79	65.83%	0.51 (0.30 - 0.86)
None	11	9.24%	12	10.00%	0.92 (0.39 - 2.17)
Access to Mains Electricity:					
Yes	87	72.50%	70	58.33%	**1.88 (1.10 - 3.23)**
No	33	27.50%	50	41.67%	0.53 (0.31 - 0.91)
Ownership of Television:					
Yes	100	83.33%	93	78.15%	1.40 (0.73 - 2.67)
No	20	16.67%	26	21.85%	0.72 (0.37 - 1.37)

Table 1 Wealth Odds Ratio Analysis

From the analysis, the following factors were found to be positively associated with TS 1001 use:

- Household daily income >$10
- Access to house via a good dirt track
- Ownership of a flushing toilet
- Access to mains electricity

The following factors were found to be negatively associated with TS 1001 use:

- Household daily income <$5
- Access to house via a poor dirt track or path
- Ownership of no sanitation facilities

Money spent on drinking water

A linear regression analysis of the average weekly spends for each income group shows a trend towards higher costs associated with TS1001, displayed in Figure 1. Lower variance and standard deviations were apparent for TS1001 customers with the coefficient of deviation being 0.98 compared to 0.65 for the control households.

100% of TS1001 households incur costs for their drinking water compared to only 48% of the control households. This cost comes from collecting water and treating water. Of the control group 67 (56%) boil water with 57 (76%) households having access to a free fuel source. Furthermore 27 (23%) in the control group did not treat their water while 7 (5%) stated that they did not treat water but spent money on water collection. In the control group 52% of households spent $0 on drinking water collection or treatment.

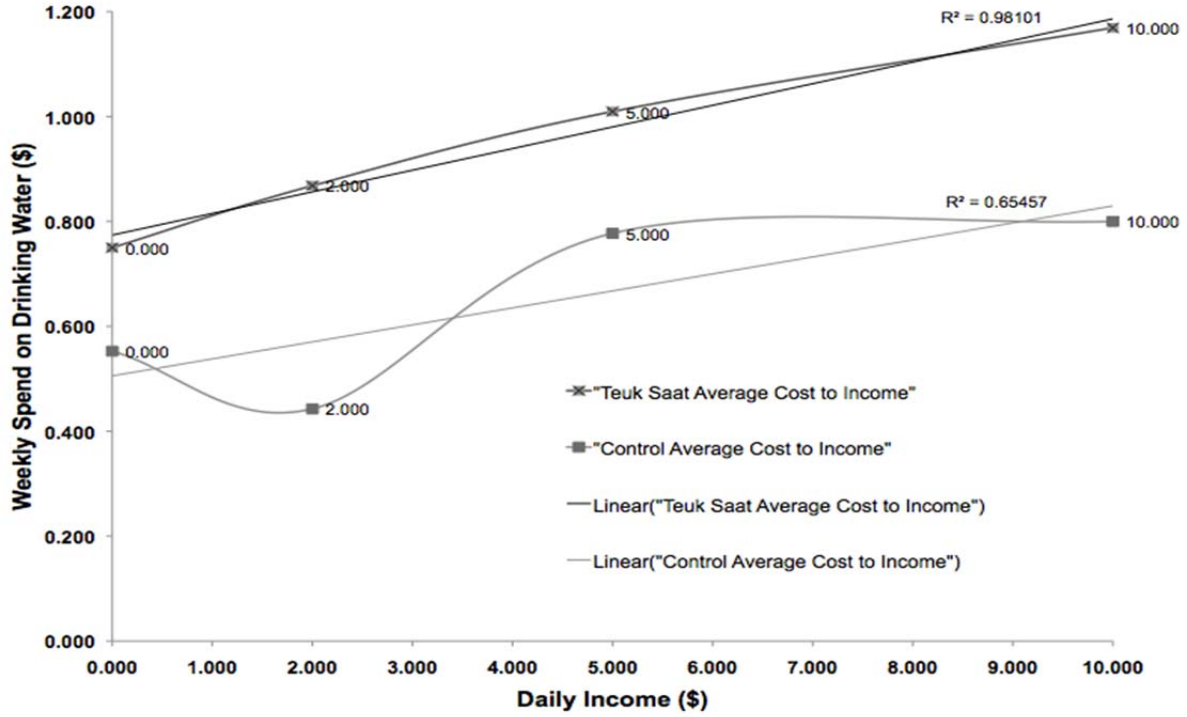

Figure 1 Weekly Cost of Drinking Water Associated with Income

Reasons cited for not buying Teuk Saat 1001

Households were directly questioned as to their financial motivation for choosing to either participate in or disregard the TS 1001 service. Families were initially asked what they liked or disliked about the cost of bottled water delivery, the results are expressed in Figure 2.

A total of 26 households buying from TS 1001 stated that they liked the system because of its 'good price'. Of these respondents, 13 (50%) earned >$5 per day, 10 (38%) earned $2-5, and 3 (12%) earned <$2. When asked, 40 control households stated that they did not buy TS 1001 bottled water because it was 'too expensive'. Of these, 4 (10%) earned >$5 per day, 19 (48%) earned $2-5, and 17 (42%) earned <$2.

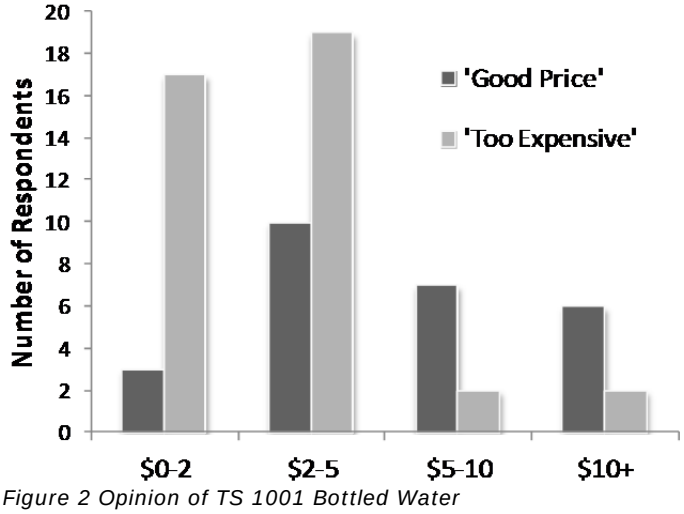

Figure 2 Opinion of TS 1001 Bottled Water

Households were questioned as to their primary motivation for not buying bottled water from TS 1001. The results are shown in Figure 3. Over a third of households surveyed answered 'too expensive'. This was the most common response by a margin of 15%.

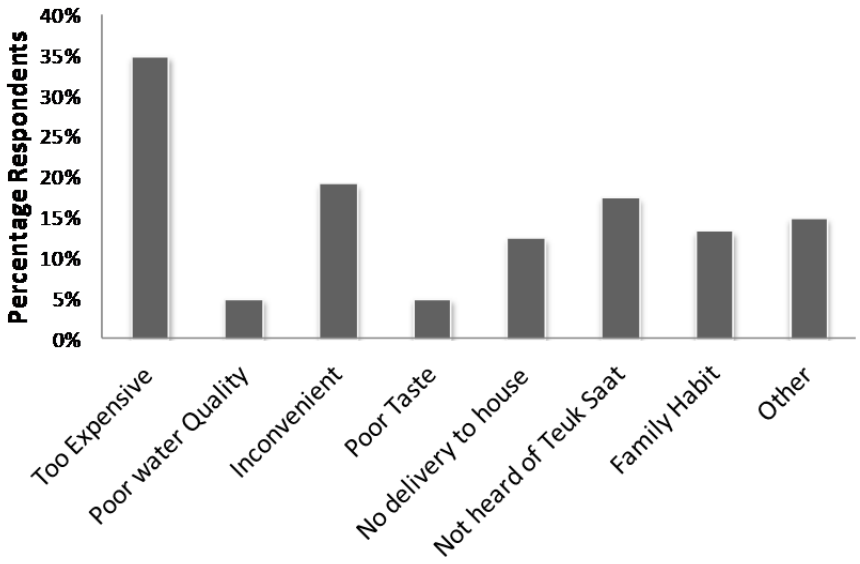

Figure 3 Reason given for not buying from TS 1001

Finally, households were asked if they had previously bought TS 1001 bottled water, but subsequently discontinued the service. Those that had were asked what their primary motivation had been for this decision; results are presented in Figure 4. Of the control households surveyed, 37 (31%) stated that they had previously bought TS 1001 bottles but had subsequently stopped. Of this group, 8 (22%) attributed this to bottled water being 'too expensive'.

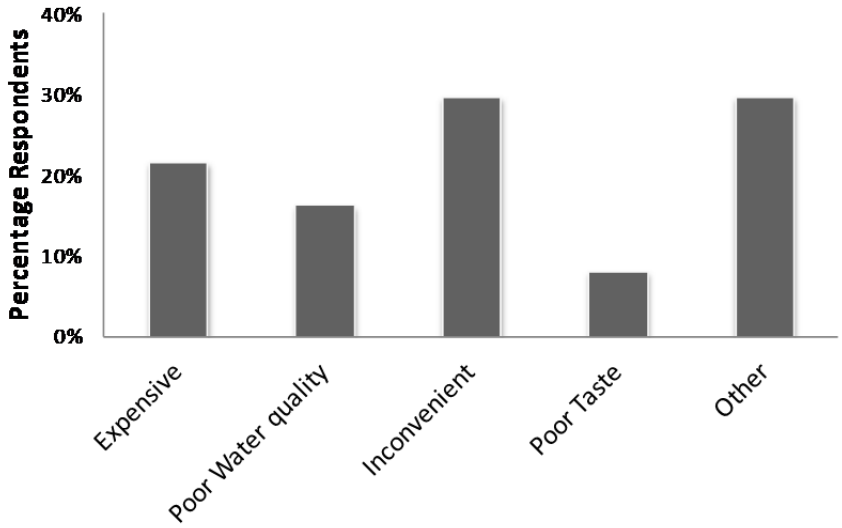

Figure 4 Reason given for not buying TS 1001

Discussion

Based on the odds ratio analysis of the sample groups, it is possible to conclude that families buying bottled water from the NGO are likely to: (i) earn over $10 per day; (ii) have good quality road access; (iii) own a flushing toilet and (iv) have access to mains electricity. In contrast, families are less likely to buy TS 1001 water if they: (i) earn under $5 per day; (ii) have poor quality road access to their home and (iii) own no toilet or sanitation facilities. This wealth divide is made more apparent when taking into account the other factors included in the odds ratio analysis (but deemed statistically insignificant due to the large spread of error). The following factors were all positively linked to purchasing TS 1001 bottled water: (i) living in a high wealth house; (ii) ownership of a car or motorbike; (iii) not having access to loans; and (iv) ownership of a television. Gleick (2004) suggested that the high cost of accessing bottled water may prove a barrier to its widespread application. The results of the odds ratio analysis support this view, despite the comparatively low cost of the TS 1001 service, families that bought bottled water from the NGO were generally wealthier than those that did not. Nearly half of the Cambodian population earn less than $1.25 per day (Irvine *et al.,* 2006), and water quality interventions must be suitably priced to reflect this if they are to be successful. TS 1001 is unlikely to fulfil this criterion, considering that at present the lack of capital prevents villages from maintaining even the current level of service for water and sanitation (UNDP and UNCF, 2007).

This study shows that as income within households increase the amount that is spent per week on average increases (Fig. 1), and this appears to follow an equal pattern between the control and TS1001 households. TS1001 is on average a more expensive option across all income brackets, possibly deterring the increase in expenditure required to access bottled water. What can be noted is that while all TS1001 receive treated water for consumption at point of use, only 77% of control households treat their water and only 48% of the control group have any associated cost for drinking water. This suggests that many households currently have access to free water and may not be willing to pay for drinking water.

In Cambodia it is a traditional and longstanding practice to boil water, PATH (2011) identified that 86% of households regularly boil water. The research in this paper identified that 56% of households in the control group boiled water and of these 76% incurred no cost for fuels to boil. Additionally 12.5% of those who switched to using TS1001 did so due to high boiling costs, suggesting that the cost for boiling may be influential in determining the uptake of bottled water. It has been previously reported that poor households spend as much as $180 per year on fuel to boil water (Hystra, 2011). Where free fuel is not available it is likely to be expensive, have a high carbon foot print, cause deforestation and involve significant collection time (CDC, 2009; Gilman and Skillicorn, 1985). The provision of safe drinking water is a core amenity of any home; however affluent households have a wider range of goods and services to choose from and are likely to spend more on services offering convenience, social status and perceived quality (PATH, 2011). These findings are reflected in the responses given by households when asked about the cost of their drinking water. Of the 40 families that described TS 1001 water as 'too expensive', 90% earned under $5 per day. This was supported by the fact that over 85% of families describing their own alternative systems as 'a good price' were in this income bracket (Fig. 2). Studies show that 26% of Cambodians rely on rainwater harvesting during the rainy season, as it is essentially free and represents advantages in convenience and water quality (ABD, 2007). Irvine *et al*. (2006) notes that households prefer to drink rainwater above other sources, which may explain the reluctance of low-income households to pay for bottled water delivery.

The Hystra report (2011) concluded that bottled water is most appropriate for medium and high density populations (>2,000 people per community), due to the logistics of transporting the water from the treatment centre. These systems are most cost-effective when treating water that has chemical pollutants or is brackish, as other systems can treat low-pollution water at less expense. In general, Cambodian waters have a relatively low level of pollution (Irvine *et al.,* 2006); although certain aquifers in the Mekong region of the country are known to be contaminated with arsenic (Polya *et al*., 2005). This high quality of both ground and surface water may mean the treatment process is over-prescribed and therefore unnecessarily expensive, although further research is required to investigate this.

A piped water connection has become the standard drinking water source for most households in the developed world, and is the level of supply to which most developing communities aspire (Baker, 2009). Data collected in the Hystra report (2011) shows that having large quantities of safe water available at the tap is the drinking water service that most households covet. While the results of this survey suggest that bottled water has proved a success with middle- and high-wealth families, it has so far been beyond the financial means of many of the poorest households. However, before piped water is widely available in rural homes across Cambodia it may be appropriate as a safe intermediate supply for those that can afford it.

Conclusion

The results of this study indicate that TS 1001 bottled water is not reaching the poorest families in rural communities. Current uptake of the system shows sales trending towards the middle- and high-wealth members of the community, with a high proportion of the lower-income households stating that the bottled water was 'too expensive' in comparison to their existing methods. This was supported by an analysis of typical household expenditure on drinking water.

While bottled water may not be financially appropriate for the most impoverished Cambodian families, it may potentially fulfil the role of an 'intermediate' supply for the more wealthy communities yet to be reached by expensive piped connections. The provision of bottled water to medium- and high-wealth families in the rural areas of the country is likely to have a positive impact on the number of Cambodians with access to safe drinking water. However, this study recommends that NGOs targeting the poorest strata of the community disregard bottled water as a financially appropriate method of distribution.

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Transitional Tents: Technical Milestone Report

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Summary

Work to date has contributed design, modelling, technical advice and analysis to the production of a procurement specification for a transitional tent. Interaction diagrams for the selected members have been created. The next steps are to produce a Disaster Severity Rating, conduct some testing, analyse possible durability improvements and structural upgrades and their impacts.

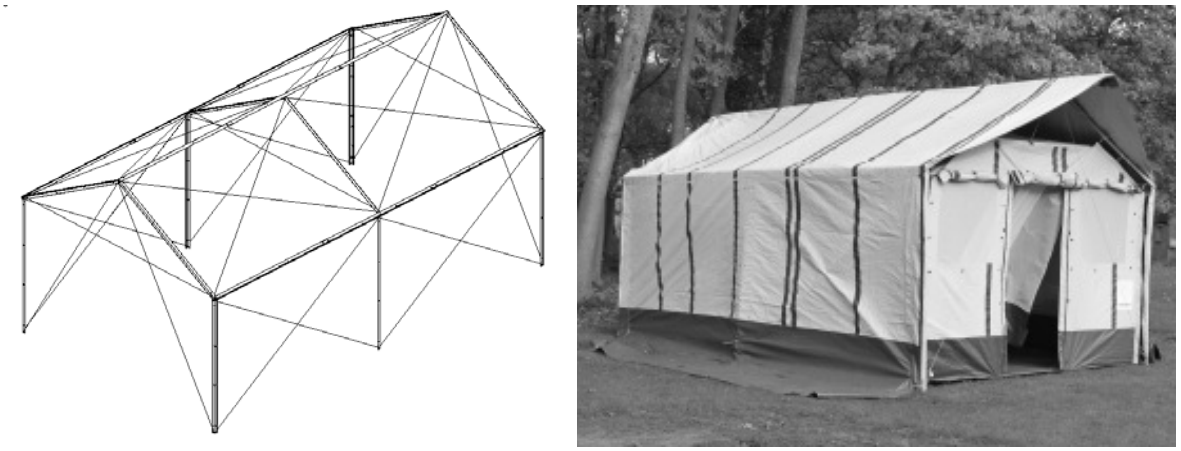

Fig. 1 – Google Sketchup image of current design's frame and photograph of similar prototype tent.

Keywords: Shelter, Frames, Transitional Shelter, Transitional Tents

Background

A transitional tent is an immediate, temporary shelter response that is airlifted to a location where the population have been displaced from their homes through natural disaster or conflict. The transitional tents are designed to last between six months and three years. They are designed to be upgradable and to be reused, resold or recycled at the end of their lifespan. The transitional tents must be designed to be stockpiled and airlifted to enable rapid deployment in the event of a disaster. The structures must be visibly temporary as landowners are often very reluctant to allow structures to be erected on their land if they feel the displaced population will never leave. Guy ropes cannot be used as these present trip hazards and limit the ability to densely pack the structures in deployment; this constraint presents several additional complications when designing temporary foundations and securement methods.

Introduction

This project is being conducted in direct collaboration with Shelter Centre, an Nongovernmental Organization based in Geneva. Shelter Centre work to support the sector of humanitarian operations that responds to the transitional settlement and reconstruction needs of populations affected by conflicts and natural disasters. The transitional tent design programme has been running for a number of years, with previous Cambridge University Engineering Department 4th year projects[i] contributing to the programme. This project began with a strict timetable driven by the need for the production of a procurement specification before the funding from DFID expired at the end of 2011.

The primary aims of this project are split into two phases: before and after the expiration of funding. The aim of the first phase was to contribute structural analysis, calculations and advice to the production of a procurement specification for a transitional tent. This was conducted during Michaelmas Term and during the Christmas Vacation before the end of 2011.

The second phase of the project has three primary objectives:

The first is to produce a Disaster Severity Rating for the designed tent. This entails analysing the structure to determine what conditions the tent should be expected to withstand. For example, it may be found to be expected to withstand Storm Force 2 winds.

The second objective is to determine how the durability of the tent can be improved, and what effects these improvements have on the Disaster Severity Rating. For example, it may be found that 6 standard sized corrugated roofing sheets can be added to the roof of the structure to improve the lifespan of the outer fly, but this may result in the structure only being expected to withstand Storm Force 1 winds.

The final objective of this second phase is to determine how the tent can be structurally upgraded. For example, it may be found that the addition of members in specific places results in the structure being expected to withstand Storm Force 3 winds. The effect of the application of these structural upgrades on the durability improvements must also be considered. For example, with the combined addition of corrugated roofing sheets and members in specific places the structure may be expected to withstand Storm Force 2 winds. NB: The Storm Force analogy is purely a simple illustration of the work to be conducted.

During this second phase testing of a tent prototype will occur. This will look to confirm the structural analysis is representative the structure and to investigate the amount of bow in the sheeting that can be expected.

Progress

Literature Review

The first stage of this project was to research the humanitarian shelter sector and grasp a full understanding of how the transitional tent is to be used. This involved researching Shelter Centre and Transitional Shelters, reading many documents, standards (1), guidelines (2) and previous CUED projects (3).

Project Plan

A series of meetings were held with Tom Corsellis, Executive Director of Shelter Centre, both in person and via video links between Cambridge and Geneva. This communication resulted in the formulation of the overall plan for the project.

Shelter Meeting

The Shelter Meeting is a biannual shelter sector event that addresses transitional shelter and resettlement needs. It is hosted by Shelter Centre and takes place in Geneva with over 73 different agencies being represented. Shelter Meeting 11B occurred at the beginning of November 2011. This project was presented at the two day meeting, this gave significant added value to the project through the feedback received. It also contextualised the project and enabled important contacts to be established.

Design Criteria

A series of design criteria were produced based on information gathered from previous experience in the sector and the requirements of DFID, the funders of the project. The most significant of these are that the structure must not exceed 100kg and must be able to be packed into two packages, each of less than 50kg, with a total volume of less than $0.5m^3$ and with no dimension exceeding 2m. The structure must provide at least $17.5m^2$ of covered living area and must have no guy ropes or extruding support structure.

Static Indeterminacy

When this project began there was already a preconceived design to work with. This included an A-Frame bracing at each end of the tent. It soon became apparent that this was statically indeterminate. The cables in the frame, which can only withstand tension, behave significantly differently depending on the forces applied; sometimes in counterintuitive ways.

Physical 2D Model

In order to analyse the end bracing, a two-dimensional model was constructed using card, wool and split-pins. This can be seen in Fig. 2 where a force has been applied as the arrow indicates; clearly identifying which of the tension members become slack. This model was used to apply forces to various parts of the frame to see which tension members were not used under various load cases. This enabled hand calculations to be performed for a series of load cases, removing the slack cables in each case, thus making the structure statically determinate.

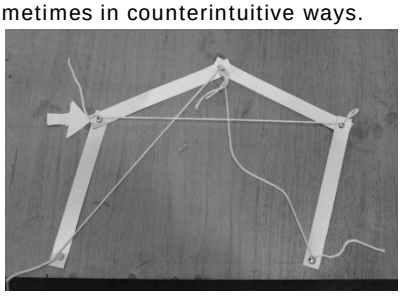

Fig. 2 – 2D Physical Model

Oasys 2D Model

Having performed hand calculations based on the 2D physical model, a two-dimensional finite element model was created in Arup's Oasys software. This was used to confirm the accuracy of the hand calculations and to form a basis for the three dimensional model to be constructed later.

Physical 3D Model

To appreciate the flow of forces in three dimensions, a physical 3D model was constructed. This model has one significant limitation: the joints carry moments whereas the real structure is pin-jointed. This model can be seen in Fig. 3 with a force being applied by a finger in the same position and direction as the model in Fig. 2.

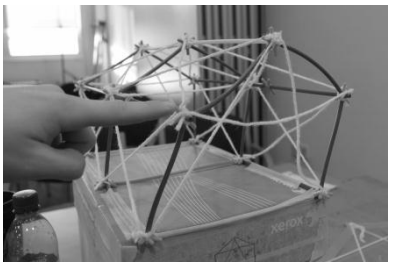

Fig. 3 - 3D Physical Model

Oasys 3D Model

A 3D model was constructed in Arup's Oasys software. This required several iterations of building to achieve a model that was representative of the structure. Eventually it was constructed using "struts" as the members because otherwise either the joints carried moments or there were singularities resulting in an unsolvable model.

Member Selection

With such stringent weight and volume constraints the member size selection in this design was critical. It was decided that equal angle sections would be most suitable as there is significantly less wasted space when packed in comparison to hollow sections. They are also significantly easier to join and repair if bent than circular hollow sections. This project continues on from previous work[ii] conducted that suggests a 40x40x4mm equal angle aluminium section would be most appropriate. Research was then conducted into regular steel sections around the world. This was to ensure that if the original aluminium members need to be replaced during deployment, locally sourced steel sections could easily be interchanged for the aluminium members.

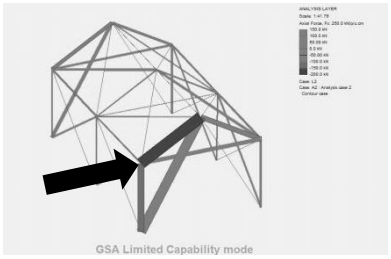

Fig. 4 – Oasys 3D Model

Consultation with Existing Manufacturer

Losberger produced a similar design of a transitional tent, based on early Shelter Centre work. This has never been taken beyond the prototype stage. Meetings have been held to consult with the Director of Business Development Humanitarian Relief at Losberger RDS. The company manufactured and assembled several of these structures and therefore relevant technical experience and advice was provided. This was fed back into the procurement specification produced.

Interaction Diagram

Two interaction diagrams have been produced after hand calculating a series of moment and axial capacities for both 2000mm and 2800mm members these are summarised in table 4.1. Once the aluminium equal angle's section properties had been calculated the Euler buckling load was calculated for buckling about both the minor and major axis. This was done using equation 4.1.

$$P_e = \frac{\pi^2 EI}{L^2} \qquad \textit{Equation 4.1}$$

The axial-torsional buckling (ATB) load was calculated using Equation 4.2. This was found to be significantly larger than the Euler buckling loads and has not been included on the Interaction Diagram as these modes will dominate before the ATB load is reached. Its inclusion would also result in a much bigger scale on the y-axis making the interaction diagram less clear in the area of importance.

$$P_{ATB} = AG\left(\frac{t}{b}\right)^2 \qquad \textit{Equation 4.2}$$

The bearing capacity was calculated using equation 4.3. This has also not been included on the Interaction Diagram for the same reason as axial-torsional buckling.

$$P_{pl} = \sigma_y A \qquad \textit{Equation 4.3}$$

The plastic minor and major moment capacities of the aluminium sections were calculated using equation 4.4.

$$M_{pl} = Z_p \sigma_y \qquad \textit{Equation 4.4}$$

The minor lateral torsional buckling moment capacity was calculated using equation 4.5 (equal angle sections do not warp).

$$M_{LTB} = \frac{\pi}{L}\sqrt{EIGJ} \qquad \textit{Equation 4.5}$$

Axial Capacity		Moment Capacity	
P_{pl}	83.6KN	$M_{pl_{Minor}}$	120Nm
P_{ATB}	79.0KN	$M_{pl_{Major}}$	1100Nm
$P_{e_{Minor}}$*(L=2000mm)*	6.3KN	$M_{LTB_{Minor}}$*(L=2000mm)*	360Nm
$P_{e_{Major}}$*(L=2000mm)*	25.4KN	$M_{LTB_{Major}}$*(L=2000mm)*	730Nm
$P_{e_{Minor}}$*(L=2800mm)*	4.4KN	$M_{LTB_{Minor}}$*(L=2800mm)*	260Nm
$P_{e_{Major}}$*(L=2800mm)*	18.1KN	$M_{LTB_{Major}}$*(L=2800mm)*	520Nm

Table 4.1

The moment capacities have been plotted on the X-axis of the Interaction Diagram and the axial capacities on the Y-axis. The diagram has been completed by the addition of a straight line from the lowest value on each axis, as can be seen in Fig 4. Initial calculations of member moments due to wind loading show that the moment is expected to be in the order of 200Nm. This shows that the moment is likely to be the dominating failure mode, and therefore a straight line between the lowest critical axial force and lowest moment is likely to be sufficient for the Interaction Diagram.

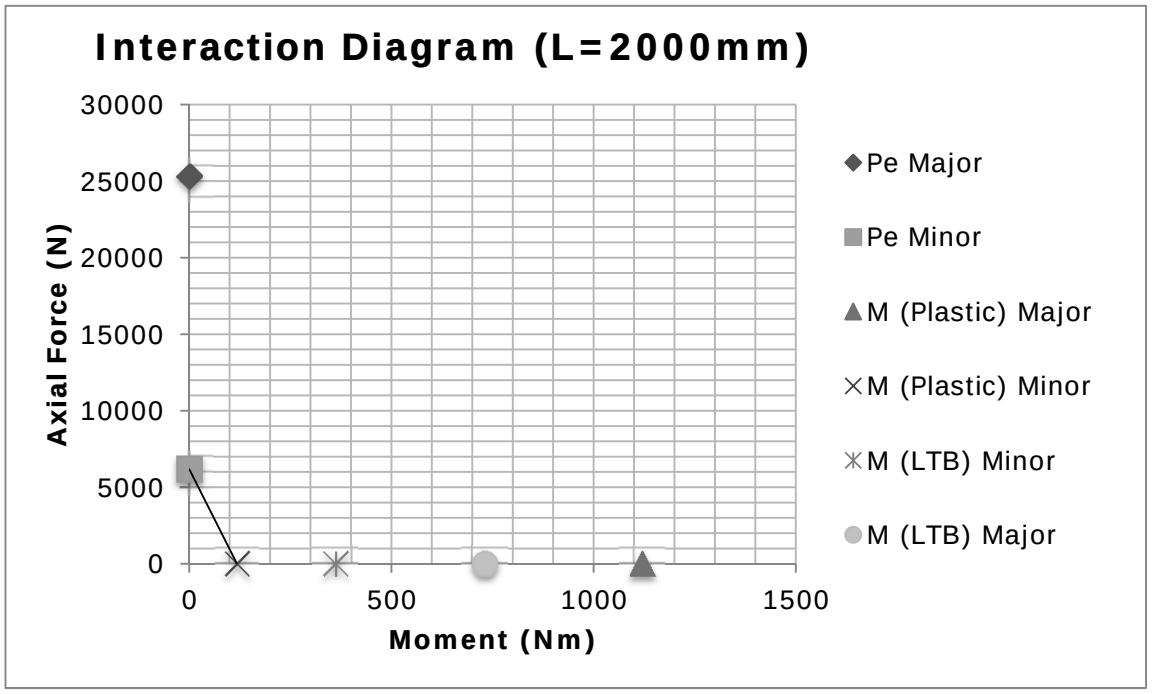

Figure. 5

Future Work

The second phase of this project has now begun. This phase aims to perform tests to analyse the reliability of the modelling, produce the Disaster Severity Rating, assess potential improvements and upgrades and analyse their impacts.

Oasys Model

The next step which must be undertaken is to upgrade the current Oasys model to be constructed out of members, which can carry moments that are appropriately released at each joint to allow the structure to be pin jointed. This will allow the load cases to be applied and run. When previous attempts to make the model in this way were made it resulted in singularities in the stiffness matrix causing the model to be unsolvable after end constraints were removed. The "struts" the model currently uses are not able to carry moments and cannot have distributed loads or moments applied to them. It is anticipated that the method required to build this model will be to change each of the 48 members individually and release end constraints and run some test cases after each change to ensure that the model runs accurately.

The model will also be upgraded to allow the securement against uplift via the sidewalls of the fly being buried to be modelled.

Load Cases

Load cases for various scenarios will be developed. This will be done primarily consulting Eurocode 1, building up a series of cases relating to different environments and weather conditions. Once they have been developed these will be applied to the Oasys model and the results related to the interaction diagram, which has already been created.

Improvements

Potential improvements such as the addition of corrugated roofing sheets will be investigated and considered. Loading cases will have to be built up for each improvement and combination of improvements. This will then be run on Oasys with all previous live load cases for analysis on how the structure responds.

Upgrades

From applying the load cases to the model it will become clear where the most vulnerable parts of the structure are. Reinforcement "Upgrade Packs" will then be designed to improve the performance of these aspects of the structure. The new, upgraded, structure will be constructed in Oasys and the change in response to the various live load cases analysed.

Testing

Steps will be taken to attempt to obtain a prototype for the procured tent design to enable testing. This will be highly valuable, as it will enable the theoretical and modelling work to be verified. If a tent can be acquired it will be erected and various loads applied to it, most notably wind loads. If it is not possible to test a full tent then a panel of the tent will be constructed with outer fly attached to it and wind loading applied to examine the behaviour of the fly and the way forces are to be transferred to the structure. It is important to understand how much the outer fly will bow as this has significant effects on the forces transferred to the aluminium members.

Implementation of Work

The purpose of producing a transitional tent procurement specification is for it to be used to manufacture a series of prototypes. These will be tested by various parties in the humanitarian shelter sector. The Disaster Severity Rating will be used to determine the structure's suitability in response to disaster situations. Information about the improvements and upgrade packs investigated in this project will be released in information packs with the tents during deployment. The conclusion of this work will enable the inhabitants to live safely in a shelter that will last. If found to be successful, or after some refinements, DFID are likely to produce and stockpile a large number of the transitional tents. Several other NGOs have expressed a strong interest in purchasing orders to stockpile, including Save the Children, Medecins Sans Frontieres and USAID.

References

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Characterisation and fluidisation of synthetic pit latrine sludge

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Abstract

Half the world's urban population will live in informal settlements or "slums" by 2030. Affordable urban sanitation presents a unique set of challenges - lack of space and resources to construct new latrines necessitates the de-sludging of existing pits and is currently done manually with significant associated health risks. Various mechanised technologies have been developed to facilitate pit emptying, with the majority using a vacuum system to remove material from the top of the pit. However, this results in the gradual accumulation of unpumpable sludge in the pit, which eventually fills the latrine and forces its abandonment.

This study has developed a method for fluidising unpumpable pit latrine sludge, based on laboratory experiments using a harmless synthetic material. Such a sludge was developed using clay and compost to replicate the physical characteristics of pit latrine sludges characterised in Botswana. Undrained shear strength and density are identified as the critical parameters in controlling pumpability and a method of sludge characterisation based on these parameters is reported.

A series of fluidisation tests using a one-fifth scale pit emptying device found the reduction in sludge shear strength to be caused by i) dilution, which increases water content, and ii) remoulding, in which mechanical agitation breaks down the structure of the material. The tests demonstrated that even the strongest sludge could be rendered "pumpable" by sufficient dilution. Additionally, air injection alone caused sufficient remoulding to produce a three-fold decrease in strength of consolidated samples at constant water content.

The implications for sludge treatment and disposal are discussed, and the classification of sludges according to the equipment required to remove them from the latrine is proposed. Possible field tests to estimate sludge density and shear strength are suggested. The feasibility of using low cost vacuum cleaners to replace expensive vane pumps is also demonstrated. This offers great potential for the development of affordable technologies that can remove significantly stronger sludges than current devices through fluidising the wastes at the bottom of the pit before emptying.

Keywords: Pit latrine, de-sludging, sanitation, developing counties, urban slums

Introduction

Providing adequate sanitation to rapidly growing urban populations is one of our generation's greatest challenges. An estimated 2.6 billion people lack access to improved sanitation, contributing to some 1.8 million deaths per year from diarrhoeal disease [WHO, UNICEF 2010]. Target 7C of the Millennium Development Goals is to halve by 2015 the proportion of people without access to basic sanitation, yet even "improved" facilities often constitute no more than limited access to a shared latrine [UN-Habitat 2003].

Urban informal settlements provide very different challenges to those encountered in rural areas. Many houses do not have space for individual toilets and those that do will typically be unable to dig a new pit when their latrine is full. An estimated 100 million urban dwellers have no option but to defecate in open spaces or plastic bags because public latrines are overflowing, too far away or unaffordable [UN-Habitat 2003]. This problem will only get worse with urban populations in developing countries forecast to double in size to over five billion by 2050 [UN-DESA 2009]. Much of that urban growth will be in informal settlements or slums.
Regular de-sludging of existing pit latrines is therefore necessary if they are to provide a sustainable service in high density urban settlements [Jere et al, 1995]. The *vyura* (frogmen) of Dar es Salaam earn a living from manually emptying pits – spending up to six hours at a time waist deep in faecal sludge [Still, 2002] without protective clothing. In addition to the wide range of diseases they may contract, there is also a risk of collapse in unlined pits and they are stigmatised by local communities, forcing them to work after dark and to illicitly dump sludge in the nearest available sewer or stream [Eales 2006].

To address this problem significant work has been done to develop affordable mechanised pit emptying technologies for use in high density urban settlements. The most common system uses a vacuum to draw waste out of the pit, either by hand pumping (e.g. "Gulper") or with a motorised vacuum pump (e.g. UN-Habitat Vacutug) [O'Riordan, 2009]. Vacuum systems are beneficial as they allow minimal human contact with the pit contents and reduce the likelihood of blockages as the sludge does not pass through the pump.

However, most vacuum devices can only generate a few metres of static head and are therefore limited to extracting the liquid waste at the top of a pit [Kwach, 2008]. This leads to the progressive build up of highly viscous sludge at the bottom of pits, which becomes "unpumpable" after around two years of consolidation. There has been limited quantitative comparison of the performance of different pit emptying prototypes due to the variability of pit latrine sludge and a lack of data on its physical properties. Prototype development tests currently either use faecal sludge, with

significant health and safety hazards, or an artificial sludge mixed with little control over its physical properties. This paper describes the development of a synthetic sludge with well defined physical characteristics that are representative of pit latrine sludge, and uses this to develop new testing procedures for sludge characterisation and the assessment of 'pumpability'. A fluidisation process is also described that extends the capability of vacuum based systems by injecting pressurised water and air into the bottom of an "unpumpable" sludge using low-cost, appropriate technology.

Characterisation of a synthetic sludge

Development of a representative synthetic sludge

For safety and consistency in testing, a synthetic sludge which replicates the range of strength reported for pit latrine sludge was developed using inert materials readily available in the developing world. This was based on the only data in the literature, from a study conducted by the International Reference Centre for Waste Disposal (IRCWD) in Gaborone, Botswana during the mid-1980s [Bosch & Schertenleib, 1985]. Their report presents the density, water content and viscometer scale reading of 47 samples of pit latrine sludge as shown in Figure 1.

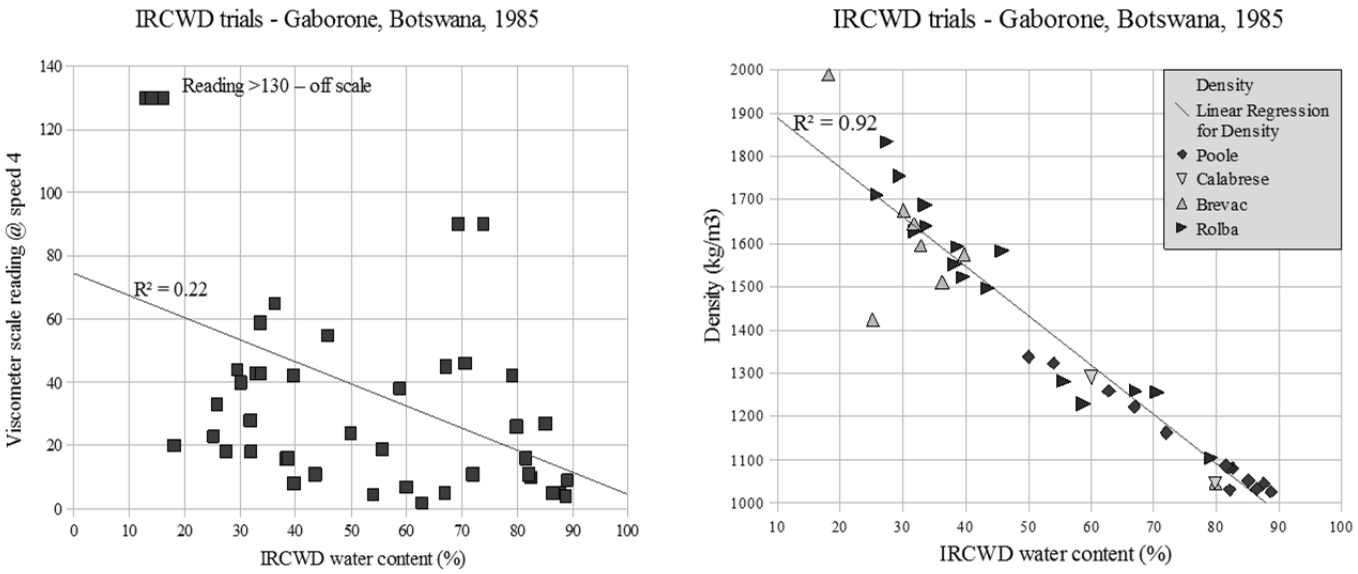


Figure 1: Effect of water content on sludge properties

Sludges were classified according to BHRA strength classes , ranging from "low-" to "high+" and equivalent to shear strengths of 20-400Pa at a strain rate of 10/s. This demonstrates the variability of pit latrine sludge (viscosity range: 2-130+, density: 1027-1989kg/m^3). There is no correlation between viscosity and water content (R^2 = 0.2), however density is strongly negatively correlated to water content. Various synthetic sludge compositions were investigated and low-cost, readily available materials were considered, including compost, clay, sand, animal feed, maize meal and shredded newspaper. A mixture containing equal parts by dry mass of compost, clay and sand, with 80% water content was selected to investigate how varying the composition would affect sludge density and shear strength. The moisture content was increased by increments of 5% up to 125% and each resulting sludge characterised. There was concern that the large, heavy sand particles would settle out, therefore a second series of tests was conducted on a two component sludge where the sand was replaced with additional clay. A series of sludges with clay contents ranging from 64% to 85% and constant nominal water content of 105% were then characterised to assess the effect of solid composition on sludge behaviour, as detailed in Table 1 below.

First series: Constant solid composition of 33% clay, 33% compost, 33% sand by dry mass							
Water content	80.3%	83.9%	92.9%	97.3%	105.8%	113.3%	125.7%
Second series: Two component (clay-compost) sludge with constant nominal water content of 105%.							
Solid composition (clay-compost)	64% clay	69% clay	73% clay	78% clay	85% clay		
Water content	104.7%	102.2%	104.6%	122.9%	113.7%		

Table 1: Details of synthetic sludge compositions

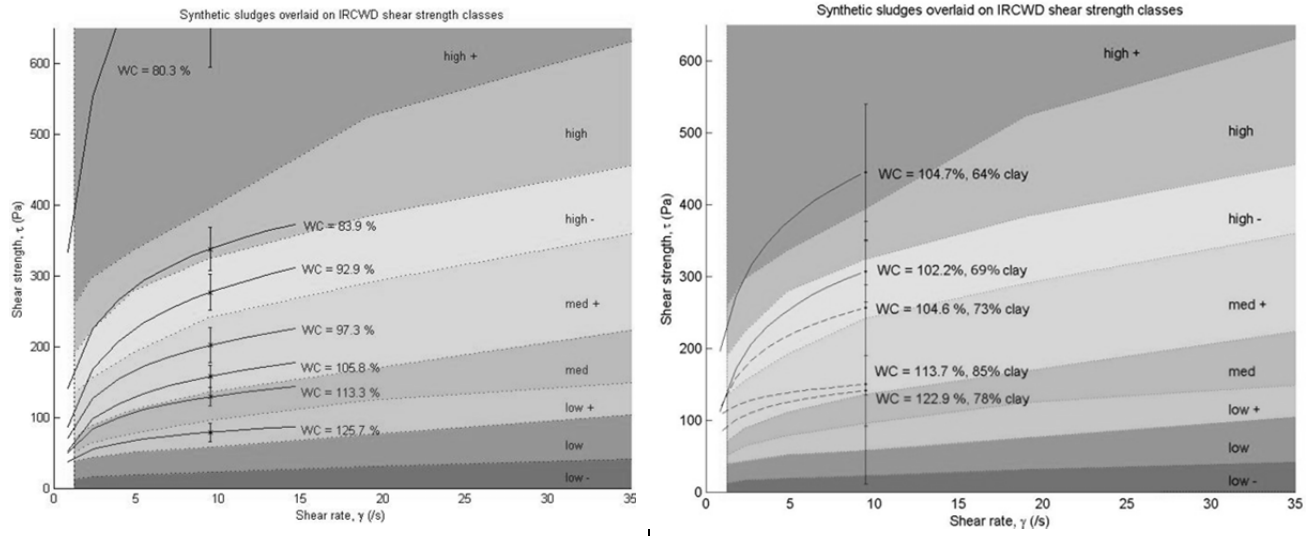
Sludge measurements

The IRCWD study used viscosity as the characteristic parameter for flow behaviour. Pit latrine sludge is both thixotropic (viscosity decreases with time at constant strain rate) and pseudoplastic (viscosity decreases with increasing strain rate) making it difficult to measure an absolute viscosity. The IRCWD viscosity data was recorded as a "scale reading at nominal speed" which is specific to the particular viscometer used in that study. It has therefore been converted into "shear strength at strain rate" data for comparison with this study. Consolidated pit latrine sludge behaves more like a soil than a fluid as it does not readily flow, making undrained shear strength a more intuitive measure of "pumpability" than viscosity.

A mini ball penetrometer developed for testing very low strength marine muds was used to measure shear strength in the laboratory. The penetrometer uses a local measurement device within the ball [Kuo, 2011] and a linear calibration curve was plotted by placing small masses on top of the ball and taking readings. The penetrometer was driven by a computer controlled actuator and the penetration rate calibrated using a linear voltage distance transducer. The shear strain rate at the surface of a ball penetrometer can be estimated as twice the penetration rate divided by the ball diameter [Randolph & Anderson 2006]. The shear strength of the sludge is calculated by dividing the recorded penetration resistance by a correction factor N_{ball} which was calculated as 14.4 through calibration against a viscometer. Penetrometer tests were carried out in a container large enough to perform five tests with non-overlapping zones of influence. Penetration tests were performed at speeds from 10-200mm/s, corresponding to shear strain rates of 0.8-15.7/s, and included the 10/s rate quoted in the IRCWD report.

Results and characterisation

The effect of water content on sludge shear strength is demonstrated in Figure 2a below, which overlays the strength of the different synthetic sludges on the IRCWD strength classes. The full strength range of pit latrine sludge can be covered by simply adjusting the water content of the synthetic sludge. The results from varying the solid composition of the two component sludges are shown in Figure 2b. This indicates that increasing the proportion of clay, at approximately constant water content, reduces sludge strength. This is because compost has a moisture content of around 90%, whereas clay is supplied in dry form, so less liquid is added to a high compost sludge due to the moisture already bound within the compost. This results in compost-rich sludges having higher strength and drier consistency than clay-rich sludges of similar water content.



a – Water content | **b – Solid composition**

Figure 2: Effect of water content and solid composition on sludge shear strength

On the basis of these tests it was decided that a suitable composition for subsequent fluidisation testing would be 30% compost and 70% clay, adjusting water content to control shear strength.

Fluidisation of synthetic sludge

A second phase of the investigation examined the fluidising effects of injecting water and compressed air into the bottom of a pit of sludge. There are two principal effects to consider: dilution decreases shear strength by increasing water content, whereas remoulding breaks down the structure of the material by mechanical agitation. Unconsolidated sludge was first used to investigate the effect of dilution and then a series of consolidated sludges were fluidised using compressed air to determine the decrease in strength from remoulding alone.

Experimental procedure

A one-fifth scale Vacutug was manufactured and powered by a 2kW vacuum cleaner, producing 0.3bar suction and 0.27bar pressure. An additional vacuum cleaner could be connected in series to generate 0.45bar suction. A schematic layout of the apparatus is shown in Figure 3.

Figure 3: Schematic diagram of the fluidisation apparatus

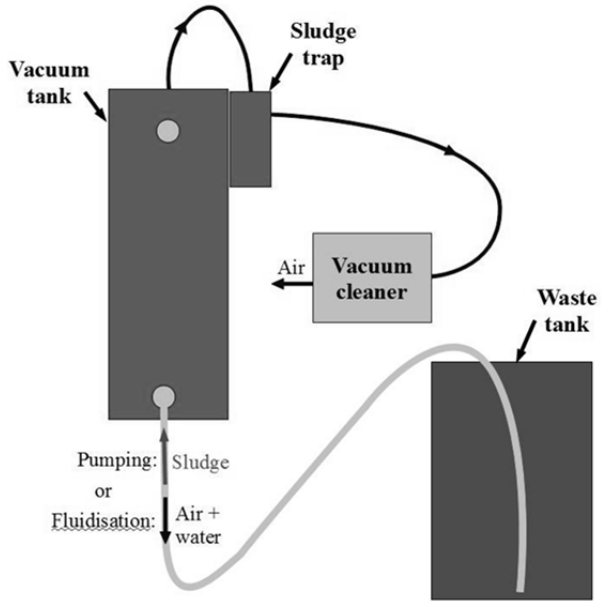
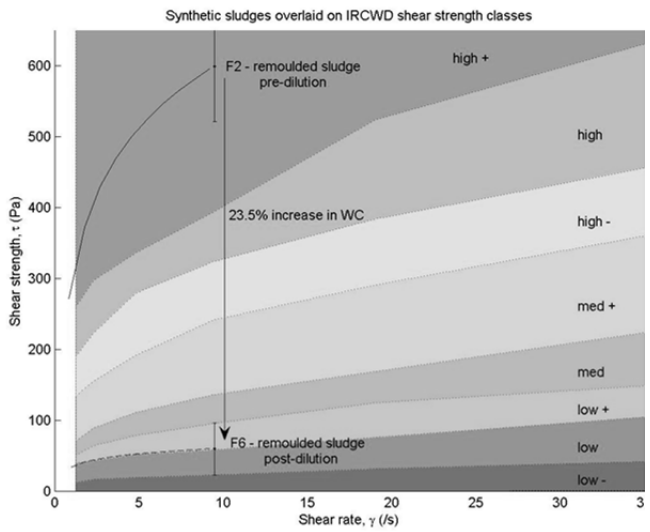


Figure 3: Schematic diagram of the fluidisation apparatus

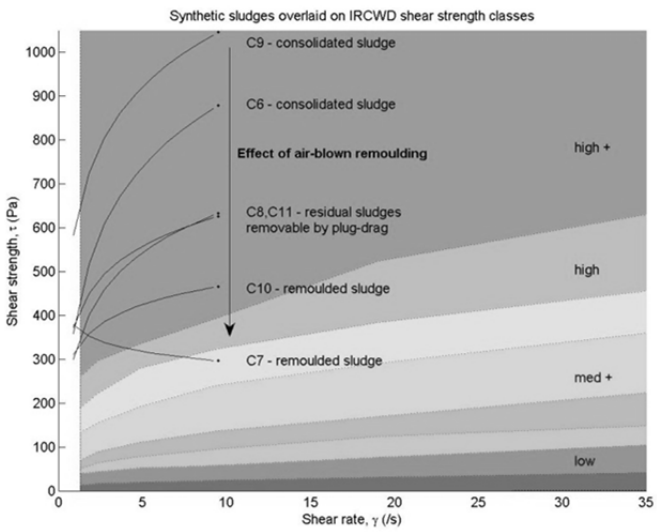
Research into water jetting offshore identified the number of fluidisation cycles and the volume of water injected as key control variables [Bienen et al., 2009]. The volume of water used for waste disposal should be minimised as it may be either unavailable or unaffordable in urban informal settlements [UN-Habitat, 2010]. An 'unpumpable' high+ strength sludge consisting of 30% compost and 70% clay by dry mass was selected for the dilution trial, and water added in small increments. The sludge was characterised at its first 'pumpable' composition. In a further series of tests, submerged sludges were left to consolidate for two weeks, producing a material more representative of pit latrine contents. The consolidated sludge was tested 'in-situ' with the ball penetrometer, producing a profile of shear strength with depth, and the total depth was recorded. Every consolidated sludge was tested at two different speeds (20 and 121mm/s) with four repeats, totalling eight tests at different points in each sample. The lower speed is the standard rate quoted in the geotechnical literature and the higher speed corresponds to the shear rate from the IRCWD study. A burst of compressed air was then forced into the bottom of the waste tank and the 'in-situ' test repeated to produce a shear strength-depth profile for the fluidised sludge. The pumps were set to suck and if 'pumpability' had been achieved, the vacuum tank filled with sludge and the waste tank emptied. The depth of any residual sludge in the waste tank was recorded and a sample taken for characterisation.

Results

Figure 4a shows the results from dilution tests on unconsolidated sludge. A dramatic decrease in strength was produced by dilution, and a previously 'unpumpable' high+ strength sludge was successfully emptied using a single vacuum cleaner. This confirms that the process of injecting water followed by compressed air effectively mixes the sludge, demonstrating that even the strongest of sludges can be rendered pumpable by sufficient dilution.



a – Dilution



b - Remoulding

Figure 4: Fluidisation of synthetic sludge

Tests on consolidated sludge (which is more representative of the material in pit latrines) are shown in Figure 4b and better indicate the system's true potential. These results suggest that air blown remoulding alone can reduce shear strength by a factor of three.

Discussion

Strong fluid or weak soil?

The work described herein proposes the use of undrained shear strength, rather than viscosity, as the control parameter to determine whether sludge will flow under suction. The different approaches stem from whether pit latrine sludge is treated like a strong fluid and therefore a hydraulic problem (most sanitation professionals are from a water engineering background) or whether it is treated as a weak soil. Where pit latrine sludge was previously seen as an unusual non-Newtonian fluid, whose viscosity was difficult to quantify in absolute terms, here it is treated analogously to very weak clay. Conceptually, it also makes sense to treat the sludge as a solid soil rather than a fluid – if it behaved as a fluid then emptying pit latrines would be a far easier task.

Although the sludge strength is an important parameter controlling whether it will flow towards a suction hose, density is equally important in determining the depth to which a pit can be emptied. Unfortunately the importance of density is often overlooked, as demonstrated by numerous pit emptying devices with unnecessarily high tank mountings which require greater suction to empty a pit. In order to effectively characterise a sludge, tests should be conducted to determine both its density and undrained shear strength.

Making sludge more "pumpable"

The investigation into fluidisation and pit emptying using remoulded sludge found that all strengths tested could be made 'pumpable' by adding water, establishing an upper bound on the amount of dilution required for pit emptying. This includes sludge more than twice as strong as those reported in the IRCWD study and suggests that injecting sufficient water can render any sludge pumpable. It is vital however, that the water is injected into the bottom of the pit, otherwise it will simply form a lower density layer above the sludge. A 23.5% increase in water content was required to make a 'high+' strength sludge pumpable by dilution alone. This would increase volume by approximately 35%[1], which may not be feasible as latrines are typically filled until they become unusable [Jere et al., 1995]. Additionally it would require 350L of water per cubic metre of sludge. Although poor quality water could be used, the only option available in many urban informal settlements is potable water bought from vendors at great expense.

One potential solution would be to first remove some of the weak supernatant fluid from the top of the pit and reinject it to fluidise the remaining sludge at the bottom of the pit. This would avoid wasting valuable potable water, whilst at the same time eliminating the volume increase. However, the supernatant fluid contains the most recently deposited faecal matter and is therefore heavily contaminated with pathogens. The tests on consolidated sludge demonstrated that compressed air could reduce strength by a factor of three, suggesting that remoulding has a significant effect and fluidisation could be achieved using significantly less water. The fluidisation process suggested in this investigation would

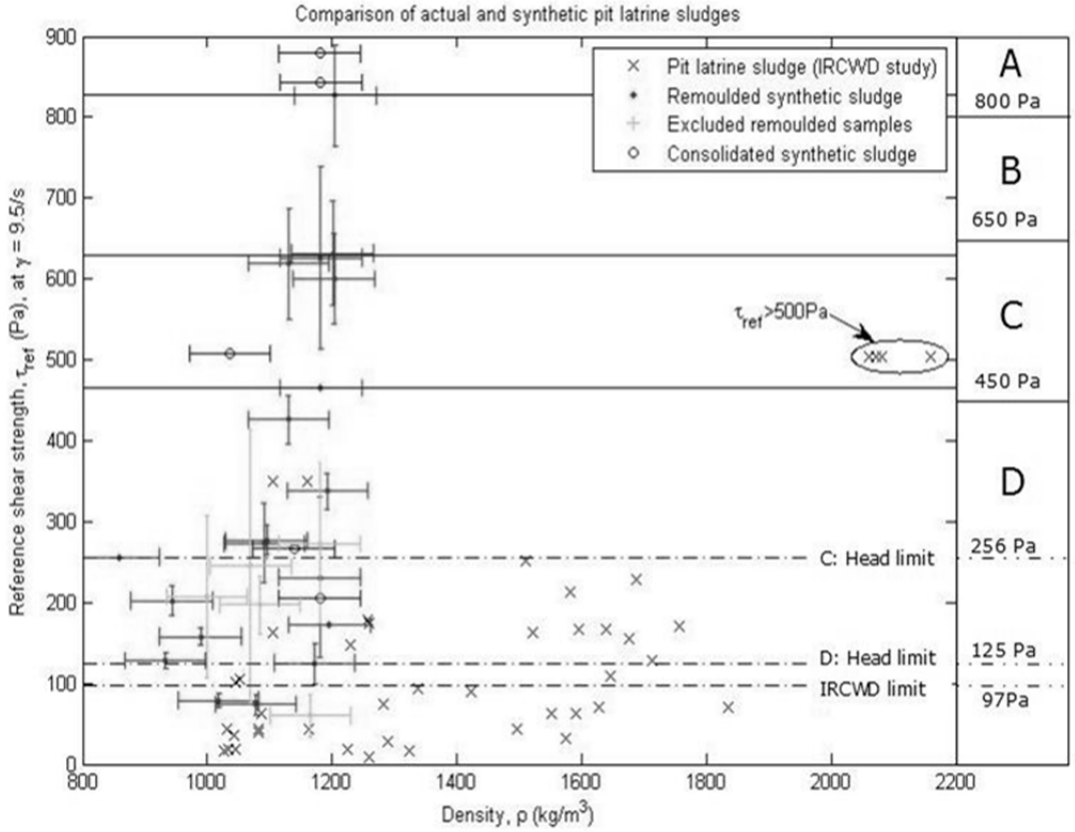
[1] Assuming a typical sludge density of 1800kg/m^3

increase the solids content and volume of sludge that can be removed from pits mechanically, as currently only the water-like supernatant is pumped out. This increase could be problematic as "Appropriate low-cost treatment options for such FS [faecal sludge] need as yet to be developed" [Koné & Strauss, 2004]. However, older, consolidated sludge from the bottom of the pit is partially decomposed, so poses less of a public health hazard [Sharpe, 2010], therefore even if it is dumped directly into the environment it would be an improvement over the current practice of dumping only the most highly contaminated sludge from the top of the pit.

It has been widely reported in the literature [e.g. Strauss & Montangero, 2002] that transportation of sludge to its disposal point is the slowest and most expensive part of pit emptying - the Vacutug for example travels at just 5kph. The additional sludge that can be extracted by first fluidising the wastes could therefore result in increased environmental dumping if suitable haulage and treatment processes are not implemented, and there is a particular need for the development of decentralised treatment [Strauss & Montangero, 2002] or faecal sludge transfer stations. To prevent indiscriminate dumping it is also important that innovative payment systems are developed so that pit emptiers are reimbursed rather than charged for delivering sludge to treatment works [Strauss & Montangero, 2002; Newton, 2010].

Sludge classification

The undrained shear strength and density of the range of synthetic sludges tested are compared with those recorded by the IRCWD in Figure 5. The difference in densities is caused by the relatively high proportion of compost used in the synthetic sludge, which has a low bulk density. However, replicating the range of shear strengths was considered more important than replicating the density range because shear strength determines whether sludge will start to flow under pumping, regardless of the scale of the test. The effect of density, in contrast, depends on scale as it controls how much static head is required to pump a given sludge. An important outcome of this investigation is to make recommendations on how to categorise different 'classes' of pit latrine sludge in the field. If data were collected by pit emptiers rather than in isolated scientific studies, a database of physical properties of sludge could be rapidly developed. Sludge testing should therefore be of benefit to pit emptiers and it is proposed that sludges are classified according to the emptying methods and equipment required. The different classes of sludge proposed here relate to the performance limits of the vacuum-cleaner system used in this investigation. Further tests using other devices are required to produce a wider range of classes, from heavily consolidated sludge that is removed manually, to thin supernatant liquid that behaves like water.



Class A: 'Unpumpable'

Class B: Dual vacuum cleaners, plug-drag operation, 0.45 bar suction

Class C: Dual vacuum cleaners, continuous operation, 0.45 bar suction

Class D: Single vacuum cleaner, continuous operation, 0.3 bar suction

Figure 5: Proposed sludge classification

The dashed lines showing head limits were found to occur at significantly lower shear strengths than the corresponding sludge class boundaries. This highlights the importance of sludge density in controlling whether a waste is 'pumpable', as relatively strong sludges can be pumped provided that no static lift is required. Where possible, the vacuum tank should be positioned downhill from the latrine, minimising the height over which the sludge is lifted – particularly in informal settlements built on steeply-sloping marginal land, such as Kibera in Nairobi. A strength limit of 97Pa was reported by IRCWD for continuous operation[2] emptying, marked as a horizontal line in Figure 5 and comparable to the Class D head limit of 125Pa. The devices tested in Botswana all produced in excess of 0.3 bar suction, suggesting they would be capable of remoulding a sludge of strength 450Pa and that the IRCWD data represents the maximum density, not strength, of sludge that could be removed. This highlights the need for strength testing of pit latrine sludge as the only currently available data is from the IRCWD study which is not truly representative of sludge strengths. The proposed method of sludge classification could save pit emptiers time and money by enabling them to only inject water when required. The IRCWD report noted that crews occasionally wasted time looking for non-existent blockages when a lack of static head caused pit emptying to cease. If tests were done when emptying ceased one could rapidly determine whether the limit of pumpability had been reached, or if the system is blocked. The benefits outlined above could provide an incentive for pit emptiers to characterise the sludge before emptying, and report that information upon delivery for treatment and receipt of payment. Unfortunately faecal sludge management chains are usually far removed from the smooth-running system described above [Boot & Scott, 2008] and it is questionable whether a rigorous and accurate sludge reporting procedure could actually be implemented.

Field test procedures

The variability of pit latrine sludge is widely acknowledged [e.g. Strauss & Montangero, 2002], however the current knowledge of its physical behaviour is based entirely upon the IRCWD study. There is therefore a critical need for widespread characterisation of pit latrine sludge in order to support the development of improved pit emptying technologies. An accurate measurement tool is required, however the delicate laboratory equipment used in this

[2] As opposed to plug-drag operation or other pneumatic conveyance systems

investigation would be impractical in the field. A simplified and robust pit latrine characterisation device is therefore needed. Such a device could be a form of ball penetrometer, vane shear test or bearing capacity test, designed specifically for the range of shear strengths expected from pit latrine sludge.
In addition to gathering detailed data on the physical characteristics of pit latrine sludge, simple tests carried out by unskilled workers to classify sludge (e.g. 'Class B') also need to be developed to enable widespread data collection of approximate sludge characteristics and support the development of appropriate pit emptying technologies.
The effective viscosity of drilling mud is estimated using a Marsh funnel (ASTM D6910-04), which may prove accurate enough for classifying sludges. It may also be possible to develop a simple tool that could be used for slump tests on stronger sludges, and as a Marsh funnel for weaker sludges. A calibration chart could be developed to convert the readings into undrained shear strengths for classification. Other alternatives include simplified bearing capacity tests or ballistic penetration tests.

Any of these simple tests would allow pit emptiers to estimate what volume of sludge could be removed and how much it would cost their customer. However, the additional contact with faecal sludge may discourage them from testing, rather than just attempting to empty the pit. Significant further work is required to determine which tests are feasible and to calibrate their results against more accurate procedures.

A low cost system

The successful conversion of 'Class A' sludge into 'Class C' material by air-blown remoulding alone has a number of important implications for pit-emptying technologies (PETs). Firstly, it confirms that fluidisation can greatly extend the range of sludge removable with vacuum-based systems, helping prevent the gradual accumulation of 'unpumpable' sludge in latrines. The experimental work in this study also demonstrated the use of low cost vacuum cleaners to power mechanical PETs. The maximum vacuum head of the ALH and Calabrese tankers tested in Botswana was 0.5bar – a marginal increase on the 0.45bar achieved here using two vacuum cleaners in series, and tests on a worn Vacutug only registered 0.2bar [Coffey, M., *pers. comm.*, Oct. 2010]. The use of sliding vane pumps, which cost as much as €500, [Coffey, M., *pers. comm.*, May 2011] have hampered previous attempts to develop 'low-cost' PETs. Despite being significantly cheaper than full-scale vacuum tankers, the systems remain unaffordable to entrepreneurs in informal settlements and the combination of heavy use and limited maintenance results in significant wear and loss of suction performance within a few years.

In contrast, the pair of 2kW vacuum cleaners used in this investigation cost €50 each. Some performance may be lost with time, but the availability of vacuum cleaners throughout the world allows a poorly performing 'pump' to be easily and affordably replaced. The cost of replacing the 'pump' is low enough to be covered by pit-emptying fees, enabling entrepreneurs to start pit-emptying businesses. The long-term performance of the Vacutug, in contrast, is often dependent on municipal support for major maintenance costs [Kwach, 2008].

The need for education

Although the importance of adequate provision of sanitation is increasingly recognised, much work remains to be done and education is required at all levels from government policy makers to urban slum dwellers. To name just a few examples, researchers need to learn to characterise and report the physical properties of sludge, designers need to be educated on the importance of sustainable pit-emptying business models, town planning authorities need to learn how to implement functioning faecal sludge management systems and slum dwellers need to be educated to stop the stigmatisation and abuse of pit emptiers.

Conclusion

A simple two-component synthetic sludge has been developed which replicates the full range of strengths reported for pit latrine sludge. The strength of this sludge can be readily adjusted by varying water content, however its density was found to be significantly lower than that of pit latrine sludge. A system has been proposed for the physical characterisation of pit latrine sludge based on both density and undrained shear strength, and the benefits of these parameters over others such as viscosity have been discussed. It was shown that the injection of water and compressed air into the bottom of a tank of sludge at relatively low pressure (0.3bar) produces sufficient mixing to render even the strongest of sludges pumpable with vacuum-based technologies. Additionally, air-blown remoulding alone can reduce the strength of a consolidated sludge by a factor of three, reducing the need for dilution when emptying latrines.

The equipment used in this study demonstrates that cheap and readily available vacuum cleaners can replace costly sliding vane pumps, with minimal loss of performance. This could lead to the development of truly affordable pit emptying technologies that are able to fluidise the waste at the bottom of the pit, and remove significantly stronger sludges than current devices.

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Researching temporary sanitation: a case study of a UK MEng thesis

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Abstract

Disasters such as the earthquake in Haiti or floods in Pakistan necessitate the provision of short-term sanitation facilities for the affected population. Carrying out field research in such locations at undergraduate level would be prohibitive from a logistical, cost, ethical and safety perspective, so alternative methodologies are required. This case study looks at the human, social and technical lessons that can be learnt about providing emergency or temporary sanitation in the UK for a range of reasons (e.g. damaged infrastructure, planned building work, festivals). The paper shows how existing literature guiding responses to disasters has been used to shape the research and identify gaps in current knowledge in the UK, allowing lessons to be learnt and underlying principles to be established.

Introduction

This literature review looks at literature relating to temporary sanitation facilities in the United Kingdom (UK) in different circumstances. The work included in this paper forms part of a larger research project. Despite, or perhaps because of, the lack of documented information based on experience and practice in the UK, related subjects and areas of interest, including public toilet facilities and temporary sanitation facilities used in other countries, have been used in order to gain knowledge in and around this area of what is an appropriate response to temporary sanitation provision, both planned and unplanned, in the UK. This review can then be used to inform the process of emergency sanitation provision from a global perspective.

The World Health Organisation says that 'Sanitation refers to the means of collecting and disposing of excreta and community liquid wastes in a hygienic way so as not to endanger the health of individuals and the community as a whole' (WHO, 1987, p.12). This definition was derived in relation to other countries, but is still directly relevant to the provision of adequate sanitation facilities in the UK.

No clear definitions exist on what constitutes temporary sanitation, especially in the UK, however there is a definition for a portable toilet: The British Standards Institution's Standard BS6465 Sanitary Installations – Part 1 defines a Portable Toilet as a 'movable structure containing sanitary appliances, either temporarily connected to drainage and/or water supply systems, or with self-contained supply and waste collection systems' (BSI, 2006, p.4).

Figure 1. Emergency latrine, Sri Lanka (Photo Bob Reed, WEDC)

Temporary sanitation

Access to adequate functioning and safe toilets is vitally important, but little time tends to be taken to find out what people want or need in terms of the facilities provided –particularly in the case where the facilities are temporary. The World Water Council says of the benefits of safe sanitation 'it respects human values, improves the health of the community, generates economic benefits and improved life at all ages' (World Water Council, 2010). The World Bank classifies the UK as having 100% of the population with access to improved sanitation facilities (The World Bank, 2008), but the standards of many temporary facilities can be poor compared to what is perceived as an acceptable level.

For some situations, particularly large public events, there is guidance available regarding the provision of the temporary facilities in terms of the number, size and location. However, there appears to be no fixed rules or laws in place regarding aspects of acceptance by users in terms of comfort, safety and other user-focused criteria.

Figure 2. A water supply failure required a fast sanitation response (Photo M Smith)

The BSI's Standard BS6465 Sanitary Installations – Part 1 briefly mentions portable toilets in reference to temporary facilities that may be provided. It provides table 1, to determine the scale of provision that is needed. It is clearly stated that 'as a code of practice, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification' (BSI, 2006, p.31).

Sanitary Appliance	**For events with a gate opening time of 6 hours or more**	**For events with a gate opening time of less than 6 hours**
Female WC, and male WC where only WCs are provided	1 per 100 females	1 per 120 females
Male WC where urinals are provided	1 per 500 males	1 per 600 males
Urinals	1 urinal per 150 males	1 urinal per 175 males
Washbasins	1 per 5 toilets or urinals	
Wheelchair accessible toilet	As required, minimum 1	

Table 1 - Minimum provision of sanitary appliances for temporary events (BSI, 2006)

Specific guidance for some situations, such as at music festivals and at construction sites has been published and is discussed later on in this paper.

Planned circumstances of temporary sanitation

There are some situations where the need for temporary sanitation facilities is planned for in advance, for example: building works on a private property, during public events or during construction work. The Building Regulations mention the loan of temporary sanitary conveniences in relation to works on the drainage system of an area which may lead to the need for temporary facilities, at the request of the building's occupier to the Local Authority carrying out the works (Tricker and Alford, 2011, p573).

Individuals

In the Approved Document G of the Building Regulations it outlines the need for there to be 'adequate and suitable sanitary conveniences' and then goes onto detail the need that 'any dwelling should have at least one sanitary convenience and associated hand washing facility' (2010, p.28).

The British Standards Institution's (BSI's) Standard BS6465 – Part 1 sets out guidelines for the level of sanitary provision in different buildings, including private dwellings, as shown in table 2.

Sanitary appliance	Number of sanitary appliances per dwellings	Remarks
WC	1 for up to 4 persons; 2 for 5 people or more	
Washbasin	1	There should be a washbasin in or adjacent to every toilet
Bath or shower	1 per 4 persons	
Kitchen sink	1	

Table 2 – Minimum provision of sanitary appliances for private dwellings

This is provided alongside the guidance that 'a WC with a washbasin should be provided on the entrance storey of a private dwelling' (BSI, 2006, p.13).

Large scale public events (such as music festivals)

Although there is much literature aimed at members of the public attending large public events, there is little about the views that users have on these toilets or the impact of what is implemented on the health and habits of the users. A lot of the literature that is published takes the form of guides to the general public about what they should expect when attending these events, in particular music festivals. A lot of what is published portrays the facilities that are provided negatively. "Survival guides" are available which give advice to people planning on attending one of these events and in particular how to cope with the toilet situation, with one such article going as far to be entitled 'Infamous – can you survive them?' (Safeconcerts, 2012) which is available alongside others on a similar theme, such as 'Festival toilets – To go or not to go…?' (efestivals, 2003). Table 3 shows some of the information that is included in these guides.

Table 3 – information included in music festival "survival guides" relating to the festival toilets provided

- Make sure you wash your hands after
- You may need to take your own wet wipes and toilet roll with you
- Don't touch anything if you can avoid it
- They can be dark at night (and you want to be sure where you are sitting and putting your feet)
- The queues are long, but some times of the day are busier than others
- Some types of toilets that are provided are better than others, but it does come down to personal preference (for example, do you like the outdoor experience of a long-drop or the more private experience of a portaloo?)

Adapted from: Safeconcerts, 2012 and efestivals, 2003.

The UK Health and Safety Executive (HSE) has a guide specifically about health, safety and welfare at music festivals and similar events which outlines, and refers back, to the guidance set out in BS6465 – Part 1 with the add on to 'ensure that adequate sanitary provision is made for the number of people expected to attend the event, and that consideration is given to location, access, construction, type of temporary facilities, lighting and signage' (HSE, 2006, p.82).

The guide makes reference to the maintenance that is required of the facilities, stating that there should be: 'regularly maintained, repaired and serviced toilets using suitably experienced, competent workers throughout the event to ensure that they are kept safe, clean and hygienic. Toilets need to be supplied with toilet paper. Arrangements should be made for the rapid clearance of any blockages' (HSE, 2006, p.82).

As well as providing details of the desired location of the facilities, 'where possible, locate toilets at different points around the venue rather than concentrating in one small area, to minimise crowding and queuing problems...Attention should be given to access requirements for servicing and emptying' (HSE, 2006, p.82). As well as about the type of toilets that should be provided 'where temporary toilets are required, an assessment should be made of the suitability of each of the available types of temporary unit, for the nature and duration of the event being organised' (HSE, 2006, p.82) before giving further guidance on the options that are available to the event organisers.

Construction sites

An area where the requirements of the level of temporary facilities is clear is on Construction Sites. The HSE have published numerous guidance documents on different aspects of the rules and regulations that govern the welfare of workers on construction sites.

Public toilets

There is literature which looks at public toilet provision which can be useful in looking at issues which also arise for temporary facilities in the UK. Many of the issues that are currently experienced by the users of temporary sanitation in the UK are mirrored in terms of public toilet provision in the UK. Increasing amounts of academic research is being undertaken in this area. Research has been carried out on planning and social inclusion within this context, in order to avoid exclusion of any groups of society (Greed, 1999).Greed (2004) summarises the factors that need to be considered when designing a code of practice for public toilet provision, of these seven of them are relevant to temporary sanitation and are listed in table 4.

Table 4 - Summary of factors that need to be taken into account when providing public toilets in the UK which are relevant to temporary sanitation

1.	Make at least equal male/female provision and full provision for the disabled
2.	Define minimum acceptable queuing times
3.	Allow for intensity of use at different times and peaks
4.	Survey existing provision
5.	Include accessibility, siting, location, signage and urban design factors
6.	Take into account negatives, crime, anti-social factors
7.	Show means of implementation, funding and management

Source: Adapted from Greed (2004)

Unplanned, or emergency, provision of sanitation

There are many situations which are unplanned where temporary facilities may be required, for example in the case of a flooding event. The Health Protection Agency does not give any guidance in terms of the use of temporary facilities, but does give some advice on what to do if residents are still able to stay in their home, but there is no mains water or there are blockages in the system. It does mention temporary sanitation when referring to alternative options for householders, saying that 'It may be possible and practicable to use the facilities of unaffected family, friends, neighbours, public toilets, rest centres, local shops, supermarkets and hotels. Chemical toilets ("portaloos") may be provided in your area' (HPA, 2009).

The Environment Agency offers advice and guidance for before, during and after a flood, but not in direct relation to temporary sanitation facilities.

There is a lack of specific information relating to unplanned and emergency provision in the UK, although some places have disaster plans which cater for the needs of a specific area in the case of an unexpected event.

Emergency sanitation in other countries: Sphere Standards

Much research has been undertaken into the sanitation provided in post-disaster situations and many guidelines offer advice on how to deal with such situations. The Sphere Handbook is a Humanitarian Charter which provides Minimum Standards in Humanitarian Response and is a collaboration of various organisations and agencies which 'reflects the determination of agencies to improve both the effectiveness of their assistance and their accountability to their stakeholders, contributing to a practical framework for accountability.' (The Sphere Project, 2011, p.iii) It aims to improve the response that is given to people after a disaster, knowing that these events cannot be avoided completely. A lot more research has been done into the provision of services post-disaster and in developing countries than has been undertaken into temporary facilities in the UK.

The section of the Sphere Handbook relating to excreta disposal is broken down into two standards and talks of safe excreta disposal being a 'major priority and in most disaster situations should be addressed with as much speed and effort as the provision of a safe water supply.' (The Sphere Project, 2011, p.105) The first of the excreta disposal standards talks of creating an 'environment free from human faeces,' specifically in reference to areas where food and drinking water are present. The second standard talks of 'appropriate and adequate toilet facilities,' which are 'sufficiently close to their dwellings, to allow rapid, safe and secure access at all times, day and night' (The Sphere Project, 2011,

pp.105-109). Key actions, indicators and guidance notes are provided in order to aid in the implementation of these facilities, not just in terms of how many toilets, but also in terms of consultation, management and other factors.

The Sphere Handbook goes on to provide guidance on minimum numbers of toilets in a selection of public places in disaster situations. The level of detail provided in The Sphere Handbook is greater than that provided for many situations in the UK where temporary facilities are required.

Other sources of literature provide broad objectives for the immediate, short- and long-term response in order to establish a state of safe excreta disposal in both physical terms as well as in a way that is culturally and socially acceptable for the situation (Harvey et al., 2002 and Davis et al., 2002), whilst others give direct advice for those working in the field in order to provide an adequate response in terms of excreta disposal in emergencies (Harvey, 2007). Much of this information relates back to The Sphere Handbook.

Findings so far

There are many points for comparison between the different situations which are discussed throughout this literature review, however as there is little literature on many of these circumstances in the UK the best point of comparison is between the Sphere Standards and the other situations. There are many important points to be considered within each context, each carrying a different level of significance in that particular circumstance.

After critically the literature, the following research questions have been formed in order to fill gaps in relation to the provision of temporary sanitation in the UK:

- Are there guidelines and legislation currently in place to adequately cover every situation where temporary sanitation is required?
- Do the users of the temporary sanitation feel that the provision of facilities is adequate and acceptable in the investigated situations?
- Is there a gap between the level of services being provided, operated and maintained and the level expected in terms of cleaning, access and usability?
- Are there improvements that can be made to what is currently in place, using past experiences as the basis for any recommendations?

The Educational Lessons

This case study shows how UK students are able to learn about global issues through examining their local context and comparing the situation with reports from other countries. As an initial foray into Humanitarian Engineering, this introduces the student into the multidisciplinary nature of the topic and allows them to gain some level of insight into the issues that international aid workers face, but in a safe, affordable and ethical manner. The student is also gaining transferable skills, as literature reviews for research are similar to situation reports in emergencies. Consulting the public (which is another aspect of this project not reported on here) is a vital skill for engineers providing emergency sanitation, whatever the context. Some of the technical aspects of toilet provision (such as maintenance) are not restricted to a single geographical location and so benefit the student wherever they end up working. Interestingly the social aspects of latrine provision, emphasized in emergency responses, should have a place in UK practice so this study demonstrates the two-way nature of global engineering, with both UK and global practice benefiting from the research.

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Energy Poverty in Developing Countries: The problem of lack of access to electricity and Flywheel Energy Storage system as an appropriate technology

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Abstact

Millions of people in the world, the majority of which resides in rural areas of developing countries, either have no access to electricity or rely on intermittent power supplies from the grid with frequent and abrupt power cuts. Renewable energy technologies, increasingly promoted to improve rural electrification rate in developing countries, depend on charging of chemical batteries, which are expensive and are not practically maintainable and recyclable in developing countries. This paper explores various issues with current energy systems in developing countries. It then presents a low cost Flywheel Energy Storage system as an appropriate technology for tackling the problem of lack of electricity in those countries. A technology with huge commercial potential as backup power system for intermittent grids of developing countries, a sustainable alternative to chemical batteries used in renewable energy systems, and a device to provide electricity to households relying on traditional energy sources for lighting.

Keywords: Energy poverty, electricity, development, batteries, Flywheel Energy Storage (FES).

Introduction

One in five people in the world have no access to electricity, living in darkness, with poor health and educational facilities, limited access to modern means of telecommunication, and unproductive business activities. Close to 80% of these people live in rural areas of developing countries [1], and they still depend on archaic energy sources for lighting. A further 1 billion[2] only have access to electricity by name. They rely on poor and intermittent energy supply from grid and other energy systems. The International Atomic Energy Agency (IAEA) has estimated the yearly investment need of developing countries for electricity to amount to US $160 billion from 2010, increasing at an annual rate of 2-3% through to 2030. [1] Energy poverty constitutes a real barrier to development. Efforts have been made by multilateral and bilateral organisations, NGOs, academic institutions to tackle the issue. And this has certainly contributed to the progress made on energy access over the last 40 years –however slow, with figures decreasing from 2 billion lacking electricity in 1970[3] to 1.5 billion in 2009.[4]

Among the technologies promoted to increase electrification rate in developing countries, are renewable energy systems (solar PV, hydro, wind). However, they rely on charging of chemical batteries, which are expensive, with short lifespan and are not practically maintainable and recyclable in developing countries. The development of low cost, long life, reliable and environmentally friendly energy storage systems is therefore paramount for the effective exploitation of these renewable energy resources. Recent researches have shown Flywheel Energy Storage (FES) systems to be a viable alternative to lead acid batteries.[5] The use of this rotating device to store energy is in fact an ancient technology, with much advancement now being made for application in the automotive industry and load balancing of electrical grids. This technology presents a huge commercial potential for backup power systems in developing countries where erratic power supply and power cut is frequent. The aim of this paper is thus to explore various energy systems used in developing countries and the issues they encompass. Then, it presents the flywheel energy storage system as a potential sustainable solution to the problem of lack of access to electricity.

Traditional Energy Sources

The electrification rate in developing countries has increased overall in the last decade, 68.3% in 2005 to74.7% in 2009 (International Energy Agency IEA). However, in looking at specific instances, there are still countries such as Malawi, Uganda and RDC where less than one tenth of the population has access to electricity.[6] Table 1 shows regional electricity access around the world.

	Electr. rate %	**Urban electr. rate** %	**Rural electr. rate** %
Africa	41.8	68.8	25.0
North Africa	*99.0*	*99.6*	*98.4*
Sub-Saharan Africa	*30.5*	*59.9*	*14.2*
Developing Asia	81.0	94.0	73.2
China & East Asia	*90.8*	*96.4*	*86.4*
South Asia	*68.5*	*89.5*	*59.9*
Latin America	93.2	98.8	73.6
Middle East	89.0	98.5	71.8
Developing countries	**74.7**	**90.6**	**63.2**
World[iii]	80.5	93.7	68.0

Table 1: Electricity access in 2009 - Regional aggregates.[6]

Many living without electricity rely on traditional energy sources such as wood, crop residue, dung or kerosene lamps for basic lighting. Such lighting methods are inefficient; measuring the amount of light emitted for instance, a kerosene lamp emits only 30-80 lumens compared to 730 lumens for a 60-watt light bulb. Furthermore, they can constitute serious health and safety hazard at level several times higher than the World Health Organisation's standard, with risk of bodily burn and indoor air pollution. [7]

The lack of access to electricity has impacts on education, the good operation of health services and the productivity level of local businesses. The benefits of electrification of a region are evident. A study conducted by the World Bank Independent Evaluation Group (IEG) in selected countries quantifies the benefits of access to electricity, as shown in table 2.

Benefit	**Philippines**	**Peru**	**Lao PDR**
Lighting	7.36[iv]	16.16	5.60
TV	15.11	8.5	2.22
Education	12.46	Not estimated	Not estimated
Productivity existing home businesses	6.30	0.0	3.40
Productivity new home businesses	5.25	0.0	2.35

Table 2: Rural electrification benefits (US$ per household per month). [7]

[iii] World includes OECD and Eastern Europe / Eurasia
[iv] IEG estimates for the Philippines differ from those by ESMAP (2002) because that study used a linear demand curve.

Grid Electricity

Grid electricity constitutes the main source of power for many in urban areas. Its unit cost may often come down to be lower than that of inefficient traditional energy sources. The World Bank IEG has established that moving from kerosene to electricity connection is about 10 times more cost effective, as illustrated in the demand curve in figure 1. However, access to grid electricity remains difficult for many in rural and periurban areas, due to low purchasing power from the community, low investments in the sector, poor infrastructure for extending connections to remote villages, and high transmission and distribution losses from the grid (15% to 45% of electricity distributed [8]).

For the fewer percentage of the population that depends on electricity from the grid, the problem of intermittent and unreliable power supply can be serious. Frequent and abrupt power cuts from the grid put health systems at risk, damages are caused to domestic appliances, and the productivity level of students and local businesses is also affected. World Bank enterprise surveys show that in countries such as Nepal (2009) and RDC (2010) losses of more than 20% of annual sales were experienced due to electricity outages. Nepal was found to have 52 power outages in a typical month, each lasting in average up to 7 hours. Table 3 shows details of power outages and annual losses by region.

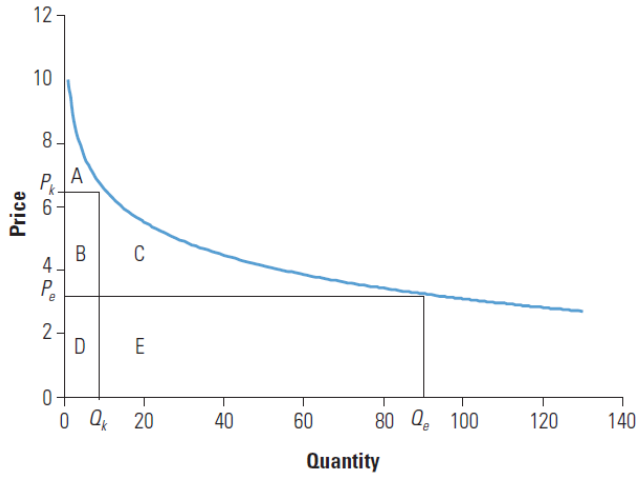

Fig. 1: Demand curve of lumens –Price of lumens vs. quantity consumed. [7]

Note: P_e = price of electricity from the grid; P_k = price of kerosene; Q_e = quantity of electricity used from the grid; Q_k = quantity of kerosene consumed.

These losses can be considerably reduced when firms use a backup power system. Another report from the World Bank (2009) shows the average lost load of US $917.3 per hour in a country like Malawi to be halved when a firm has a backup generator.[10]

	Number of electrical outages in a typical month	**Average duration of a typical outage (hr)**	**Losses due to electrical outage (% annual sales)**
High-income OECD	2.1	3.3	1.3
Latin America & Caribbean	3.7	2.5	2.8
Eastern Europe & Central Asia	5.8	4.7	4.2
East Asia & Pacific	5	3.2	3.2
South Asia	42.2	4.6	10.7
Sub-Saharan Africa	10.7	6.7	6.7
Middle East & North Africa	14.3	3.2	5.7

Table 3: Power outages and percentage of losses incurred for regional figures.[9]

Off Grid Systems

In remote rural areas where the provision of grid electricity is difficult, off-grid systems have been the main form of supply. Intermittent services from the grid, also leads many in urban areas to resort to decentralised off-grid systems as backup power supply. The most common off-grid systems used in developing countries are diesel sets and renewable energy systems.

Diesel sets have been famous over the past decades, for their lifespan (around 15 years) [11], their relatively short planning and implementation time and small initial investment [1].They have been commonly used for rural electrification programme in certain developing countries, with the Multifunctional Platform project of the UNDP in Mali being an example[12]. However, they have become less favourable nowadays, because of their high running and maintenance cost (three times more costly than grid electricity) [1], their low operation time (only runs for few hours) [1], and their polluting effects.

With growing concerns over global warming, technologies using renewable energy sources however are becoming widely promoted and subsidised to tackle energy poverty in developing countries. Over 50,000 small scale wind turbines are installed in remote rural areas.[13] The World Energy Outlook (2011) has reported 1.1 million solar home systems and solar lanterns existing in rural areas of developing countries. And hundreds of thousands of household in Vietnam use small hydro generators for electricity supply. [13] These systems are commonly used in modular and decentralised forms (e.g. pico hydro in Cambodia). But centralised systems also exist (e.g. mini-grid solar PV systems in Tanzania). Undoubtedly, much political and financial effort is still to be done in making full advantage of the freely available renewable energy sources to fulfil the basic needs of the energy poor. The African continent for instance, with the highest percentage of those lacking access to electricity, has a potential of 1,750TWh hydropower [14], with abundant solar radiation in the Saharan region; yet only 5% of this hydropower is utilised. [14]

Most renewable energy sources, being intermittent by their nature, require the system to be equipped with a receptacle to store the energy collected; hence, allowing a constant power supply to electrical loads. The most common energy storage devices used for this purpose are electrochemical batteries (particularly lead acid batteries). The problem with lead acid batteries for application in developing countries however is their relatively short lifespan, low depth of discharge, limited number of charge cycles, high maintenance cost and the lack of adequate local recycling infrastructures to process them. Used lead acid batteries in many cases end up dumped in land fields, with high environmental and health risks. Or they are reused for lead extraction by smelters, often in very poor sanitary conditions. Despite guidelines from the Basel Convention for environmentally sound recycling of used lead acid batteries, it remains amongst the top ten toxic pollution problems in the planet. [15]

Flywheel Energy Storage System – A Potential Sustainable Solution

The flywheel technology, which stores energy in the form of rotational motion, is being considered in this research as a non-toxic and locally recyclable alternative energy storage device with longer lifespan, short charge times and unlimited number of discharge cycles (comparison table of FES and lead acid batteries shown in Table 4). There is however a challenge in designing such device for application for developing countries electrification. And this challenge lies in making the system low cost, simple enough for local manufacturing or assembly and local maintenance, yet with high efficiency and good level of reliability. An independent study[16] carried in South Africa in parallel with the current research programme was found to have achieved a cost saving of 35% for a Solar Home System integrated with an FES instead of lead acid battery for energy storage. The flywheel made of locally available composite materials for the rotor and low cost conventional bearings achieved an energy conversion efficiency of 18%. The present research proposes a flywheel with cost effective, recyclable steel rotor, improved bearing system, and an innovative magnetic levitation system for an optimised efficiency.

The flywheel shown in figure 2 is made of laminated rotor discs (1) bolted together through specially aligned non-concentric holes for minimal stress rise in the discs[v]. The discs are connected to a shaft (2) to enable rotation of the assembly, all within a casing (3). The housing unit sealed and vacuumed to reduce windage losses, must be resistant enough to contain broken parts in case of rotor failure. The system can be buried underground, or enclosed by a concrete wall for even higher safety factor at decent cost. The flywheel weight is supported by a levitation system (4) comprising a passive magnetic bearing and two lightly loaded ball bearings. The rotating discs are balanced by small E2 energy efficient radial bearings (5) and (6) mounted unto the shaft to counteract the centrifugal forces. The motor-generator connected to the rotor shaft supplies and extracts power from the flywheel. The Permanent Magnet motor used because of its relatively high efficiency and low rotor losses, has the magnets (7) connected to the rotor and the stator (8) attached to the casing. In motor mode, an external power input is used to accelerate the flywheel rotor, where energy is stored in the kinetic form. This stored energy is then fed back in electrical form when the system operates in generator mode, decreasing the rotor speed proportionally. Some key characteristics defining the maximum amount of energy than can be stored and fed by the system are the material strength, the rotor weight, the frictional and aerodynamic losses. The FES is designed for a target power of 20-100W. The minimum energy storage level for basic application in a rural household is about 200Wh, and the currently designed flywheel system is believed to be able to reach 100 times that amount at 20,000rpm. The estimated production cost at of a unit with these specifications is approximately £30.

The versatility of the FES makes it suitable for tackling issues existing with the three main energy systems in developing countries. It can be an alternative to traditional energy sources in rural areas, where villagers will be able to get electricity for basic household application by physically spinning up the flywheel. The mechanical energy then converted into electrical energy. In regards to the problem of intermittency, the low cost flywheel can also be integrated into electrical grids for backup power supply or used in off-grid systems in place of chemical batteries.

[v] The configuration of multiple non-centric holes designed for stress optimisation is appending patent approval.

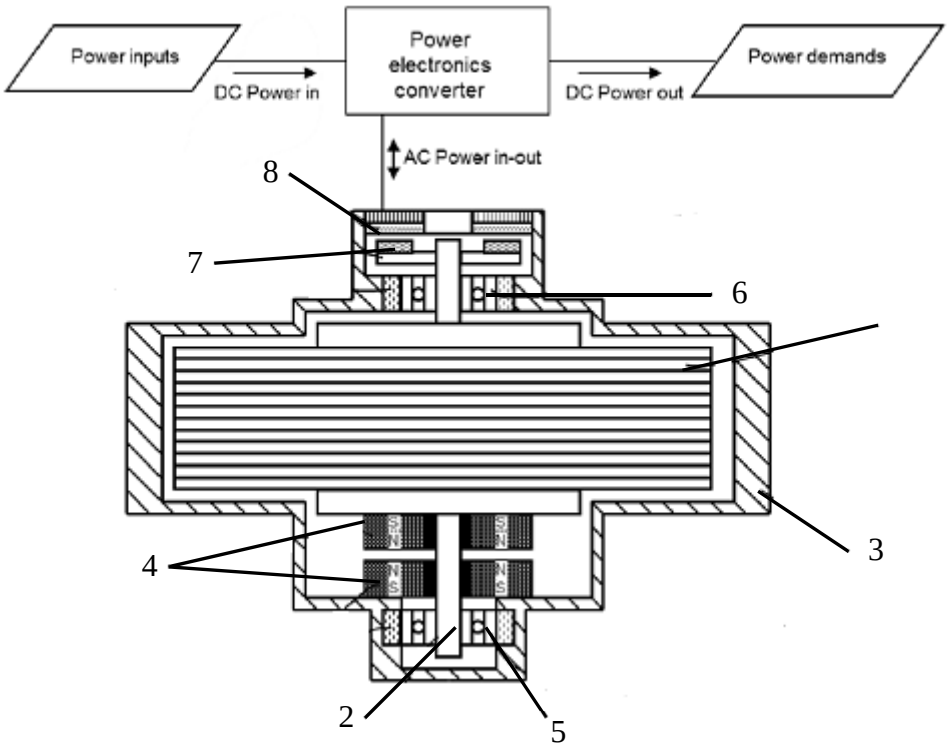

Fig. 2: The flywheel apparatus, international publication number of patent (WO 2011/086362). [17]

Advantages of FES over lead acid batteries	• long life cycle of 20 years • unlimited number of discharge cycles • shorter charge time • can be manufactured and repaired locally • higher energy efficiency • fully recyclable, non-recyclable parts such as electronics can be used in refurbished units • non-toxic • remains functional if left unused for a long period of time (months/years) • versatile: can be connected to grid, powered with renewable energy or charged up manually
Down side of FES	• higher self-discharge losses • cannot hold charged up energy for long several days • heavier (15kg) and bigger in volume (404mmx223mm) • higher initial cost • new technology, not as widespread

Table 4: Comparison of Flywheel Energy Storage System to chemical batteries (lead acid)

Conclusion and Research Plan

The problem of access to adequate energy in developing countries touches both the rural and urban population. Traditional energy sources used are inefficient and archaic, with impact on education, health and businesses. The remaining population able to access grid electricity, very often have to rely on intermittent power supply, with all the inconveniences that it carries. Off-grid systems have played an important part in improving rural electrification rate, but they depend on costly and polluting chemical batteries for energy storage. The low cost Flywheel Energy Storage system being developed presents itself as an adequate technology that can be integrated to existing energy systems in developing countries, or serve as a better substitute.

The key technical areas of the current research will cover the design and stress analysis of the rotor, the magnetic modelling and testing of the levitation bearing and the aerodynamic loss analysis and vacuum optimisation of the flywheel. The problem of energy poverty in developing countries is a complex one; a problem that certainly cannot be solved just with the introduction of new technologies. There are number of institutional, social and economical factors that must be accounted, for a successful and sustainable implementation of a proposed solution. And this will be given due consideration in the research programme (during the pilot phase) by working closely with those communities affected.

With millions of people touched by this problem of energy access, the total investment needed to provide them with electricity has been accounted to almost US $½ trillion [1]; this shows the scale of the issue. The programme on low cost FES may not be able to eradicate energy poverty in developing countries, nevertheless it has the potential to significantly improve access to electricity, and help many in meeting their basic energy needs.

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Locally Manufactured Wind Power Technology for Sustainable Rural Electrification

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Abstract

To date, the use of wind power for rural electrification has been limited. However the fact that micro wind turbines can be manufactured using only basic workshop tools, techniques and materials, and therefore can be produced locally is often overlooked. Local manufacture has the potential to boost the local economy, build local capacity, reduce costs, and produce resilient and flexible energy systems. However, locally manufactured technology must be seen as socially embedded due to the variety of local knowledge, skills, equipment and materials needed to construct and maintain such systems, as well as the organisational structures needed to ensure their long term sustainability. Evidence from successful initiatives suggests that stable institutional support from intermediaries such as the local/national government or NGOs is necessary to foster the development of a wind power industry based on local manufacture. The roles of these intermediaries include identifying and targeting windy areas with favourable environmental conditions, conducting research and development, collecting feedback from end users, creating supply chains for new parts and materials, and developing relevant knowledge and skills. In this paper, three case studies of specific initiatives are analysed to draw out the social, economic and technical factors that could facilitate its wider adoption.

Keywords: local manufacture; wind; rural electrification

Introduction

In the right local context, wind power has the potential to meet the needs of remote communities with limited or no access to electricity. However, wind power must be seen as a socially embedded technology, especially when manufacturing occurs locally. This implies that any technological decision will need to be made within the context of, among other factors, the availability of skills, knowledge and materials in a particular locality. The role of intermediaries such as NGOs, government and research institutions and private enterprise in helping to support the development of a local wind turbine industry is particularly important. In this paper, the combination of social and technological factors is examined through three case-studies of local wind turbine production.

Case Study I: Inner Mongolia Science and Technology Commission (IMS&TC), Inner Mongolia (China)

Batchelor, Scott et al. (1999), Xiliang, Gan et al. (1999) and Lew (2000) all agree that the Northern Chinese autonomous region of Inner Mongolia stands in a class of its own when considering the scale of use of micro wind turbines, known in this context as household wind generators (HWGs). The plains of Inner Mongolia contain not only 40% of China's exploitable wind resource, but also hundreds of thousands of households too remote for grid connection. Local universities and research institutions were supported to develop over 20 models of HWG from 50W-5kW, the most popular of which is the Shangdu Livestock Machinery Factory's FD2-100 {Ø=1.5m, RAE=549kWh/yr, P_{max}=185W}[6]. Strong institutional support was given, in particular from the IMS&TC, and HWG sale/service centres were established in all counties. Successful product redesign based on feedback from these service centres led to the evolution of the HWG into a product that not only adequately meets the needs of the end user, but is also available on the open market for an affordable price. Consequently, by 1997 there were 137,000 HWGs installed in the region supplying 18.5MW of electricity.

China's strong manufacturing industry allowed production of the entire wind turbine system to take place within the country (Lew, 2000). The wind turbines were produced within Inner Mongolia itself, whilst the electrical system components (batteries, charge controller, inverter etc.) could be sourced from within China at a fraction of the cost at which they are usually exported to other nations.

Case Study II: Soluciones Prácticas, Peru

The approach to wind-based rural electrification in Peru, where over 67% of the country's rural population do not have access to electricity (IEA, 2010), has been very different. Here, NGOs have been using Piggott (2009)'s wind turbine technology to electrify a number of rural communities. The intention is for these communities to serve as demonstration projects for local and regional authorities to replicate and disseminate on a larger scale. Specifically, the electrification of El Alumbre in the mountainous region of Cajamarca (co-ordinated by the NGO Soluciones Prácticas) will be discussed in detail. Here 33 IT-PE-100s {Ø=1.7m, RAE=548kWh/yr, P_{max}=300W} (Chiroque and Dávila, 2008) were installed for individual homes and 2 larger SP-500s {Ø=4m, RAE=1,807kWh/yr, P_{max}=1,000W} (Chiroque, Sánchez et al., 2008) for the local school and health centre. As in Inner Mongolia, household scale micro wind turbines have been employed, however the technology developed by Soluciones Prácticas is many times more expensive and the wind resource in the majority of El Alumbre is considerably lower (3-4m/s annual mean wind speed). Although Ferrer-Martí, Pastor et al. (2011) have shown that the use of mini-grids can reduce initial capital costs, the cost of meeting user demand in this way remains prohibitively expensive with the technology currently employed.

[6] Ø = rotor diameter (m), RAE = rated annual energy yield at 5m/s with a standard, Rayleigh distribution (), P_{max} = maximum power (W)

Case Study III: blueEnergy, Nicaragua

Craig (2007) describes the work of blueEnergy, an NGO based in Nicaragua that performs a similar role to Soluciones Prácticas in Peru. It has installed wind turbines in 5 communities on the country's Caribbean coast, where 80% of the population does not have access to electricity and a lack of infrastructure means that many communities can only be reached by boat. Due to the large distances between households and the low-speed Caribbean wind regime (typically 3-4m/s annual mean wind speed), blueEnergy chose to install a single larger wind turbine beside a community building. For example, in Monkey Point, a PV-wind hybrid system was installed in a communal building and a community battery charging station was established initially with a bE12ft wind turbine {Ø=3.7m, RAE=2,062kWh/yr, P_{max}=889W} and a 100W PV panel. Domestic users bring their batteries to and from this central station for charging, whilst a number of community buildings such as a radio room and a school. Whilst this may provide a more affordable supply of electricity than Soluciones Prácticas, again the fundamental problem of a lack of wind resource means that the cost of energy is still higher than the HWGs of Inner Mongolia, despite offering a DC battery charging service as opposed to a direct AC supply.

Coupled with the lack of wind resource, further problems have meant that the majority of these turbines have now been uninstalled (Bennett, Gleditsch et al. , 2011). Major factors in this decision included: corrosion from heavy rainfall, heat and high salinity; lighting strikes; hurricanes; difficulties in building and sustaining communal energy commissions; as well as preoccupation of the communities with more basic issues such as territorial disputes with neighbouring communities.

Evaluation of Case Studies

The following section compares and contrasts the three case studies with regards to the key socio-technical factors that influence the long-term sustainability of wind-based rural electrification initiatives: system level planning, consistency of supply and stable institutional support.

System Level Planning

An economic assessment of the technology employed in each case study was conducted by calculating its levelised cost of energy (equation I) from the data shown on the following page.

		Case Study I (IMS&TC, Inner Mongolia)	Case Study II (Soluciones Prácticas, Peru)		Case Study III (BlueEnergy, Nicaragua)
Data sources		Batchelor, Scott et al. (1999)	Chiroque, Sánchez et al. (2008); Ferrer-Martí (2009); Ferrer-Martí, Pastor et al. (2011)		Craig (2007); (Bennett, Gleditsch et al. , 2011)
Electricity distribution strategy		Direct connection	Direct connection		Direct connection & battery charging station
Energy system		Household Wind Generator (HWG)	Household	Community building	Community
Turbine	Typical system	FD2-100	IT-PE-100	SP-500	bE12ft + 1,387W PV
	Diameter (m)	1.5	1.7	4	3.7
	Maximum power (W)	185	300	1,000	889+1,387
	Reference annual energy yield (kWh/yr@5m/s)	549	548	1,807	2,061+1,871
	Typical wind resource (m/s)	4.6	3.5	3.5	3.5
	Typical annual energy yield (kWh/yr)	490	194	748	1,168+1,871
	Cost (US$)	137	974	5,132	3,000+4,161
Battery	Capacity (Ah)	2x60	120	2x200	8x105
	Cost (US$)	2x37.5	225	2x292	8x110-
	Lifetime (yrs)	2.5	5A	5A	2.5A
	Charge/discharge efficiency (%)	56	85	85	90
Controller	Current rating (A)	30A	35	60	2x60A

	Cost (US$)	19	165	285	2x250
	Lifetime (yrs)	10	20A	20A	7A
Inverter	Power rating (W)	300A	300	300	-B
	Cost (US$)	81	377	377	- [B]
	Lifetime (yrs)	10	20A	20A	- [B]
	Efficiency (%)	95	85	85	- [B]
Demand	Energy demand (kWh/yr)	130	139	484	2,226
Lifetime	System lifetime (yrs)	15	20A	20A	20
Reference (5m/s) levelised cost of energy	DC (US$/kWh)	0.15	0.49	0.30	0.35
	AC (US$/kWh)	0.20	0.67	0.39	-
Typical levelised cost of energy	DC (US$/kWh)	0.17	1.38	0.73	0.46
	AC (US$/kWh)	0.23	1.91	0.93	-
Levelised cost of meeting user demand	DC (US$/kWh)	0.36	1.63	0.96	0.56
	AC (US$/kWh)	0.45	1.92	1.04	-

Table 2 using ESMAP (2007)'s methodology (with simplified input parameters):

$$LCoE = \frac{\sum_{t=1}^{n} \frac{C_t + M_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad (I)$$

Where: LCoE = Levelised cost of energy (US$/kWh)

n = System lifetime (years)

C_t = Capital costs in year 't' (US$)

M_t = Operation and maintenance costs in year 't' (US$)

E_t = Electricity generated in year 't' (kWh)

r = Discount rate (set as 10% (ESMAP, 2007))

		Case Study I (IMS&TC, Inner Mongolia)	Case Study II (Soluciones Prácticas, Peru)		Case Study III (BlueEnergy, Nicaragua)
Data sources		Batchelor, Scott et al. (1999)	Chiroque, Sánchez et al. (2008); Ferrer-Martí (2009); Ferrer-Martí, Pastor et al. (2011)		Craig (2007); (Bennett, Gleditsch et al. , 2011)
Electricity distribution strategy		Direct connection	Direct connection		Direct connection & battery charging station
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	Lifetime (yrs)	2.5	5[A]	5[A]	2.5[A]
	Charge/discharge efficiency (%)	56	85	85	90
Controller	Current rating (A)	30[A]	35	60	2x60[A]
	Cost (US$)	19	165	285	2x250
	Lifetime (yrs)	10	20[A]	20[A]	7[A]
Inverter	Power rating (W)	300[A]	300	300	-[B]
	Cost (US$)	81	377	377	-[B]
	Lifetime (yrs)	10	20[A]	20[A]	-[B]
	Efficiency (%)	95	85	85	-[B]
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Lifetime	System lifetime (yrs)	15	20[A]	20[A]	20
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	AC (US$/kWh)	0.20	0.67	0.39	-
Typical levelised cost of energy	DC (US$/kWh)	0.17	1.38	0.73	0.46
	AC (US$/kWh)	0.23	1.91	0.93	-
Levelised cost of meeting user demand	DC (US$/kWh)	0.36	1.63	0.96	0.56
	AC (US$/kWh)	0.45	1.92	1.04	-

Table 2 – Economic breakdown of a typical system from each case study

Practical Action (2010) have devised an Energy Access Index (EAI) and with respect to electricity, have defined the following five levels:

1. No access to electricity at all
2. Access to third party battery charging only
3. Own low-voltage DC access for home applications
4. 110-240 V AC connection but poor quality and intermittent supply
5. Reliable 110-240 V AC connection available for all uses

Figure 5 relates the levelised cost of meeting user demand for a typical installation with the level of energy access in each of the case studies.

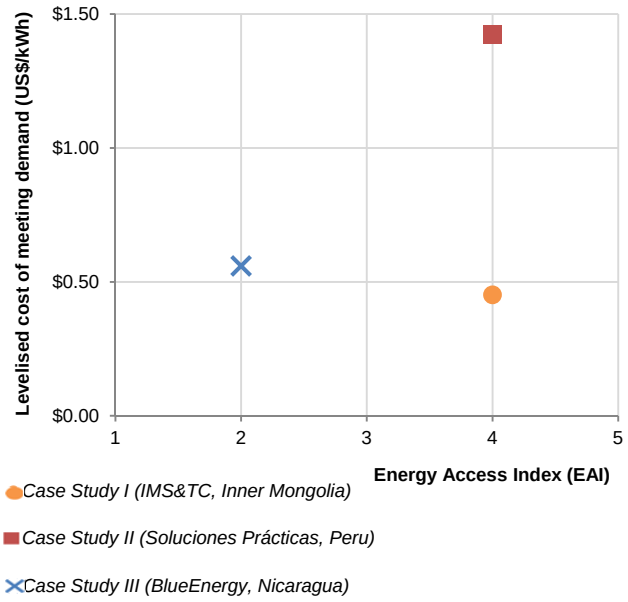

Figure 5 – Levelised cost of meeting demand for the three case studies with respect to the level of energy access provided. Alternative electrification strategies for case study II (Soluciones Prácticas, Peru) proposed in this paper and by Ferrer-Martí (2009) and Ferrer-Martí, Pastor et al. (2011) are also shown.

In Inner Mongolia households are often very isolated and although family ties are strong, community links are not (Batchelor, Scott et al., 1999) and as a result, the HWG was designed for a single household. On the Caribbean coast of Nicaragua, blueEnergy chose to take advantage of the economies of scale associated with larger, centralised installations with their hybrid PV-wind community battery charging station. The Andean communities in which Soluciones Prácticas operate have a more cohesive sense of community than in Inner Mongolia, however individual household scale micro wind turbines in the same style as the HWGs of Inner Mongolia were installed as distances between households varied considerably. Unfortunately the complex mountainous terrain meant that the wind resource varied considerable, with the majority of the community situated in the valley, the area with lowest wind resource. Combined with the high cost of the technology employed, this resulted in not only a high levelised cost of meeting demand, but also failing to meet demand for a number of households. However, these figures must be put into context: both NGOs have produced less than 100 turbines, whilst there are over 100,000 in Inner Mongolia, meaning that there are high potential cost reductions as further experience is gained and the design is adapted further to the local context.

Consistency of Supply

Consistency of supply is critical in off-grid systems and is determined by both reliability (how often breakdowns occur) and resilience (the speed at which repairs can be made). Reliability is often cited as the biggest problem with micro wind turbines (Piggott, 2009), yet resilience is particularly important in remote areas where obtaining spare parts (and the knowledge required to make repairs) can be difficult unless the technology has been manufactured locally.

Meteorological unreliability

The inherently intermittent and geographically variable nature of the wind resource can be mitigated by accurate resource assessments, adaption of the technology to the local wind regime and/or through the use of hybrid systems. Increasing the capacity of energy storage devices is also possible, but is costly and provides short term mitigation only.

Resource assessment should ideally be carried out at a national level, as occurred in the plains of Inner Mongolia which were deliberately targeted by the Chinese government, as not only are they windy, but the simple, flat terrain implies that individual site assessment is unnecessary. In complex terrain such as the Peruvian Andes, local resource assessment is difficult. Soluciones Prácticas used the computer modelling software WAsP by Risø DTU to predict the wind resource in and around El Alumbre from limited anemometry sites, topography and surface roughness data (Ferrer-Martí, Pastor et al., 2011).

Wind power should be seen as complementary to other decentralised power sources, in particular PVs, as the wind and solar resources often peak at differing times of day and in opposite seasons. blueEnergy have employed PV-wind hybrids

in all 5 of their community installations (Craig, 2007), newer Inner Mongolian systems tend to be hybrids (Batchelor, Scott et al., 1999) and the performance of hybrid systems installed by Soluciones Prácticas in Campo Alegre and Alto Perú are currently under investigation (Ferrer-Martí, Sempere et al., 2010).

Technological unreliability

The natural variations in wind speed cause wind power systems to experience variable cyclic loads that make them particularly susceptible to the effects of fatigue. This leads to the inevitable decrease in performance and eventual failure of vital components that put the system out of action until a repair can be made. Simple, robust design and the following of proper operation and maintenance procedures can increase technological reliability.

Effective feedback loops such as those shown in Figure 6 are necessary for the technology to develop in accordance with the needs of the users. Finding and addressing the weakest link/s in the system is vital, whether it be batteries, hub bearings, appliance incompatibility etc. In fact, Batchelor, Scott et al. (1999) found that the evolution of the Inner Mongolian HWG into a product that adequately meets the needs of the end-user (mainly herdsmen) was one of the greatest contributors to its success. Although early models were unreliable, feedback collected by service centres informed research institutions and manufacturers on how best to adapt and improve the product and consequently, reliability is now stated by herdsmen as one of their main reasons for choosing wind power. Ferrer-Martí, Garwood et al. (2010) state that in El Alumbre, Peru, monthly visits from Soluciones Prácticas, door-to-door surveys, focus groups and the monitoring of electricity use through data loggers were all employed to collect feedback on the effectiveness of the technology. The resulting data has been used in evaluatory studies (e.g. Ferrer-Martí, Pastor et al. (2011)) that have influenced the design of the energy systems used the subsequent electrification projects in Alto Perú and Campo Alegre (Ferrer-Martí, Sempere et al., 2010).

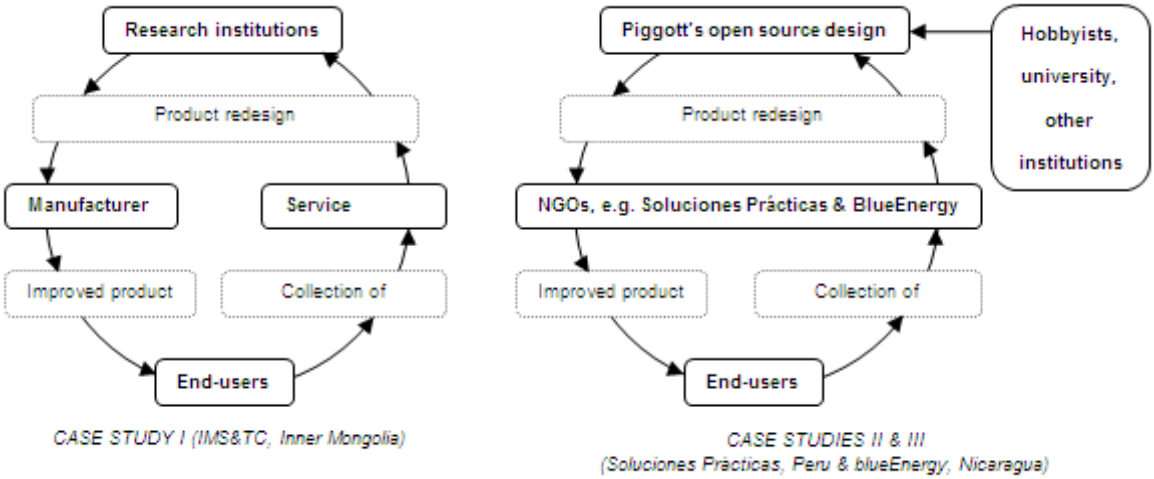

Figure 6 – Diagram showing the role of the various intermediaries involved in the feedback loops

Successful knowledge transfer on correct operation and maintenance procedures via training or printed instructions is as important as the quality of the equipment itself in ensuring both technological reliability and resilience. Both methods were in employed in all case studies (Batchelor, Scott et al., (1999), Chiroque, (2008), Craig, (2007).

Resilience

As previously mentioned, the resilience of the energy system can be increased by the creation of a strong supply chain to ensure the availability of affordable spare parts and the accompanying skills and knowledge to perform repairs. An ideal example is the network of HWG service centres in Inner Mongolia. Also, feedback through these service centres ensured that the main source of failures (blades and bearings) on the redesigned models could be repaired by the user, therefore drastically reducing downtime (Batchelor, Scott et al., 1999). In community based systems, an operator/administrator from the local community is needed to ensure the smooth running of the system on a day-to-day basis. This was accomplished in Peru through the creation of a micro-enterprise to provide local technical support for minor breakdowns. The selected operator/administrator would take part in a formal training program at the renewable energy demonstration centre, CEDECAP (Centro de Demonstración y Capacitación) (Ferrer-Martí, Garwood et al., 2010). Although local operators were also trained in Nicaragua, the extreme environment in which the turbines were installed meant that many key components had to be replaced, which in turn lead to many expensive boat trips from blueEnergy's headquarters in Bluefields. This drastically increased maintenance costs and left the communities without electricity for long periods of time (Bennett, Gleditsch et al. , 2011).

Stable Institutional Support

The stability provided by the Chinese government and the IMS&TC was invaluable during the development and dissemination of wind power technology in Inner Mongolia (Batchelor, Scott et al., 1999 and Xiliang, Gan et al., 1999). A similar role is being played by the NGOs in Peru and Nicaragua where it is hoped that their respective regional/national governments or NGOs in other areas of the world will follow their example and promote the technology on a larger scale.

Potential users of the technology require access to the capital required in order to be able to purchase the equipment. The sheep and goats of the Inner Mongolian herdsmen provided them with readily exchangeable assets with which to purchase HWGs (Batchelor, Scott et al., 1999). However, in both Peru and Nicaragua, international donors provide the capital for both Soluciones Prácticas and blueEnergy to install their wind power systems. Once up and running, micro-enterprises controlled the collection of fees (Ferrer-Martí, Garwood et al., (2010), Craig, (2007)), although in neither case was this enough to cover maintenance costs.

Conclusion

The paper has identified the key generic elements of an effective locally manufactured wind power system, but has also emphasised the need to see wind power as a socially embedded technology. Table 3 gives a comparison of the key factors found in each case study. It was found that continuity of supply must be guaranteed by addressing both technological and meteorological reliability and by increasing resilience through the creation of a strong supply chain. Significant feedback resulting in appropriate design modifications is needed to iteratively improve the technology and continue adapting it to the local context before it can be disseminated on the scale seen in Inner Mongolia. It was also evident that the stability in the institutional framework provided by the Chinese government through the IMS&TC allowed HWGs to grow from a research project to widespread use over the course of 20 years. This was only done by taking a holistic, system level view to providing the required energy services to the end-user - the herdsman. Finally, one of the most fundamental problems in Nicaragua was found to be the lack of wind resource, whilst in Peru it was its variability that made its exploitation difficult. Assessment of wind potential should take place primarily on a national (or even international) basis in order to effectively target wind-based rural electrification initiatives to areas with a sufficient wind resource that do not require local resource assessment, such as Inner Mongolia. If working in complex terrain, local resource assessments must be conducted and larger wind turbines should be located at the points of highest wind resource. In addition, the external environment should be taken into account – hot, wet, high salinity coastal environments with frequent thunderstorms are likely to increase the cost of wind power dramatically and regularly leave communities without power. Finally, the community's willingness to maintain the system must be accurately assessed, i.e. are they financially able to do so and is the energy that the system provides valuable enough to them to make it worthwhile?

	Case Study I (IMS&TC, Inner Mongolia)	**Case Study II (Soluciones Prácticas, Peru)**	**Case Study II (blueEnergy, Nicaragua)**
Community building electricity distribution strategy	n/a	Direct connection	Direct connection
Domestic Electricity distribution strategy	Direct connection	Direct connection	Battery charging station
EAI (Energy Access Index)	4/5	4/5	2/5 (domestic users) 4/5 (community buildings)
Wind resource	High & evenly distributed	Highly variable	Evenly distributed, but low
Resource assessment	Not necessary on local level	Anemometry and computer modelling	Anemometry after installation
Hybrid systems	Newer systems only	Latest projects PV-wind hybrid	All projects PV-wind hybrid
Cost of meeting user demand (US$/kWh)	Domestic: 0.36	Domestic: 1.63 Community building: 0.96	Community: 0.56
Resilience	End-users perform most repairs, network of service centres for serious problems	Operators perform most repairs, regional office for serious problems	Operators perform simple repairs only
Knowledge transfer to end users	Printed instructions, formal training, demonstration centres, installation performed by end-users	Printed instructions, formal training, demonstration centre, participation in installation	Printed instructions, formal training, demonstration centre, participation in installation, participation in construction (Cuajinicuil only)
Capital provided by	End users	International donors	International donors
External environment	Desert, inland	Mountainous, inland	Tropical, coastal, frequent lightning strikes & hurricanes
Technology demonstration	Multiple centres for demonstration & training	CEDECAP for demonstration & training	Demonstration models in Bluefields
Feedback	Service centres & formal evaluatory studies	Service centres, formal evaluatory studies, maintenance visits & open-source Piggott design	Maintenance visits and open-source Piggott design
No. turbines installed	>100,000	<100	<10
Wind power successful in this local context?	Yes	Potentially	No

Table 3 – Comparison table for the three case studies

To conclude, it is not argued that locally manufactured wind power systems are the answer to improving energy access in all remote areas. Quite the contrary, the locations in which they should be employed must be carefully chosen with among others, the following place-specific factors in mind: the viability of other power generation technologies and of conventionally manufactured wind power equipment, the wind resource, the external environment, the needs of the community and their ability to pay for energy services. However, it is suggested that the local manufacture of wind power technology has a much greater potential than the limited circumstances in which it is currently employed.

Further Work

The full article is due to be published in Energy Policy this April (Leary, While et al. 2012), with follow up work already in progress by the authors.

Acknowledgements

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Concepts, Simulation and Testing for Pico Hydro Networks

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University of Bristol

Abstract

This paper describes the work investigating the development of a pico hydro powered off-grid electrical network. The turbine modelling and performance is described, with a maximum experimental efficiency found of 91%, and the electrical system concept using parallel inverters without interconnection is presented along with some initial simulations in Simulink.

Keywords: Pico-Hydro, Turgo, Performance Testing, Parallel Inverter, Off-Grid Network

Introduction

Over 1.5 billion people across the world do not have access to electricity, which is hindering the UN achieving its Millennium Development Goals 0. In many countries, such as Nepal, it is not economically feasible to extend the national power grid into the more rural locations due to terrain and low population density. For these areas to achieve rural electrification, local off-grid supplies are required using either diesel- or renewable-based technology. Where the resources are available, pico hydropower has been shown to be the most cost effective solution or off-grid rural electrification 0.

The research reported investigates the development of a pico hydro powered off-grid electrical network to provide a cost effective solution for rural electrification 0. A diagram of the system concept can be seen in Figure 7. A system specification was developed, with the key points as follows:

Power: 1kW electrical power generation at 3.5m head;

Head range: 0.5 – 3.5m;

Electrical Output: 50/60 Hz, 120/230 V AC

High reliability;

Modular design allowing unskilled labour to diagnose faults and replace modules as required;

Plug-and-play capability of a generator unit to form a network;

Low cost.

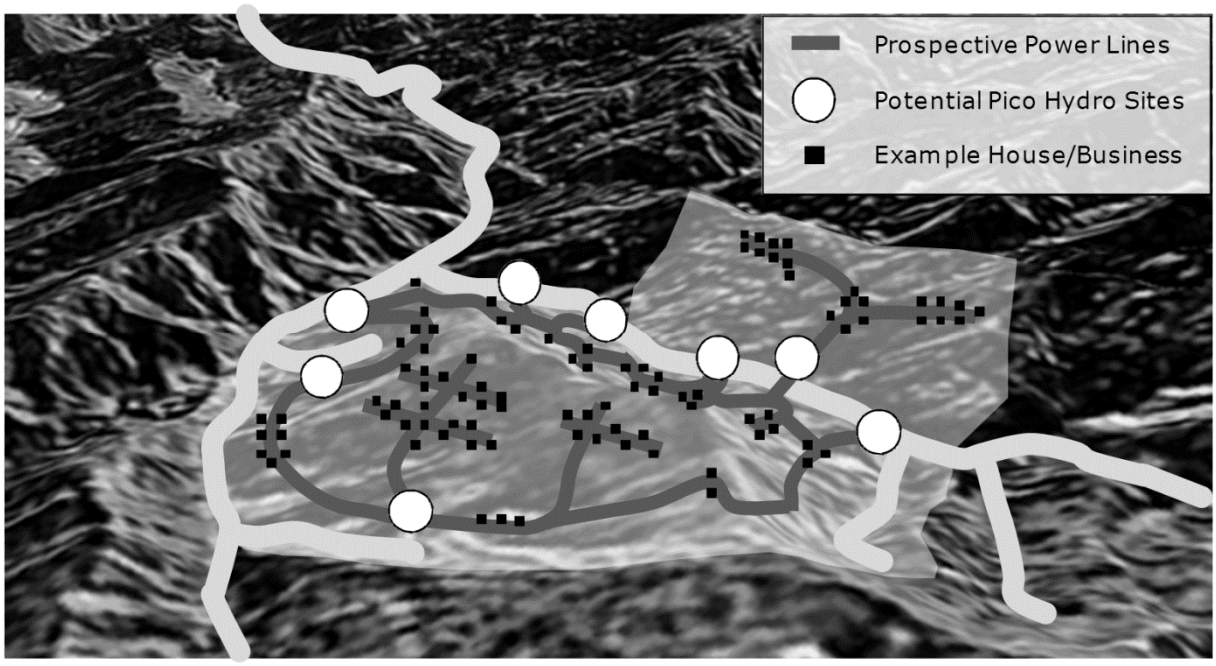


Figure 7 – Pico hydro network concept

Normally with pico hydro installations, the turbine is designed for the head and flow of a site or the site is adapted to the turbine. Each turbine supplies a number of houses, and so when there is a failure with a turbine, those houses connected to it are without power. With the pico hydro off-grid network concept, all sites can utilise a single turbine design able to operate over a range of flow rates and heads. There is redundancy in the system, a single turbine failure will not cause a power cut. At each location, one or more turbines are installed, depending on the head and flow availability at the site, which can each produce a nominal electrical power of 1kW at rated flow and head.

A multi-criteria analysis selected a Turgo turbine as being suitable for the specification 0. A Turgo turbine is an impulse turbine, where a jet of water impacts a wheel built up from several cups, as shown in Figure 8, which is connected to a generator. The analysis looked at quantitative criteria, such as power density and rated flow efficiency, and qualitative criteria, such as modularity, maintainability and serviceability.

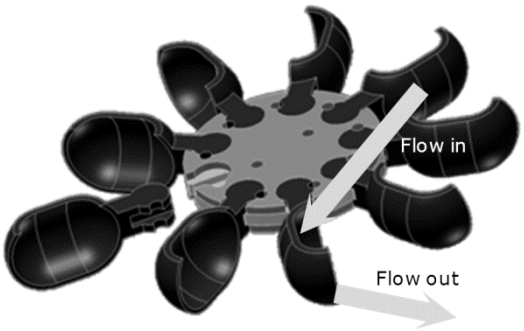
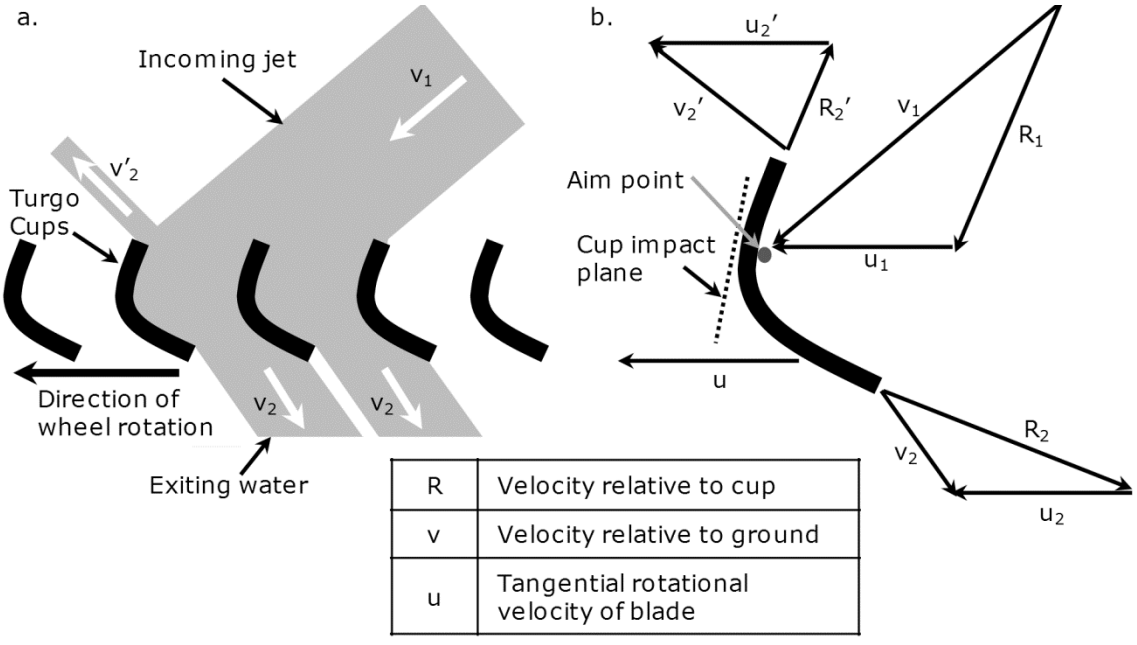


Figure 8 – Turgo turbine used in this work

The following sections give a brief description of the modelling and testing of the Turgo turbine, followed by discussion of the electrical system design required to implement pico hydro network concept and some simulations of the chosen system in different configurations.

Turbine Modelling and Testing

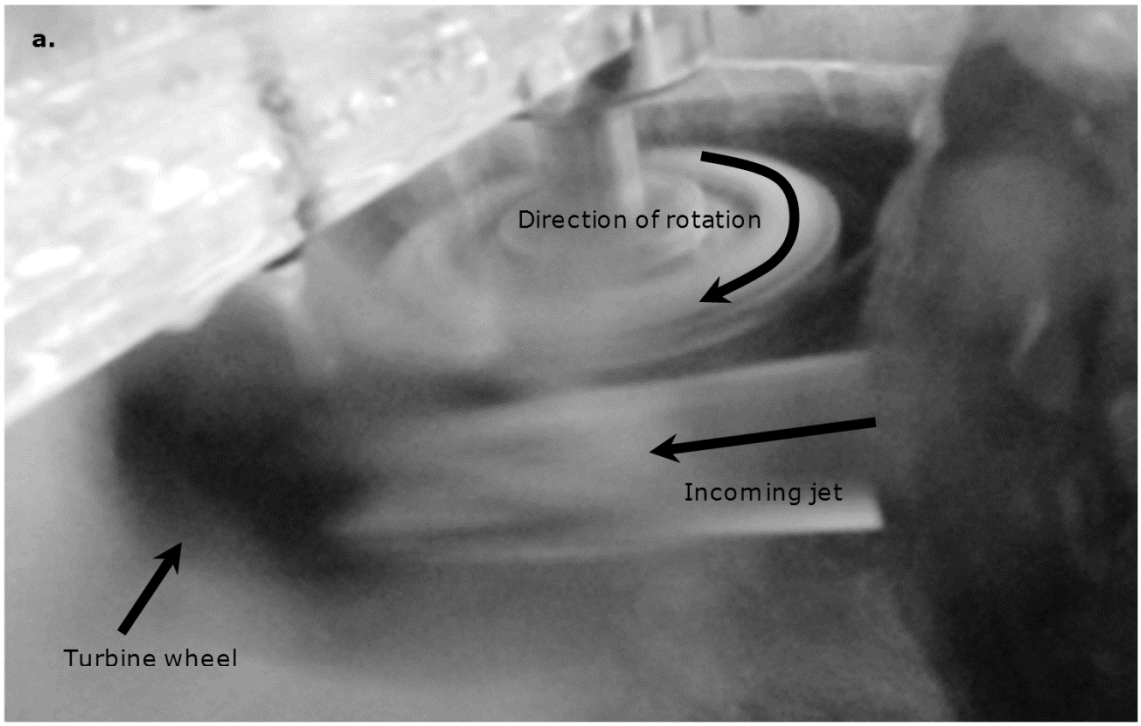
The turbine modelling is based on momentum theory, looking at the entry and exit velocity of the water 0. The flow is assumed to be 2D, with a 5% frictional loss in the cup and no losses in the penstock or through the drive train. As the jet impacts the cup, it splits into two parts with flow exiting through the top and bottom of the cup. The proportion of the division of the flow is dependent on the angle between the plane perpendicular to the cup surface at the aim point and the relative velocity vector of the incoming jet. When the aim of the jet moves deeper into the cup, there is more flow exiting through the top of the cup as the angle of this plane increases. Figure 9b. shows the velocity diagrams for this method.



R	Velocity relative to cup
v	Velocity relative to ground
u	Tangential rotational velocity of blade

Figure 9 – a. Torque generation principle for Turgo turbine. b. Velocity diagrams for Turgo turbine with a split jet exiting through both top and bottom of the cup.

This model is used to evaluate the Turgo turbine over varying turbine rotational speeds. An experimental turbine testing rig has been developed, which can vary the head available to the turbine and the turbine rotational speed, measuring this speed and the turbine torque. A photo of the test rig in operation is shown in Figure 10a. An extensive series of tests has been done on this rig, firstly to validate the model and then moving on to finding the optimum configuration for the turbine. Figure 10b. shows the efficiency-rotational speed characteristic comparison between the experimental results and model.



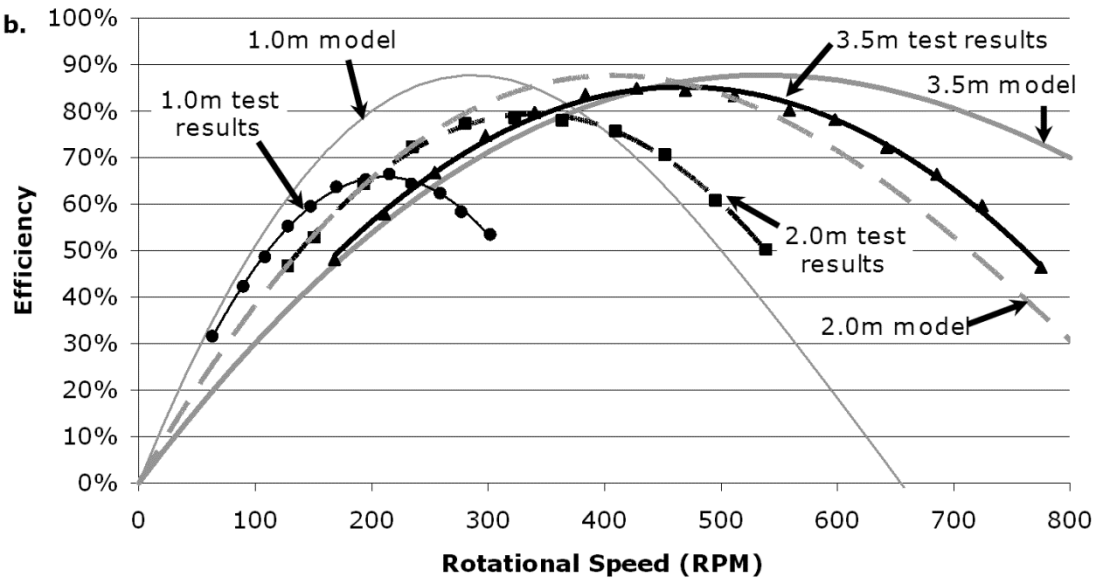


Figure 10 – a. Photo of the turbine in operation. b. Comparison of modelling and experimental results for turgo turbine at different heads.

As can be seen from the graph, the model performs well at a high head, but at lower heads the deviation between the experimental results and model increases. This deviation is due to some of the simplifying assumptions used in the model becoming less suitable. When observing the turbine, it can be seen that the flow in the cups splashes with 3D flow patterns, the jet enters and exits at different radii and that there is interference between the oncoming cups and the jet. These effects are hard to model and so further experiments can be used to generate empirical functions for these. At 3.5m head this is not necessary as the model can relatively accurately predict the results. Through experimental optimisation, the maximum jet-to-mechanical efficiency found was to be 91% at 3.5m and 87% at 1.0m. When typical penstock, nozzle and generator efficiencies are added to these experimentally derived efficiencies, the total water-to-wire efficiency is 68–71%. Comparing this to other low head systems which typically use propeller turbines, the water-to wire

efficiency is between 40-60% 0, which shows that the Turgo turbine has the potential to provide more power from a specific site.

Electrical Concept and Simulation

There are several different topologies that could be used for an off-grid multiple source network. The chosen topology uses an AC grid with each source unit having an inverter front-end, as shown in Figure 11. This would allow variable speed generators, either hydro turbines or wind turbines, to connect to the grid, as well as other sources such as solar panels and batteries.

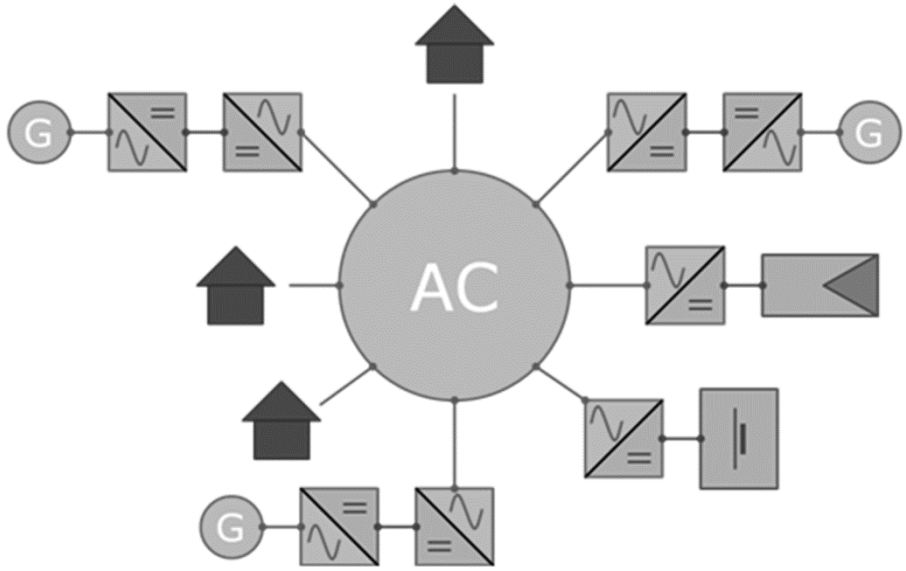


Figure 11 – Chosen grid topology – AC grid with inverter front-end

Using this topology requires that inverters are connected in parallel. Again, there are several methods of doing this. Several systems operate with a central controller, giving each inverter a set point. However, this would neither provide the plug-and-play system capability, as the system would need to know how many different systems were online, nor give a high level of redundancy due to the communication link being a single failure point. Connecting inverters together without communication requires each inverter to support the grid, contributing to the voltage and frequency control of the network.

The most popular method to control parallel inverters is known as droop control 0, which is based on the simple model of connecting a source to a grid through an impedance 0. Assuming the impedance is inductive, as most power lines are, the active power flow from the source into the network is proportional to the power angle between the two. The power angle is related to the output frequency of the source. The reactive power is proportional to the voltage difference between the source and the grid. Therefore, controlling the frequency and output voltage can control the active and reactive power output from the inverter, or visa versa. As the active power demand increases then the inverter control system causes the output frequency to droop, and similarly as the reactive power demand increases the control causes the output voltage to droop. So, using the common frequency and voltage, this can automatically spread the load between several different sources without requiring communication between them. These relationships are implemented using constants known as droop coefficients which convert the measured active or reactive power to frequency or voltage.

Several simulations have been undertaken to investigate the performance of droop control using MATLAB/Simulink. Figure 12 shows the frequency output for a paralleled inverter without communication using a droop based control system. Figure 12a. shows that upon connection to a stiff grid system at 50 Hz, the inverter settles at a constant frequency output after about 450 ms. The system is reasonably well damped, and so only small oscillations occur during synchronisation. Figure 12b. shows that when two inverters are connected together in parallel with a line impedance between them it takes about 750 ms for the frequency to settle, with the frequency oscillating back and forth over the settling time. Figure 12c. shows the frequency when two inverters are connected in parallel with a load between them. The settling time is a lot shorter than that for Figure 12b, at around 400 ms, with fewer oscillations.

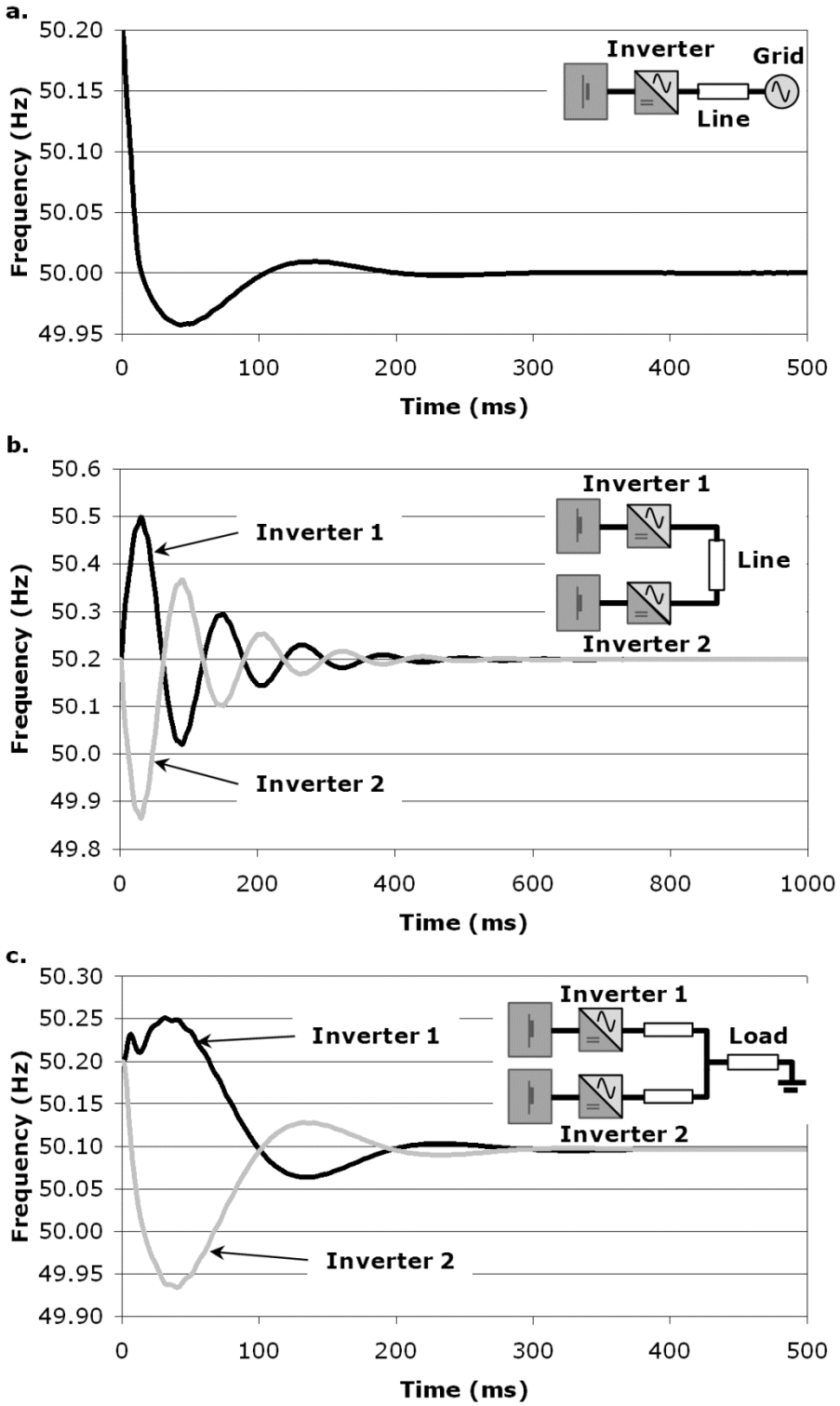


Figure 12 – Inverter simulation frequency output. a. Single inverter connected to 50 Hz stiff grid. b. Two inverters connected in parallel, no load. c. Two inverters connected in parallel with load.

Currently the droop coefficients are set to low values, improving the frequency and voltage regulation. However, with low droop coefficients the load sharing between units is compromised, as small changes in power angle and voltage along the transmission line cause large deviations in power output. For the current system, if the droop coefficients are too large then the system becomes unstable. There are several different methods to increase the stability of the control system which are currently being investigated. There are also issues with large current spikes at during connection due to the voltage between the two sources being out of phase. This can be solved using a circuit breaker that connects the inverter to the grid once the two sources are closer to synchronisation.

Future Work

Currently there are further experiments being carried out on the turbine, focussing on the design of the disc to try to reduce the volume of the system without adversely affecting the efficiency. From this a final turbine design will be derived, which can then be scaled up to a full size turbine. This turbine will be designed and the performance of it will be calculated using the experimental tests and non-dimensional scaling laws.

The parallel inverter control system will be continued to be developed to achieve higher droop coefficients whilst remaining stable. A full system simulation will be built, from water flow input to load output, to assess the whole system performance. A hardware system will be built to validate and test the control system, with different loads and generators able to be switched in and out to assess the performance of the control design for representative system loads.

To keep up to date with the research please visit http://saminnepal.blogspot.com or follow me on twitter at http://twitter.com/saminnepal.

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Research Poster Papers

Developing global text books for global engineers

Brian Reed

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Keywords: E-learning, text book, publishing, low-income country, education

Introduction

Text books are an established resource for lecturers and students alike. For vocational courses such as engineering, they continue to be a resource throughout the professional career of the student.

In 2008, in the university library in Blantyre, Malawi, students studying at the Centre for Water, Sanitation, Health and Appropriate Technology Development have access to only two copies of the core water and sanitation text book *Environmental health engineering in the tropics: An introductory text* (Cairncross and Feacham 1993) and that is for periods of one hour at a time. The other water and sanitation books in the library were so out of date that they are now only of historical interest. This book is available in Bristol, Durham, Leicester, Nottingham and Derby University libraries.

A graduate about to go on an EWB placement to construct concrete tanks for rainwater harvesting systems was not aware of the standard text book in this area (Watt). It is not available in the UK libraries listed above.

Both these examples illustrate that, although knowledge exists, it is not always accessible, due to issues of cost, local availability or just knowing where to look. Searching the Internet may provide some information, but this is not always reliable and may not provide sufficient depth. The text book publishing process has various quality assurance stages to ensure that the investment by the publisher results in a trustworthy volume. The lower costs of publishing on-line can result in large quantities' of lower quality information. Wikipedia does contain an article on skyscrapers, but there is not enough information to design such a structure. Web portals and more specialised wikis can help identify improved sources of information, but again these are limited. Open access material may appeal to the viewer of such material, but does not provide a way of recovering costs for the knowledge supplier.

Distance learning trials have shown that students do like to read some material as hard copy (e.g. on the bus) and to retain it for future reference, so this project is looking at e-delivery of material. Also, studies have shown that on-screen reading can be slower, less accurate and there is less comprehensibility, so efficiencies in delivery through e-learning needs to be balanced with effectiveness of learning. The physicality of a text book appeals to some people, especially if they are making notes or are looking for an occasional reference, but downloading and printing off whole text books can be as expensive as buying a printed copy. CDs or "e-books" are one way of reducing the physical printing and distribution costs. Some older text books are not available electronically and scanning or inputting into specific software comes at a cost.

Problems with text books

Text books do become out of date and the investment needed to keep then current may not be cost effective. *Environmental health engineering in the tropics: An introductory text* (Cairncross and Feacham 1993) has a chapter on water quality that has been superseded by recent advances in water safety planning. This problem becomes more acute when the topic becomes specialist or for a narrow audience (e.g. "botany for engineers" is not the same as a basic introduction on botany for botanists). Broadening the range of topics may make the book more commercially viable but loses the depth and detail required for specialist work. Add to this the limited availability and higher cost of books in low-income countries and it is easy to see how existing information can become "lost".

Distance learners can be sent copies of text books, but this then focuses their course around a few standard works rather than the breadth of material that is available to students studying at a university with a well stocked library. It is uneconomic to send a dozen books out and expect the student to only read a chapter from each.

Practitioners without access to standard reference material have to reinvent basic technologies afresh, often learning from (costly) mistakes in terms of resources and wasted opportunities.

Emerging issues

Universities are encouraging the use of Virtual Learning Environments (VLEs), but the full potential of these has yet to be explored. Advances in publishing and IT have enabled high quality yet affordable books to be delivered electronically and printed locally on demand. However, the authoring process is still a problem for specialist texts.

The development of "e-text booklets"

In the 1980s and 1990s, the Water, Engineering and Development Centre (WEDC) at Loughborough University, produced a series of technical briefs published in Practical Action's journal "Waterlines". These were four page explanations of water and sanitation issues and are still popular today judging by continued sales and downloads.

More recently WEDC have been piloting some e-learning courses, as an alternative to their existing distance learning courses. E-learning courses tend to be broken down into short sections, such as a full day of study, rather than the standard university block of a term or semester (often around two or three weeks if you were studying continuously). This makes the issue of text books even more acute as text books are normally hundreds of pages long rather than the single chapter needed for a shorter course. There is still a need to provide students with reading material to aid study and provide for future reference.

In response to this need to provide short text books, often in very specialist areas, the WEDC team have begun to produce booklets to provide reading and reference material for the e-learning courses and their specialist MScs in water and sanitation. These have been designed so they can be downloaded from the Internet and printed off on a simple A4 printer to form an A5 booklet. High quality production has been used to encourage people to keep them for future reference rather than print off once and throw away.

Having learning materials on line allows the student to tailor their reading to the areas they feel they need support in, rather than covering material they already know, especially with mixed groups of students (postgraduates with different levels of prior learning or students on different programmes). The short size (16-32 pages) allows the student to select and print off only the material they are interested in. The lecturer can also mix and match the booklets to the level and subject matter of their course, reducing the need for bespoke teaching notes for different courses. Having a suite of text booklets allows common issues to be addressed across a series of modules rather than having to cover them repeatedly in each specific module. The author can easily keep their material up to date and add to the series in convenient stages. It also keeps download times to a minimum and reduces wastage of downloading and printing off material that is not required.

A few text booklets have already been written and produced for a professional audience on an opportunistic basis but this project aims at assessing their effectiveness and attractiveness as "learning objects" from a student perspective. Lecturers are used to using lecture notes, text books and reference books and other resource material in their teaching. Lecture notes are specifically tailored to teaching the course material; text books are more general but still have a teaching element whilst reference books assume familiarity with the concepts. These form a continuum of text-based material, but with a gap between bespoke lecture notes and standard text books in terms of quality of production and content.

Figure 1: an example of one of the text booklets (not to scale)

Future studies

This project aims to assess the use of "E-text booklets" by students, from a practical and an educational perspective, including:

- Production process (writing, editing, quality assurance);
- Content (comprehensibility, length, language, style, illustrations);
- Format (physical style (including appearance, size, use of images), file type, file size);
- Delivery (email, web, library, printing on demand);
- Use, during and after teaching (level of use, level of continued reference); and
- Impact of use (on their studies, professional practice).

Core issues are the comprehensibility and accessibility for users (Saywell and Cotton 1999). Comprehensibility will be reviewed from the perspective of level of prior learning assumed, length and depth of content, explanation of jargon and use of illustrations rather than clarity of writing style. A clear writing style and quality of content will be assured through a robust technical review and editing process.

Whilst this project is generic to any student, there are specific groups who may accrue additional benefits, such as.

- Distance learners
- E-learners
- Students from overseas who do not want to carry lecture notes home
- Alumni who wish to access lecture information once they graduate
- Those who cannot afford a hard copy traditional text book
- Students at universities that do not hold relevant collections of texts in their libraries
- Those who have difficulty reading traditional text books and would benefit from being able to choose the size of the printed text
- Professionals reading for continuing professional development
- Professionals reading for technical support

Research plans

As part of this trial, the following activities are envisaged:

- Write, produce and deliver a series of text booklets specifically for existing courses;
- Monitor the process, cost and timing of production;
- Conduct an information needs assessments with a selection of students to assess the content, access, use and impact of the text booklets; and
- Synthesize findings and disseminate results.

As this is a trial, success will be judged on receiving a clear preference from students for or against the use of these text booklets and a clear indication of the preferred method of delivery. If these learning products are not useful, then this outcome will still be counted as a success (as we will have learnt something) and alternative document delivery methods will then be explored.

Conclusions so far

The authoring process does require the material to be written for this particular format. Although lecture notes can form the basis for a text booklet, they do need to be edited and adapted to suit the medium (Davis and Smith 1995). The quality assurance process needs to be clear, with the content (including illustrations) substantially complete and checked before the material is type set. Planning the series allows text booklets to build on each other – so a text booklet on "handpumps" has to be drafted before one on "India Mark II handpumps" and another on the "Rope and Washer Pump", to allow generic material to be used once and note repeated in each text booklet.

The text booklets produced so far are available on http://wedc.lboro.ac.uk/knowledge/booklets.html .

Acknowledgements

The author would like to thank Rod Shaw, Bob Reed, Julie Fisher, Tricia Jackson and the WEDC team for their help and support in developing these booklets.

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The Fetishism of Microalgae species in High-Organic Industrial Wastewater

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Keywords: Microalgae, Wastewater, Bioenergy, Renewable Energy

Introduction

The International Energy Agency (IEA) has predicted a 53%-increment in global energy consumption from 2000 to 2030 that will result in an international competition for energy resources. IEA also predicted that the increase in energy utilization, especially of conventional fossil fuels would contribute to the release of more greenhouse gases (The International Energy Agency, 2011). Furthermore, over the past twenty years, global interest in renewable energy sources, such as biomass-based energy production, has boomed, given the context of climate change and depletion of conventional fossil fuels. Resource depletion has driven a sustainability element of renewable energy economy. Yuan *et al.* (2008) reported that bioenergy could play an important role as the substitute to the conventional petrol engine while reducing long-term CO2 emissions, if and only if sustainable. The term of environmental pollution control biotechnology gives an exciting tool to solve a problem in protecting environment with the involvement of microbes. For e.g., remediation of industrial wastewater using the biomimicry of microalgae to provide the basis for designing and operating new biological wastewater treatment systems, it also supplies several potential co-products, such as biomass that can be transformed for bioenergy purposes. Dependability on hydrogeology of the water sources must also been rectified as the groundwater and surface water have undergone critical stress of demands. The production of water that is safe for human and aesthetically pleasant, advanced treatment processes must be also selected that can be used to remove specific constituents. To ensure this, it would be necessary to measure and monitor the sustainability and technology advancement in cultivating microalgae. Microalgae offer considerable potential benefits as a low-cost and environmentally friendly means of phycoremediation and bioenergy production. The cultivation of microalgae using industrial wastewater – as regarded as one of the biggest issues in environmental pollution, offers advantages in carbon sequestration and renewable energy production which result in the possibilities of an economical viable way to achieve a reduction of greenhouse gases (GHG) emission and tackling the challenges in fresh water scarcity. Wastewater, in general, provides a nutrient rich environment for the growth of microalgae. Clarens *et al.* (2010) agrees that microalgae would deliver a better performance because it can be cultivated in surroundings that require minimal total land usage, less fresh water supply, and reduce the tendency towards eutrophication. Despite these sustainability arguments, it is nevertheless essential to have good cultivation techniques in order to demonstrate that microalgae are economically competitive compared to the first and second generation bioenergy, and conventional fossil fuels. United Nations (UN) Conference on Climate Change in Bali called for several steps between the developing and developed nations in renewable energy sector to co-operate in R&D for new and innovative technologies, to develop mechanisms for technology transfer and to support financially or incentives of affordable environmentally technology in order to encourage the members of UN to accelerate the implementation of the mandates in renewable energy production, including those in transport sector.

Methodologies

This project is divided into 3 main steps in order to oversee optimal procedures, and to manage the procedures as microalgae cultivation can be very time consuming.

Step 1: The selection of microalgae species and review on selected strains are done in order to have more insightful information on the species that will be used in this project. This is due to lack of information on every single species as there are more than 35,000 species of algae in the world. 5 species are chosen (*Tetraselmis sp.*, *Stichoccoccus bacillaris*, *Euglena mutabilis*, *Oscillatoria sp*. and *Dunaliella salina*). Axenic **stock cultures** are obtained from CCAP and MBA Plymouth and are inoculated inside transparent and autoclavable with the selected medium. This process is in order to maintain the cell to be alive before **starter cultures** are set-up to accelerate the growth of the biomass that can be used for experimental stage (Step 3).

	Environment	Division	pH Tolerancy	Temperature Tolerancy	Medium
Stichococcus bacillaris	Acidic	Chlorophyta	Survive acidic medium (high pH)	16-27°C	MBBM
Tetraselmis sp.	Marine	Chlorophyta	Alkaline (moderate pH)	16-27°C	f/2
Dunaliella salina	Hypersaline	Chlorophyta	Alkaline (high pH)	Up to 40°C	2ASW
Oscillatoria sp.	Brackish	Cynophyta	Alkaline (low pH)	16-27°C	BG11
Euglena mutabilis	Freshwater	Euglenophyta	Acidic (low pH)	Up to 40°C	EM

Table 1: Brief information on each selected microalgae species.

Step 2: The starter cultures from stock culture of the species are grown for the purpose to scale up the growth rate of each species. This is typically done by adding the stock cultures inside a flask with the selected medium, and let the cultures expose to light illumination that represent the diurnal cycle at 18 to 20°C and aerated with air/carbon dioxide mixture. Starter cultures are grown for variable periods of time prior to use, and analysis such as protein/biomass determination for the growth rate study is done to establish the growth curve which can be used for experimental stage.

Step 3: Industrial wastewater is used in this experimental stage in order to study the ability of microalgae species to grow successfully. This is to proof that without using a vast amount of fresh water, species that are highly tolerated to high organic compound of wastewater can survive and to deliver high biomass accumulation. Analysis of wastewater turbidity, protein/biomass accumulation and also nutrients removal such as nitrate content and metal (e.g. Copper) are done to support the remediation process of industrial wastewater. This stage is still on-going and will be included in the future work for upscaling process.

Conclusions and Future Works

Microalgae cultivation for bioenergy purposes is an intensive work. Several precautions shall be taken care in order to avoid contaminations and also to ensure the healthy state of the species for an optimal growth rate. The selection of the parameters such as light illumination, temperature, aeration technique and also the methods of analysis shall also be vigilant to ensure reliable data for a perfect conclusion in the future. Figure 1 concludes the preliminary studies of this project and is set-up as the guidance and improvement methods towards better results. The microalgae part includes the selection and studies of the species, medium preparation, optimal parameters and type of bioreactor that is used for subculturing and experimental processes. As one of the main purpose for phycoremediation study, industrial wastewater shall also be analyze and handle according to the guidelines of Department of Environment (DOE) in order to understand the whole concept of safety procedures. Whilst the third part, social economics and policies studies that incorporate the regional and international frameworks is also included, in order to ensure the sustainability of the project.

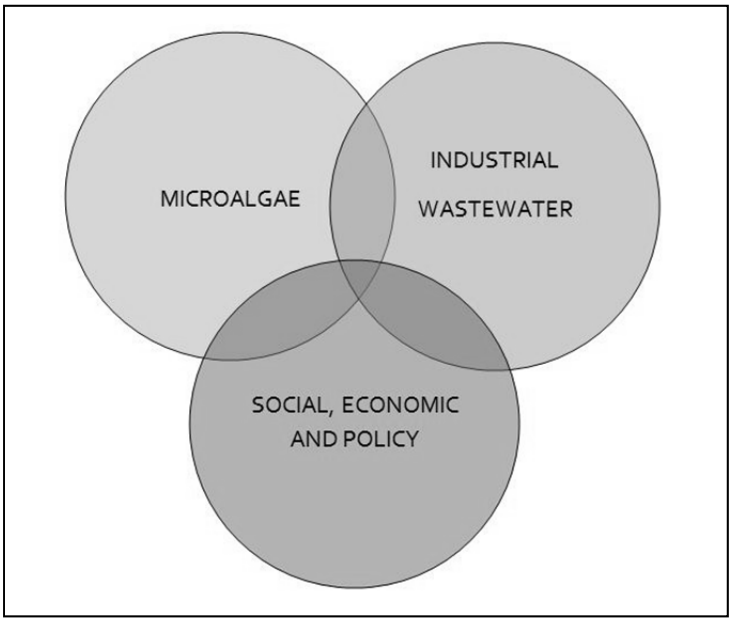

Figure 1: 3 major topics of the project

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Can bamboo be a suitable replacement for steel in the use of gabions?

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Key Words: Bamboo, Gabions, Civil Engineering, Retaining structures

Introduction

Gabions are used for a wind range of uses around the world; however the most common material for these is galvanised steel. Steel uses a lot of energy to produce, and also is not a sustainable solution. When used in remote communities, for example Practical Actions project in Chitwan, Nepal; the steel gabions cannot be constructed to as high standard as if they were by a specialist contractor, Noble (1997) also states that the gabions can be made locally by hand although this is physically demanding for the people doing the work. Swedish Architect Ingemar Saevfors designed an alternative to the steel gabion, using bamboo. After further research on this design, it became clear that this design was better suited for the use of erosion protection. Bamboo is a sustainable and widely available material, and therefore using Saevfors inspiration, this project looks at other bamboo gabion design possibilities, especially in the use of retaining structures.

Research

Retaining structures are used 'to bring greater stability to dangerous slopes, or to support existing landslides' (Záruba and Mencl 1982: 218). Retaining walls in the UK are designed to BS Eurocode 1997 (British standards 2004). This document suggests there are three types of retaining walls, gravity, embedded, and composite. Gabion walls usually fall under the category of gravity walls, Saevfors design on the other hand, is a composite design. Using the mass of the walls, along with soil nails, this can be seen in figure 1.1.

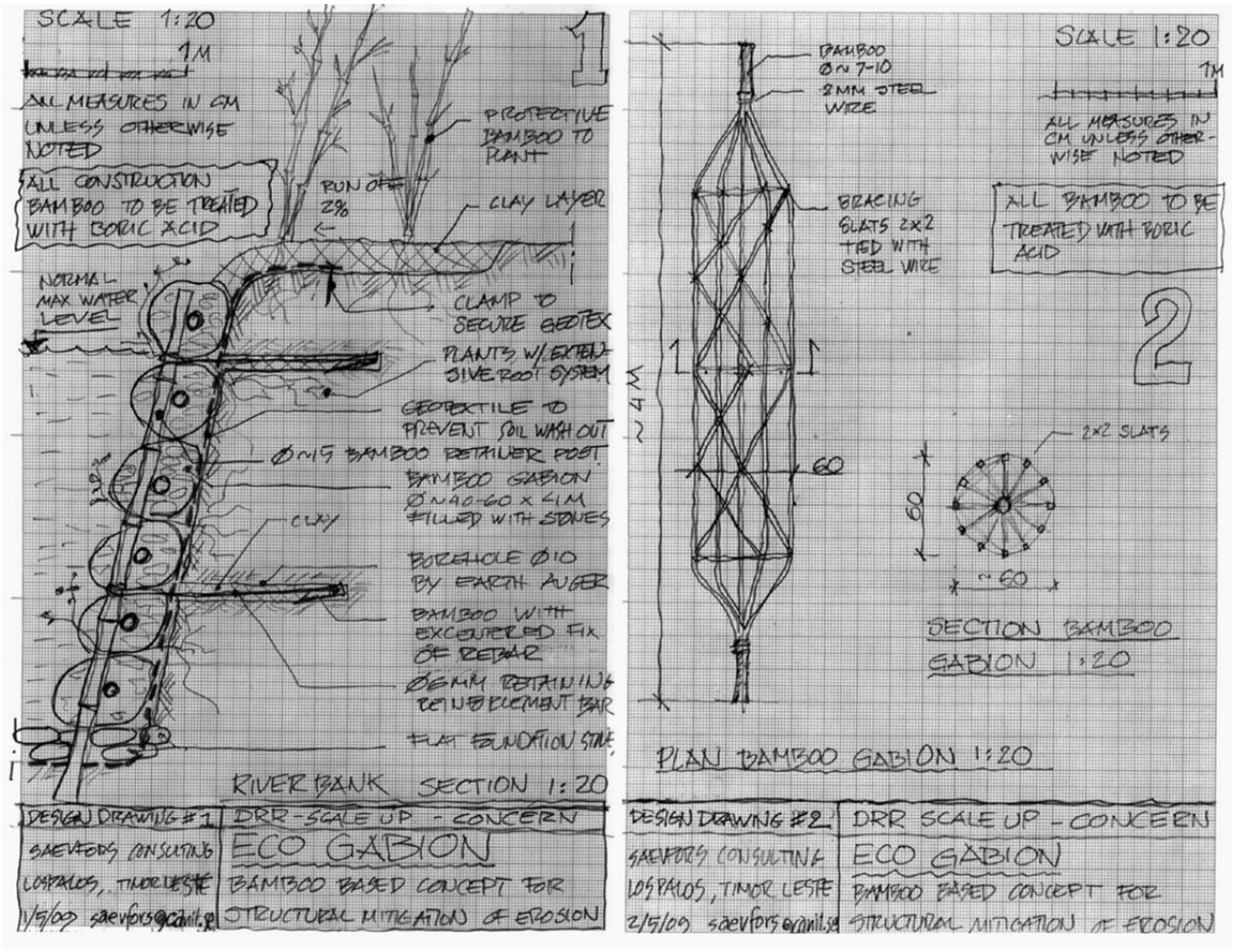

Figure 1.1 (Not to scale) (Saevfors 2010)

One of the advantages of using gabions in retaining structures is that the fill material provides gaps for water movement; therefore the occurrence of water pressure is removed (McCarthy 1997: 652). As mentioned, retaining structures are designed to BS EC7 in the UK; however gabion specialists, Hy-ten (2011), state that they use BS 8002 as well. This document has more guidelines and information for gabions, giving information about mesh material, assembly, fill material, design and construction.

Practical Action (Noble 1997) used gabions for spurs and dykes for flood protection in Chitwan, Nepal. They used gabions here as they were felt to be the best structural option, however Noble (1997), does state that although the gabions can be made locally by hand, that this is very physically demanding for the people that do the work. Also, by using the easier to construct rectangular mesh, there is a tendency for the gabion to unravel, even is a single wire is broken, resulting in premature failure of the structure.

Saevfors design, the 'Eco Gabion', is made from a 6-7cm diameter, pole of bamboo. The bamboo has 2-3cm wide slats cut, but leaves both end nodes intact, these nodes are then tied with wire to prevent splitting. The pole is then compressed to create a spool shaped basket; a length of bamboo is then split, to create 2-3cm wide lengths, which are then tied at a 45^{o} angle to create the basket (Saevfors 2011). All of the bamboo is treated in a boric acid solution, and then dipped in waste motor oil which provides a water repellent coating. Saevfors (2011) expresses the environmental concerns with this treatment, but according to the installation in Timor Letse, the released quantities observed were minimal for the motor oil. The boric acid provides protection from insects and decay, it is inexpensive, low toxic and not harmful to people or domestic animals and has a very limited effect on plants (Ahmed et al. 2004). The gabions are then installed as in figure 1.1.

Bamboo is seen as some as 'the vegetable steel' (Bamboo Costa Rica n.d.), this is down to its mechanical properties. A bamboo species called, *Guadua angustifolia Kunth*, has the following values (Trujillo 2011):

- Compressive strength parallel to grain: 28 N/mm^2
- Tensile strength parallel to grain: 90 N/mm^2
- Tensile strength perpendicular to grain: 0.1 N/mm^2
- Bending strength: 46 N/mm^2
- Shear strength: 4-5 N/mm^2
- Modulus of elasticity in compression: 15 000 N/mm^2
- Modulus of elasticity in bending: 11 800 N/mm^2
- Unit weight: 6 kN/m^3

When the compressive strength to weight ratios are compared, for *Guadua angustifolia Kunth* it is 4.67, for C30 concrete it is 1.25 and for 275 grade steel it is 3.57 (Trujillo 2011). From these properties it can be seen that bamboo is very good in compression parallel to the grain, but very poor perpendicular. This poor property of bamboo needs to be considered considerably when designing gabions.

Intended Course of Action

The next stage of the project is designing a gabion, and constructing it. By doing this I can try and design a gabion as close to design guidelines as possible. Also by constructing it, I can see how easy the gabion is to build, and change my design accordingly. If I find I have time and the facilities to do so, I will test the gabion; however I need to look closer into what kind of tests I will do.

Acknowledgements

I would like to acknowledge David Trujillo, my project supervisor for his great help and support through the project.

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Hand pump Failure – Investigating the socio-technical failure modes of hand pumps in post conflict Sierra Leone using case-based reasoning

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Abstract

The United Nations (UN) set as a target to halve the proportion of the populations without sustainable access to safe drinking water by 2015. While the world is on track to meet the drinking target in urban areas, accelerated and targeted efforts are needed to secure access to drinking water in rural areas. The considerable lack of research methodology and data on the reasons behind the decline in access to improved water sources raises critical questions on project sustainability and organisational accountability and ultimately, how should the Millennium Development Goal for access to safe drinking water be measured. Sierra Leone is one example of this challenge. It is one of the most underdeveloped countries in the world and is still recovering from a brutal civil war (1991-2002). Only 1% of the population has access to piped water and access to improved water sources has been declining in the rural areas for the past decade, even though there has been a sustained effort to combat the decline through the widespread installation of community level hand pumps and wells. A large community level survey was carried out in Northern Sierra Leone on hand pumps and wells installed after 2004. This study develops an innovative non-biased methodology for quantitatively assessing the socio-technical trends in the failure rates of rural community water projects through the use of case-based reasoning and discusses the results with respect to project sustainability and continual monitoring. The study has the potential to impact not only how organisations define the failure of a project, but also how projects are continually monitored and evaluated.

Keywords: Sustainability; Case-based Reasoning; International Development.

Introduction

Overview of global water problem

Currently 884 million people do not have access to safe water supplies (WHO and UNICEF, 2008). The former United Nations (UN) Secretary General Kofi Annan stated that '*access to safe drinking water and sanitation is both a development target in its own right and integrally linked to achieving all the Millennium Development Goals (MDGs)*' (United Nations, 2006). It is also well understood that access to adequate drinking water is essential for reducing disease (Carter *et al.*, 1999). Pruss-usten (2008) demonstrated that access to safe water and adequate sanitation can potentially reduce the number of global deaths by 6.3% and significantly reduce the number of child deaths. This problem is exacerbated when considering the term '*improved water source*' infers that the source is only likely to provide safe water. The majority of the population without access to safe water live in rural areas where little infrastructure and low population density makes using large scale piped systems unfeasible (WHO and UNICEF, 2006).

Project Sustainability and Organisational Accountability: Is it happening?

In 2010 the UN stated that the world was on track to meet or even exceed the drinking water target by 2015 if current trends continued. Therefore, by 2015 an estimated 86% of the population in developing regions will have gained access to improved sources of drinking water, up from 71% in 1990 (UN, 2011). However, the issues of poor project sustainability records and lack of long term accountability of water provision organisations is casting a shadow over the success hailed by the UN (Jha, 2010). Some have argued that success should not be measured by the percentage of the population who have gained access to an improved source, but the percentage of the population who have retained access to improved sources for a certain length of time (WaterAid, 2011, Haysom, 2006). This is being recognised by organisations such as the projects developed by Water For People and Triple–S (IRC), which are developing the Field Level Operations Watch (FLOW) monitoring system, whereby beneficiaries easily evaluate and report on local Water, Sanitation and Health (WASH) projects remotely via their mobile phone (Water For People, 2011). Unfortunately, little research has been undertaken to clearly demonstrate the problem of unsustainability due to the difficulty in obtaining conclusive data (WaterAid, 2011). Consequently it is difficult to know which socio-technical factors are the most significant to the success or failure of a WASH project and hence which factors should be included in a monitoring system. Figure 1 presents one of the only published time-series of rural water supply functionality demonstrating the issue of poor sustainability (WaterAid, 2011). Although heavily cited, these results were determined from a small randomised trial and were determined through basic observational data, whereby the significance of each socio-technical factor that influenced the failure of each well was determined from the comparison of only two individual factors at any one time. One example in the study was the relationship between the age of the pump and its functionality (Haysom, 2006).

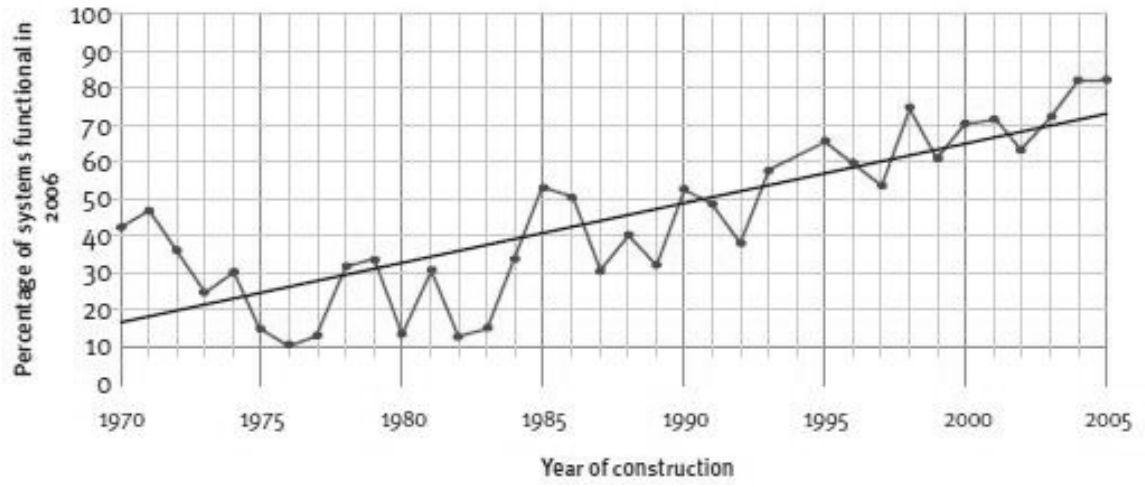

Figure 1 Percentage of water systems functional in 2006 from year of construction, Tanzania (Haysom, 2006)

Lack of methodology for recognising failure mechanisms of hand pumps

As mentioned above, very little detailed research exists on the reasons for high levels of hand pump failure in rural Sub-Saharan Africa as many organisations are seen to have their *'hands tied*' as they are required to meet the requirements of the donor over the beneficiary and therefore cannot commit to setting aside sufficient resources to continually monitor past projects over a long term period.

Currently the main method used in the field is by analysing household level knowledge, attitude and practice (KAP) surveys, whereby data are collected orally by an interviewer using a structured, standardized questionnaire. These data can then be analysed quantitatively or qualitatively depending on the objectives and design of the study. Commonly, basic statistical analysis is carried out and hypotheses are based on expert opinion and individual case studies. This method also applies to identifying the significance of a particular factor influencing the failure of a hand pump, such as the distance to a water source. It also encompasses the study of the influence of one factor on another, also known and interdependencies. An example of interdependencies could be the volume of drinking water collected per day with respect to the distance to the nearest water source. Interdependencies between various factors are incredibly difficult to evaluate. Generally only the interdependencies between two or three factors can be determined at any one time with relative accuracy, which reduces the effectiveness of the argument. It is widely known that there are many social, health, technological, economic, financial, institutional and environmental factors which can affect water treatment projects (WaterAid, 2011). Therefore any conclusion on interdependencies is weakened further when considering that the long term success of any singular hand pump depends on a plethora of interlinked factors, where each factor may affect the outcome of the other.

Access to improved drinking water supplies in Sierra Leone

Currently ranked 180th out of 187 countries in the Human development Index, Sierra Leone is one of the least developed countries in the world. It is still recovering from a brutal civil war (1991-2002) that caused severe political instability, large-scale population re-distribution and over 50,000 dead. Presently only 1% of the population has access to piped water and access to improved water sources is declining in the rural areas, even though there has been sustained efforts to combat the decline through the widespread installation of community level hand pumps (Fig. 2).

This trend is highly visible when analysing the 2011 MDG progress report by WHO/UNICEF (2008). Figure 2 demonstrates that although access to water in urban areas is increasing, it is rapidly decreasing in rural areas and has now dropped to only 26% coverage (WHO and UNICEF, 2008). The decline in access to improved water sources raises critical questions on project sustainability and organisational accountability and furthermore, how should the MDG for access to water be measured. This study investigates the widespread failure of hand pumps installed in Sierra Leone after 2004 and uses case-based reasoning to identify key socio-technical trends. It addresses the issue of sustainability and accountability within the water provision sector.

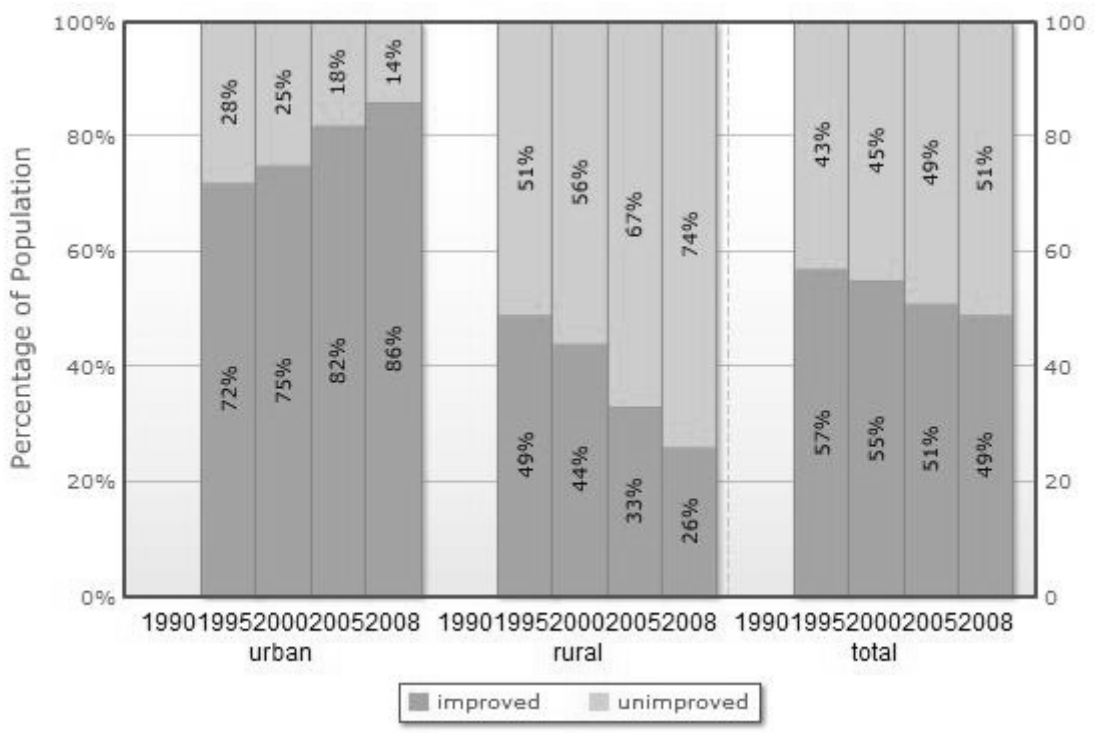

Figure 2 Decline in improved rural water sources from 1990-2008 Sierra Leone (WHO and UNICEF, 2008)

Case-based Reasoning

Case-based reasoning (CBR) is a form of artificial intelligence which attempts to replicate human learning by using past experience to solve complex problems. It has been successfully applied to solve complex problems in a wide range of holistic fields including medicine, law and engineering (Fenner *et al.,* 2007; Aleven, 2003; Holt, 2006). Aamodt and Plaza's (1994) research determined that there are four main components to CBR: (i) retrieve similar cases, (ii) reuse the cases to solve a new problem, (iii) revise the solution, and (iv) retain experience. A case may contain dozens of factors such as; the type of hand pump, number or years since installation, hand pump productivity, water quality and number of users (Fig. 3) (Barrie *et al.,* 2010). Each case contains one evaluation indicator that identifies if the case in question has failed; this study uses the quantity of water from an improved source per household. A new case, for which a solution is sought, is tested by comparing its similarity with other 'known' cases from the systems case base to determine the possible outcome of the case (Lopez de Mantras *et al.*, 2006).

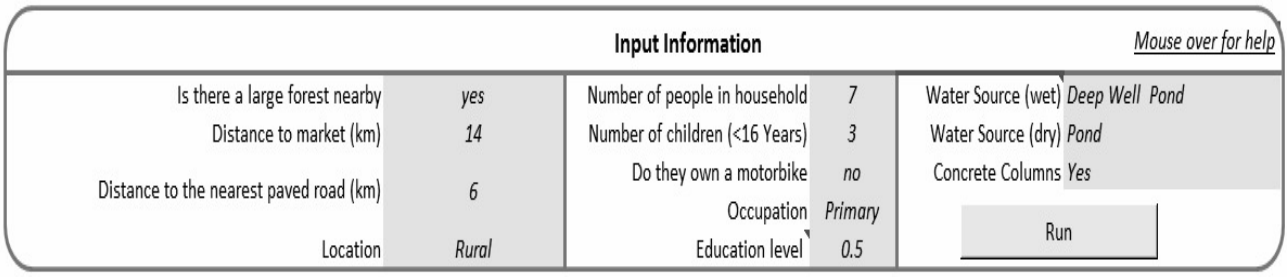

Figure 3 Example of an individual case in the CBR model (Barrie et al., 2010)

Case-based reasoning uses the process of genetic algorithms (GA) to quantitatively determine the significance and level of interdependencies of factors (or sustainability indicators) affecting the outcome of a process by processing hundreds of thousands of case evaluations, and therefore replicating the experience of the expert. There are many different methods with which to implement GA, however all methods follow the same general steps used in this research to determine the significance of each factor.

1. An initial population of random sets of weightings are created and applied to each case variable, where the weights can be either 0,1, 2 or 4.
2. Each set of weights is tested to determine the case base error with respect to predicting the value of the evaluation indicator of the case in question.
3. The more successful sets of weights are combined randomly to create a new population of weightings, the two most successful set of weights are retained unchanged.
4. Steps 2 and 3 are repeated one hundred times.
5. The most successful set of weights is then selected.

Therefore if the user selects 100 generations for a case size of 20 factors, the model will analyse 2000 possible weighting

scenarios per case. Hence, a case base of 151 cases will amount to the equivalent of 302,000 individual case evaluations.

The effectiveness of the GA's ability to ascertain the significance of each factor is determined by the size of the case base, or '*experience*'. Therefore, as the number of cases in the case base increases, the accuracy of the GA increases. The advantage of GA is its ability to gain a much larger '*experience*' than any single expert and the influence of bias is much reduced as the outcome is based purely on qualitative data. Furthermore it can assess all interdependencies between all factors included in the case-base.

Research Aim and Objectives

As of yet, no substantial evidence exists for the high failure rates of hand pumps installed in post conflict Sierra Leone. Furthermore the methodology that currently exists for determining the socio-technical failure modes for hand pumps in the developing world is basic and relies heavily on practitioner experience, which is regularly influenced by bias on the part of the practitioner. Therefore the aim of this study was to carry out an extensive hand pump survey in Sierra Leone and investigate the viability of using CBR as an unbiased method to suggest the key socio-technical factors that influence the failure of hand pumps and their respective interdependencies. In order to test the viability of CBR for this problem, the main objectives of the research were: (i) identify a range of variables that influence the uptake of water treatment technologies in Sierra Leone through a detailed KAP survey; (ii) develop a user friendly CBR model that can identify the significance of a range of socio-technical failure modes for hand pumps; (iii) to evaluate the results of the CBR model; and (iv) to discuss the applicability of CBR, for instance to help determine more efficient sustainability indicators for the FLOW continual monitoring program.

Methodology

Barrie *et al.* (2010) developed a decision support CBR model which demonstrated the capacity to predict the success of future water supply projects in rural Cambodia. Firstly the significance of each variable in the database was determined by evaluating previous projects using genetic algorithms. The user then entered the value of a range of variables linked to the community project in question. The model would then compare the characteristics of the community with regards to past community projects and their respective project outcomes and suggest the likely success. This model included social, technical, political and economic factors when evaluating. Furthermore, it included a module to determine the accuracy of the models prediction by testing the prediction of the outcome of an existing case.

The model developed by Barrie *et al.* (2010) aimed to determine the success of a project, whereas the model developed in this study aims to identify the reasons behind past projects failing. Therefore the CBR model developed by Barrie *et al.* (2010) will be altered so that each case includes a wide range of socio-technical factors determined through the Sierra Leone KAP survey. See Table 1 for a list of the factors that will make up each individual case.

1. Number of males / females in each age group	2. Overall feeling of the well (sum of five factors: strong flow of water, well had plenty of water, ease of effort to get to water, short queues, good tasting water)
3. Combined total monthly household income	4. Did you *(or do you)* expect the system to fail?
5. Age of the head of the household	6. Do you know where spares can be bought for the well?
7. Maximum level of schooling completed by the head of household	8. Total water collected in the household in one month (person with the most tokens)
9. Water sources	10. How often is the source cleaned?
11. How long does it take to reach main source?	12. Has the household ever used a water treatment system?
13. How long does it take to queue at this source?	14. Did the household participate in the building of the water supply system?
15. How long does it take to return from this source?	16. Would the household have liked to contribute more in the well projects?
17. Number of times a day water is collected from the source	18. Do you think that the village could provide a well system without outside help?
19. Number of months of the year family is most likely to have water shortages	20. Does the household own a phone?
21. Person who makes the decision for source of water , volume to be collected and buy new household items	22. Scientific and technical capacity
23. Who controls the well? Whose property is the well? Whose responsibility is it to make decisions about the well? Whose responsibility is it to fix the well? Who has the capacity to provide new wells?	24. Distance to medical treatment

Table 1 List of the factors included for each case

Results and Discussion

Upon completion of the Sierra Leone KAP survey the data will be input into the CBR model and the following results will be analysed and discussed:

1. Basic statistical analysis of survey data to determine clear trends.
2. Determine model error and learning ability of CBR model.
3. Weightings for each case variable will be determined using the CBR genetic algorithms and ranked by significance. Discussion on trends identified by model, comparison of trends to specific cases. Results compared to basic survey analysis whereby any similarities or disparities are identified.
4. Discussion on sustainability, accountability, predicting potential future failure and the potential for applying CBR to continual monitoring processes currently being developed.

Summary

Historically there has been little emphasis and resources dedicated to continual monitoring of water supply projects in rural developing countries. This has led to widespread long term project failure and misrepresented data with regards to MDG progress. There has, however been a gradual shift towards promoting continual project monitoring and organisational accountability. Currently there is little work carried out to determine, in an unbiased manner, the significance of a wide range of socio-technical factors affecting rural community level water supply project. Therefore, the process of continual monitoring is restricted both by bias and relevance. This project proposes a novel method for determining the significance of the socio-technical factors. Furthermore the results produced by the model could be used to further improve the continual monitoring processes currently being developed.

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Developing the Next Generation of Solar Lanterns

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Abstract

In the late 1990s and early 2000s Practical Action Consulting developed a solar lantern product with support from DFID to address the challenge of lighting in off-grid situations in the developing world. The Glowstar product was a ground-breaking project, won a number of design awards, was transferred into manufacture with a private company for global distribution, and spawned a wide range of similar products.

The Glowstar lantern is regarded as a high performance and quality product but the price (US$150) at which it is sold is too high. This combined with a limited distribution network put the product out of the reach of the rural poor households at which the development was targeted. [1]

Keywords: Energy, Off-grid, Solar, Lighting, Mobile phone charging, Small business, Micro-finance, Local enterprise

Educational Background

The project brief stems from Practical Action's desire to renew interest and catalyse activity (both internally and among students and the international development community) in the rapidly maturing solar lighting industry within Africa in particular, centred around Glowstar's proving grounds in Kenya. Practically, this has been achieved by initiating and supporting student research projects affiliated with EWB-UK at major UK universities, encouraging engineering students (myself included) to take the initiative in the evolution of a new Glowstar product.

This approach has given passionate students direct input into the research and development of a new generation of high-quality, portable solar lighting, while gaining academic credit for it as the basis of their major graduating projects. As a result, we as students have immersed ourselves in the sector and absorbed the specific (and almost always non-curricular) skills and knowledge necessary to develop appropriate products & technologies for developing markets, all before graduation.

British universities, on the whole, remain painfully slow to adapt their curricula in the face of global human challenges. In the meantime, research opportunities and projects with the investment and support of a committed NGO, the potential for field visits etc. are essential for starting young engineers down the path to making a worthwhile contribution to international development.

Introduction

This project builds on the work of two student research projects with the title 'Developing the Next Generation of Solar Lanterns' already completed under a Practical Action/EWB-UK partnership - those of Chris White & Karen Fearnon, and Tabrez Daya - and runs parallel to Sam Islam's project at the University of Manchester.

My aim has been to synthesise existing contributions to the brief (including field research, market analysis and technical development) with my own user-centred design process and further exploration of new technologies and concepts for a second generation Glowstar. The intended outcomes are a workable product design and specification, functioning prototype/demonstrator, and outline distribution model based on Practical Action's suggestions for potential support in taking a new product to market.

Project Snapshot

Glowstar^2 is a new portable, affordable, solar-powered lighting system, designed to meet the energy and lighting needs of small businesses & households in the developing world, and delivered through an innovative micro-rental service model.

The Glowstar^2 concept attempts to realise the feedback obtained from users and retailers of the original Glowstar, referred to previously, while exploring the potential nature of a new, disruptive product. It represents one possible manifestation of an emerging third generation of portable solar lighting (after CFL lanterns such as Glowstar, and mass-market LED lamps from the likes of d.light & ToughStuff).

The current phase of the project is directed by the creation of a comprehensive Product Design Specification, outlining a definitive set of product, user and market requirements based on, among others: Practical Action's findings during the original Glowstar project; Chris White's project report [2]; Lighting Africa's key insights [3] and performance targets [4] for new products entering the market; and my own research thus far.

This additional research is intended to fill in the qualitative gaps surrounding user interaction and lighting preferences for the new product, as well as explore further avenues of technical development. This has included:

- Interviews with recent overseas volunteers in the international development sector, including EWB-UK placementees Amy Corbett & Lauren McLean
- A 'night in the dark' style of personal immersion in blackout conditions, in order to faithfully test a range of portable lights including my own prototypes
- Luminosity testing of various light sources, both currently in use and proposed for Glowstar^2
- Investigation of alternative models of energy capture, storage & application (focussing on the use of ultracapacitors and DC mobile device charging), as well as light output, supported by the Electrical & Electronic Engineering department at Glasgow University

The UK-based work above has proved to be valid in exploring the problem – the conclusions drawn from personal immersion match up with those contained in the field research conducted by Lighting Africa and Practical Action. However, this can only achieve so much, and I have felt the inevitable friction caused by distance and lack of access to primary users for product testing and validation.

Current Design Summary

Glowstar^2 explores an untapped niche of the off-grid solar lighting market - the gulf between standalone solar-powered LED lanterns, and traditionally expensive solar home systems using multiple light sources and outdated Solid Lead Acid (SLA) batteries.

Glowstar^2 positions itself as a high-quality, reliable portable solar system suitable for entire households and small businesses. Leased and maintained via a regular fee micro-rental service operated by local social enterprise, the system is tailored to a customer's needs and budget by way of its modular, adaptable design.

Key criteria included in Product Design Specification:

• Provide options for simultaneous lighting in multiple rooms/locations

• Provide both directed (task) & diffuse (ambient) lighting options

• Charge a mobile phone or power an auxiliary device at a maximum of 500mA 9V DC.

• Capture & store a full charge from solar power in one day of minimum average insolation in Kenya (~4KWh/m^2/day).

• Price of 'basic' system (solar panel & core energy storage/lighting/charging module) should be below $50 (US).

• Light output/operation time must not degrade below 70% of original performance within minimum service period of 2 years.

Next Steps

The project has another two months to run, in which time my goal is the formalising of Glowstar^2's technical configuration to produce a detailed Bill of Materials for the product, as well as refinement of its form and user touchpoints through iterative modelling and evaluation.

Ideally this evaluation includes both UK-based 'proxy' user testing, but also the opportunity to bring high-resolution demonstrator prototypes to the Glowstar trial community in Nakuru, Kenya (or an alternative group of well-informed primary users), in order to determine first-hand how well Glowstar^2 meets the needs of its customers, and what improvements are needed.

The endpoint of the project is the delivery of a product proposal, including associated costs, to Practical Action, who have expressed an interest in supporting the route to market of a new product, while exploring multiple design and supplier options.

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Tabrez Daya

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Lighting Africa

Scottish Institute for Enterprise

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Incorporating Disaster Risk Reduction into Development Projects in Bangladesh

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Keywords: disaster risk reduction, disaster resilience, shelter, Bangladesh

Introduction

Bangladesh has undergone significant progress in human development over the last 20 years, with poverty levels falling from 59% to 40% since 1991 (DFID, 2009). However, with a growing population currently at over 160 million, it is the ninth most densely populated country in the world (Department of Economic and Social Affairs Population Division, 2009) which puts great pressure on a strongly agricultural (though increasingly industrialised) economy. Additionally, 60% of Bangladesh's land is less than 5m above sea level, making it one of the world's most low-lying countries, and its coastal position makes it highly vulnerable to flooding (DFID, 2009).

Between 1980 and 2009, there have been over 200,000 fatalities in Bangladesh due to natural disasters, with over 90% of these due to floods or storms (EM-DAT, 2010). Many major organisations, including the Government of Bangladesh, and major national and international NGOs, believe that the impacts of climate change are leading to an increased frequency and severity of major climatic events. Cyclone Sidr in 2007 and Cyclone Aila in 2009 were the latest major storms in a sequence that has been steadily increasing in frequency (EM-DAT, 2010). As well as the immediate devastation, it is the chronic affects that often make the most impact – the aftermath of cyclones often includes long-term flooding, increased salinity of water due to tidal surges or broken defensive embankments, and a lack of fresh water, alongside damaged infrastructure and threatened livelihoods. Whilst initiatives such as the Bangladesh Cyclone Preparedness Programme have helped to reduce immediate fatalities due to major cyclones, these long-term impacts of the cyclones are far harder to mitigate (EM-DAT, 2010).

These challenges have led to the development of myriad approaches designed to deal with the direct and indirect impacts of flooding, from large-scale governmental and NGO-led programmes through to community-based indigenous solutions. Most development projects in Bangladesh do not focus solely on disaster risk reduction (DRR), but ensuring that DRR issues are considered and integrated within development projects is vital. Building on the research undertaken through this report, a framework is designed to help practitioners to assess the levels of resilience and disaster risk reduction incorporated into their current projects and help identify ways in which the programmes can include stronger or more inclusive DRR. The framework is trialled on a particular programme - the Bangladeshi NGO BRAC's response to Cyclone Aila and its aftermath in 2009-10.

Outline of research to date

This research project aimed to thematically review a range of development initiatives under implementation in Bangladesh. The results of this research informed the development of a framework that is designed to help practitioners to assess the levels of resilience and disaster risk reduction incorporated into their current projects; and help identify ways in which the programmes can include stronger or more inclusive DRR.

Types of Disaster Resilience in Bangladesh

The main types of development programming with significant DRR aspects can be summarised into infrastructure; livelihoods; and communications or "community" preparedness.

Infrastructure

Plinths – effectively large, packed piles of earth which raise the ground above the threat of potential flooding – are one of the most low-risk and low-cost type of protective infrastructure. Larger-scale embankments have been built throughout the country, but particularly in coastal areas, to protect areas from floods and storm surges due to cyclones.

Cyclone shelters provide a vital first line of defence against cyclones and tidal surges. In total there are currently around 1,800 shelters built across the coastal region, each capable of offering refuge up to 5,000 people (Reuters, 2008). Many existing shelters, built in the 1970s, have since fallen into disrepair through neglect, with more than 80% lacking toilet facilities and no separate areas for men and women (Rejve, 2010). The shelters are built on pillars to keep them above the water and usually perform a dual role as schools or community centres (The Daily Star, 2010).

However, solely providing a shelter does not ensure that people will use it. During the 1991 cyclone, there were a high number of casualties among women and children. Studies found that this was partly because women were not informed about the threat of a cyclone, and in the conservative regions it was not customary for women to leave home without their husband's permission – so during emergencies many women were waiting at home for permission to seek shelter (IFRC, 2010).

Livelihoods

The microcredit concept is hugely popular in Bangladesh, with an estimated 721 MFI (microfinance initiatives) organisations in the country (Porteous, 2006) encouraging people to take out small loans to start or expand a small business, or to help with other unexpected costs. Sometimes these loans will come with training and support (Grameen Bank, 2010), however more indiscriminate organisations can be less scrupulous about the ultimate impact their lending can have on their customers, and there are few measures in place to prevent people taking out multiple loans. In addition, whilst there are many case studies of successful microfinance case studies, recent randomised control trials have shown that there is little robust evidence that microfinance does in fact reduce poverty in the long run (Bateman & Chang, 2009).

There are also a number of programmes encouraging people to work together to create community, co-operative savings associations which can also be used to provide loans. The Chars Livelihoods Programme has initiated "Village Savings and Loans" groups in around 2000 villages, where around 20 community members form a group, each regularly invest a small amount, and are then able to "borrow" from the group when they require a small lump sum (CLP, 2010) – often for a one-off cost such as school fees, medical fees, or a special occasion (Momin, 2010). These types of programmes have the advantage over institutional microfinance in that no interest is "lost" to the organisation, but more investment is needed from the community to make it work, and it can take a long time and also support from an external organisation to help it begin. Significantly, it can also enable people to feel empowered and work together within their own communities (Momin, 2010) .

An emerging challenge is the adaptation of livelihoods required due to increasing salinity of the water and soil in many areas. BRAC are experimenting with new saline-resistant rice, which can grow in salty areas (Huq, 2009). Crab fattening and genetically-modified tilapia are other forms of livestock that can adapt with the more saline conditions. Practical Action Bangladesh have set up a programme enabling crops to be grown in the barren sandbanks that were previously thought to be infertile (Chowdhury, 2010). Limited access to market can often be a barrier to forming productive livelihoods, with a number of programmes focusing on enabling people to interact with and find routes to the markets (Practical Action Bangladesh, 2010).

Communications and Disaster Preparedness

A number of organisations and the Government have initiated disaster preparedness programmes, ranging from local planning committees to complex national communication networks. A variety of means are used, from warning text messages from weather stations sent to local community leaders who then place a sign such as coloured flags in a visible location; to local radio and television broadcasts; to a volunteer cycling around the village shouting warnings with an electric microphone,. This is one area where Bangladesh's densely packed population is an advantage – due to the close clusters of people, warnings, or even a man on a bike, can reach many people quickly, and similarly, many people can access one cyclone shelter.

Although different DRR aspects within projects have been discussed above, most major projects run by large NGOs currently take a multi-pronged approach to disaster resilience. Some programmes, often those that focus on the ultra-poor, take participants through a specified programme where they can receive support in different ways, such as BRACs Ultra-Poor Programme (BRAC, 2010) or the Chars Livelihoods Programme (CLP, 2010). These "package" programmes tend to show positive results for ultra-poor people, as there are often numerous root causes that need to be scaled to help improve poverty and disaster resilience.

Challenges to Reducing Vulnerability

Whilst a number of programmes are undoubtedly making a difference to the lives of many people, many similar challenges are faced during these different types of programme design and implementation. Corruption is one major challenge faced in almost every aspect of life in Bangladesh, from top-level project planning, to hindering ordinary people as they try to go about their lives (Zakiuddin, 2009). This also pervades into the development sector. Many NGOs may account for corruption into their budgets by estimating costs to be around 10% higher than would be expected – to ensure that the project will have enough funding to run smoothly (Hossain, 2010).

Land ownership is another complex issue in Bangladesh, with many poor people living on land that they don't technically own (Ahmed, 2010). This is a particular issue in the char areas, where continuous erosion and redeposition of land mean that identifying "ownership" is a complex task – and this is a highly-politically charged issue. However, without land rights, people are not entitled to compensation when they lose land to flooding, and gaining ownership of emerging land seems to be ad-hoc (Ahmed, 2010).

There are concerns that the sheer number of NGOs present in Bangladesh, with the types of projects being run, are creating a donor culture within the country. Whilst microcredit programmes do only provide loans that people must pay back, many programmes aimed at the ultra-poor do effectively provide handouts – potentially creating an ongoing expectation from recipients.

A final challenge is that of the NGOs ability to access particularly vulnerable groups such as women or disabled people. There are a number of challenges to reaching the most vulnerable groups, most predominantly due to their invisibility. Getting their input, or even attendance in focus groups, finding the most rural and vulnerable areas, ensuring that people aren't acting as a mouthpiece for someone else, are all issues that must be addressed to ensure those most vulnerable are being supported.

Disaster Risk Reduction Framework

The case studies and challenges considered above were then used to inform a framework designed to assist NGOs in mainstreaming DRR into their development programmes. The framework is designed so that is can be adapted for specific situations, and to consider the wider issues around project implementation and sustainability.

The framework is in two parts. Part A uses a matrix structure to explore the location-specific risks, and looks at how the project is working to mitigate those threats or help decrease people's vulnerability. Part B provides a set of questions to explore the wider issues around the project.

FRAMEWORK STRUCTURE		
PART A: CORE ISSUES	Step 1: Identify Location-Specific Risks	Knowing the location and the community, the first stage is to identify risks in that location, for those community members. *Action: Identify the key risks in the location where the project is being implemented and write them in the appropriate matrix cell.*
	Step 2: Identify potential Impacts	Identify the potential impacts of these risks for the community. The impacts should be written down considering how they can affect four key life areas: • Basic Needs • Shelter and Property • Livelihoods • Access to Services (note that a risk may not necessarily impact on all life areas) *Action: In each appropriate matrix cell, write the impacts relating to the key risk and the life area it will impact (for example, if Risk 1 is "seasonal flooding", and the Life Area is "Shelter and Property", the risks may be "Housing may be damaged" and "Lose food and property".*
	Step 3: Identify Project Aims and Activities	Consider how the project's aims and activities can mitigate against these impacts of disaster. *Action: In each appropriate matrix cell, write how the project activity mitigates against that particular impact.*
	Step 4: Analyse how the project addresses impacts	*Action: Through looking at the completed matrix, consider which areas have risks and impacts are being well mitigated against, and where there are gaps. Are other projects or factors addressing those issues? Is it worth considering how these issues could be addressed?*
PART B: WIDER ISSUES	Step 5: Consider Wider Issues	After completing the matrix, it should be clear where the projects aims and activities intend to address the impact of risks. However, the wider issues should also be considered for the programme and/or specific activities. Through earlier research, key wider issues were identified. These are now used to inform the evaluation framework. *Action: Consider the wider issues list, and how these issues are addressed or dealt with by the project.*

Table 4: Framework Outline

Part A: Core Issues

The core issues matrix is shown below, and can be completed using Table 1 (the framework will be applied in the next chapter for a full example of its implementation).

	Safety and Access to Basic Needs*	Shelter & Property	Livelihoods	Access to Services
[Risk 1]				
How is the risk mitigated?				
[Risk 2]				
How is the risk mitigated?				
[Risk 3]				
How is the risk mitigated?				

* including emergency health care, disease, access to food and water

Table 5: Part A - Questions for Core Issues

Part B: Wider Issues

After completing the matrix, it should be clear where the projects aims and activities intend to address the impact of risks. However, the wider issues should also be considered for the programme and/or specific activities. Through earlier research, key issues were identified. These are now used to inform the evaluation framework.

Issue
1. Stakeholder Requirements *Was the project defined with input from all those affected? How will the project impact different stakeholder groups?*
• Was the project defined using information from all stakeholders? • Were the end-users involved in identifying needs? • Was there a needs assessment process • How does the project ensure to benefit vulnerable groups such as children, women and disabled people?
2. Building on Local Capacity *Are people becoming independent or having to rely on outside players? Are local resources being exploited suitably?*
• Has local knowledge and experience been considered in the project definition? • How has the project worked or communicated with local organisations and/or local government? • Has the project worked on any type of community capacity building?
3. Resilience to Disaster *If another disaster were to occur, how would this affect the community? What would be left of the projects successes after a disaster?*
• If there were to be another disaster, what would happen to the programme outcomes? • What non-tangible assets and skills are being encouraged? • Has any thought been given to dealing with land rights issues – what will happen to people if they lose their land?
4. Project Evaluation *Is a true picture of the impacts of the project being seen? As useful successes and failures made available to other parties?*
• How is the project evaluated? • Are external evaluators used? • Is a random sample/statistically significant sample of people being interviewed? • How are lessons learnt transferred to other interested parties?
5. Long-Term Sustainability *What are the aspects for the project in the long term? Can it be "sustained"?*
• When the project ends, will permanent partners (e.g. local government or the community) be able to maintain the work? • Has the project considered how climate change adaptation could affect the project in the long-term? • Are the projects financially sustainable in the long term? • How do the actions have the potential to affect the environment in the long term?

Table 6: Part B - Questions for Wider Issues

Framework Limitations

Completing the framework would likely be most useful in a small discussion group where it can be used as a structure and starting point for thoughts and ideas. The framework deliberately avoids assigning quantitative values or levels, or specific goals, as often the framework goals can themselves becomes the "end" rather than a means to an end. Its intention is to assist development practitioners in re-considering the impacts and sustainability of their programmes through analysing them holistically, and ideally to assist in highlighting areas of need that have not already been considered.

Case Study 1: BRAC – Aila Affected Coastal Areas

Tropical Cyclone Aila, struck the southern coasts of Bangladesh and the southern regions of West Bengal, India in May 2009, accompanied by tidal surges and severe flooding. Almost 200 people were killed with over 3 million affected, and almost 2000 km of embankments were damaged (Government of the People's Republic of Bangladesh, 2010).

One of the largest Bangladeshi NGOs, BRAC, provided initial emergency response materials, and then moved rapidly to assist the Aila-affected populations with sustained water and sanitation facilities as well as livelihoods opportunities. In the emergency stage of the disaster, BRAC provided relief including dry food, shelter materials, medicines, and drinking water. As the response moved into the recovery phase, BRAC began work assisting the community with provision for sustained water and sanitation facilities and livelihood opportunities, in a bid to support "sustainable development" of the area. However, unrepaired embankments, and the lack of drinking water and dry land for planting crops emerged as major problems (Huq, 2009).

A year later, communities are still suffering from the impacts of Cyclone Aila, and BRAC DECC is running continued programmes in four districts in the affected areas. BRAC's DECC programmes in Koyra Upazila in the Khulna District, and Shyamnagar Upazila in the Satkhira District, are now analysed using the DRR framework.

Identifying Risks

BRAC DECC's needs assessment of the area in early 2009 (Huq, 2009) identified the most pressing challenge as the salinity intrusion, and the subsequent lack of clean drinking water and impact on livelihood (this was supported by the first-hand evidence from the residents). Residents themselves identified their greatest challenge to be the lack of available drinking water, followed by the impacts of damaged buildings and the flooding.

Houses in Koyra. Some paths are raised above the floods and still passable

Flooded areas – the roots of the trees are submerged

"Temporary" housing shacks built alongside the road as no other space is available (behind the shacks is more flooding)

Barren land in Koyra. It is becoming increasingly difficult for crops to grow due to the increased levels of salinity.

Figure 13: Photographs around Koyra (Sharp, 2010)

Aims of the Programme

BRAC's programmes in the Aila regions can be split into two main aims, livelihoods and water supply and sanitation. After the initial aid and first phase recovery, BRAC has been providing technical and financial support to approximately 5000 beneficiaries to assist in building sustainable livelihoods, including salinity-tolerant rice seed, fish cultivation, and crab fattening.

Much of the affected area was still inundated with brackish water to date (August 2010), and BRAC is currently supplying one truckload of water twice every two days, providing up to 20l per family per day. Residents (usually the women of the household) have to walk up to 5km to collect it each time. BRAC have attempted to sink new wells in the area but after two failures they have not yet managed to find a clean water source.

Part A: Core Issues

As the situation is still in the recovery phase, the framework matrix has been divided into two sections, to better consider both "Current Challenges" and "Future Risks".

RISK / CHALLENGE	Safety and Access to Basic Needs*	Shelter & Property	Livelihoods	Access to Services
CURRENT CHALLENGES				
Flooding	Stagnant water potentially spreads diseases. Water sources contaminated	Lack of space to rebuild houses. Many people living in "temporary" shacks	Agriculture not possible in flooded areas	Can prevent people accessing health and schooling and markets
How is the risk mitigated?	Transporting water. Sinking and de-contaminating tubewells	No mitigation	Trialling crab fattening and tilapia farming	No mitigation to access. Some health support provided locally
Brackish water and lack of drinking water	Water sources contaminated with brackish water	n/a	Salinity makes it more challenging to grow crops	n/a
How is the risk mitigated?	Transporting water. Sinking and de-contaminating tubewells	n/a	Trialling saline-resistant rice	n/a
FUTURE RISKS				
Risk of another cyclone / tidal surge	Potential loss of life	Damage to shelter and loss of property	Flooding/destruction to current livelihood opportunities	Prevent access to services
How is the risk mitigated?	Other programmes have made cyclone shelters accessible. Miking and radio warnings will occur. BRAC are also preparing Standardised Operating Procedures to help organisation of field staff in an emergency.	No mitigation	No mitigation	No mitigation

Key Points from Matrix

The matrix illustrates how project activities are mitigating many of the threats and challenges experienced by many residents, and also highlights risk and challenge areas that are not yet being addressed. Notably, no resilience is being considered to protect the current livelihood opportunities from the risk of another cyclone or tidal surge – if another cyclone occurred then there was no evidence of measures that would protect the new livelihoods opportunities. There were also no programmes in place to assist with improving housing, and no measures in place to help reduce flooding, for example through encouraging local embankments or earth-raising[7].

Part B: Wider Issues

Stakeholder Requirements

BRAC has undertaken a number of needs assessments in the Aila-affected areas, and also has field offices throughout the region which are constantly able to monitor the local situation. BRAC's findings (Huq, 2009) do correlate well with field observations and information from secondary sources. However, there is no evidence that the individual DECC interventions were designed or informed with participation from the beneficiaries. In addition, although the programmes do focus on ensuring that women are also able to become involved in the livelihoods programme, no evidence was seen of pursuing the more vulnerable people in the communities[8].

Building on Local Capacity

BRAC's field offices are based permanently in the region, so the programmes, and BRAC's presence in these areas, will not finish at a defined end date. There was no evidence of the project working on any local capacity building for the community – all the initiatives seen were for individuals, though the individuals were given training on the new climate adaptive crops and pisciculture techniques. All of the individuals interviewed who had been involved in the livelihoods initiatives reported that they were very satisfied with their involvement with BRAC and that their businesses were doing well.

Resilience to Disaster

In the Khulna areas, BRAC's programmes are currently working to help people become more economically resilient. However, if there were to be another cyclone, there is currently nothing preventing the new businesses being destroyed as the old ones were. There are many more basic needs still outstanding, not least shelter. However, all those residents interviewed said that if another cyclone were to occur, they would recognise the warning signals and react more effectively to protect their families and goods than they had as Aila approached.

Project Evaluation

BRAC have two types of evaluation used to measure impact of this project - firstly, the monitoring and evaluation carried out by each field office, and secondly, BRAC's internal Research and Development Division, based in the head office in Dhaka (BRAC RED, 2010) The presence of an internal evaluation unit is both a curse and a blessing: the large evaluation resource provides time and expertise for people to invest in evaluation, but having an internal department does mean there can be a lack of distance between those in the evaluation division and those running projects (Evans, 2010).

Long-Term Sustainability

The livelihoods projects are designed to be economically sustainable and other than the initial investments and training, BRAC does not provide ongoing support. Environmentally, the projects are maximising use of the altered local environment by turning flooded areas – and brackish water – into a useful resource. However, the local conditions are currently unstable, with many residents thinking that the flood water is receding, albeit slowly. If the flood waters do recede, this may have consequences for some of those who have begun pisciculture businesses.

BRAC Programme - Analysis

As a trial study to investigate the feasibility of alternative livelihoods, BRAC is proving highly successful, and will be contributing to the knowledge base on climate adaptive livelihoods – and hopefully in future years, will help greater numbers of people to build disaster-resilient livelihoods. However, it seems that in the regions visited, there is such an emphasis on livelihoods resilience that less is being done to increase resilience against future disasters and to support people's basic needs. Although in the long-term knowledge is being built up regarding the potential for climate change adaptation, many people in the affected areas are still suffering from a lack of basic services, such as space shelter and potable water. If the situation is to be assessed impartially, it would have to be recommended that these areas are prioritised.

[7] these are not activities that BRAC is generally involved with, but it could be feasible for BRAC to trial these as a pilot alongside their livelihoods trials.
[8] though BRAC do have programmes in other parts of the country specifically designed for the ultra-poor and vulnerable people (BRAC, 2010).

Conclusions

With a strong country-wide emphasis on social and economic and community-based disaster resilience, there has been less investment in infrastructure based solutions over recent years. Large-scale infrastructure in particular comes with high risks, but measures need to be undertaken to help reduce flooding in the afflicted areas. Large NGOs such as BRAC have massive country-wide capacity, and it could be an opportunity for them to expand into these areas.

In almost all situations, non-tangible skills have been demonstrated to help provide long-term impacts for communities' lives. Once people are able to learn new skills and feel empowered to take control of their own lives, then even if material items are lost in a disaster they can have the knowledge to help recover their lives and livelihoods. However, the difficulty in quantitatively measuring the impact of these types of outcomes can often make it challenging to assess and compare programmes.

The importance of disaster risk reduction, routes for implementation, and a broad awareness of the wider picture, is widely demonstrated at the top levels of the NGOs and Government in Bangladesh. Unfortunately, a top-level acceptance does not necessarily translate into grassroots impacts. In some aspects - such as awareness raising, warning systems, and preventing loss of life, the country has proven a high degree of success. There have been fewer fatalities in more recent disasters - but it is the next level of resilience that now needs to be addressed, including maintaining people's quality of life, livelihoods opportunities, and coping with long-term climatic impacts to maintain ongoing development. The application of a structured framework can assist in DRR integration, but must be applied on a case-by-case basis, and to help support the development of unbiased view on how to sustainably assist people to become more resilient to disasters.

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Improving NGO-Government Relations During Post Disaster Relief Work

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Keywords: post disaster, governance, NGO, RedR

Introduction

Project overview

This report presents the findings of the individual research project undertaken as part of the MSc Construction Management Course at the University of Birmingham. This paper looks into the developments that have taken place within the construction industry and the possibility of applying best practice to organisations involved in relief work in an attempt to increase the combined output of those organisations. Through research surveys and interviews the author was able to identify key aspects of project management where the construction industry has progressed and the humanitarian industry has fallen behind. Key features from the New Engineering Contract (NEC), which have benefited the construction industry by implementing a cultural shift towards a combined effort, have been investigated for use by Non-Government Organisations (NGOs) and Government during relief work.

Background

The last century has seen a general trend towards an increase in the number of recorded natural disasters. In addition conflicts continue to affect hundreds of thousands across the world. In the first half of this decade, a total of 2,135 natural and technological disasters, such as transport or industrial accidents, were recorded, compared to 2,034 in the whole of the previous decade and only 1,498 in the 1980s.

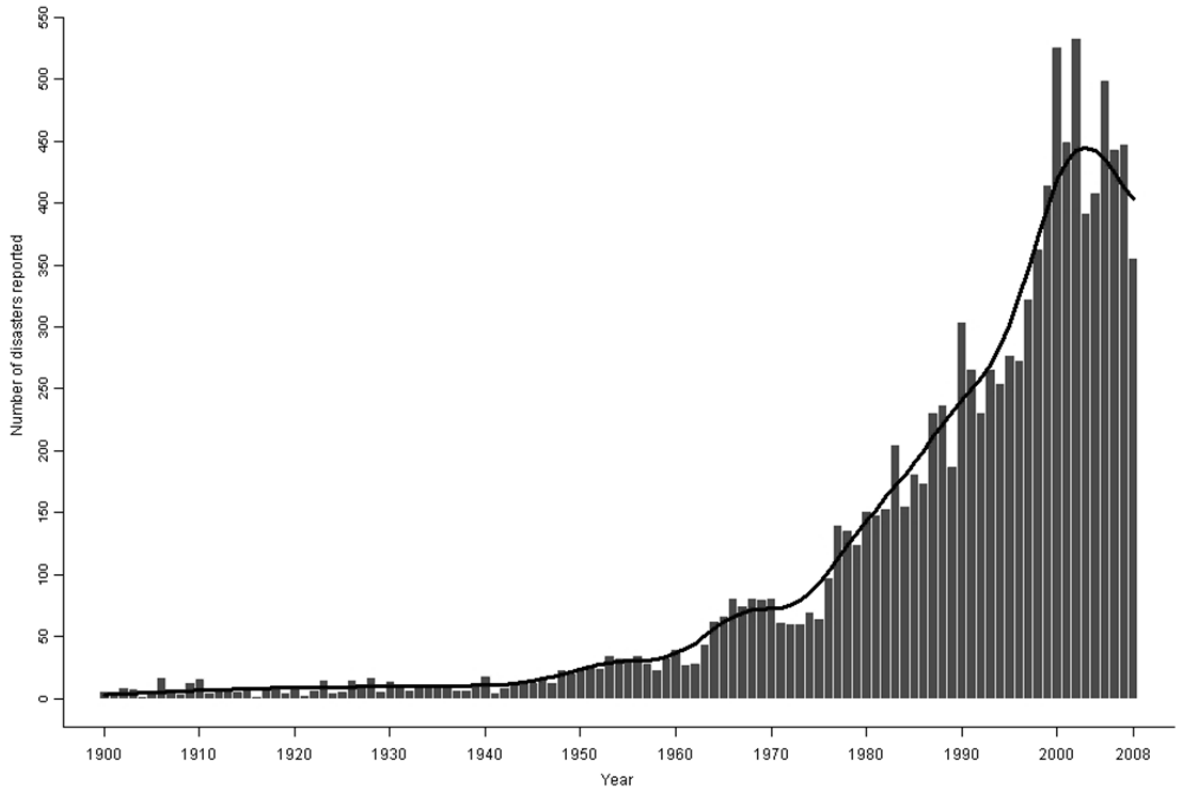

Figure 1. Natural disasters reported, 1900–2008 (RedR , 2010)

The increased number of natural disasters can be partly explained due to better recording (including the growing tendency to register smaller disasters), the increased number of people who are exposed to such events due to population growth and poverty. Some of the increase can be attributed to climate change.

Figure 2 – The number of damaging earthquakes in various countries during 2010 (Daniell, 2011)

There is a vast array of Non Government Organisations (NGOs) working in working all over the globe in response to disasters, whether man-made or natural. Often a large number of organisations respond to natural disasters providing funding, expertise and resources. Fund raising, volunteering and raising awareness has become common practice in many developed countries and NGOs now number in the hundreds of thousands. Unfortunately the systems currently in place to manage the funds and resources do not provide a combined relief work effort.

In comparison the construction industry has managed to develop systems, which allow for a number of organisations to work together on large-scale projects under vigorous standards and constant financial scrutiny from a client as well as the public.

Naturally the challenges that are faced for a project during relief work will be very different to those that are typically faced in the construction, but many similarities can be drawn with regards to working with a number of competitive organisations to achieve a goal with is mutually beneficial.

By identifying areas which NGOs are failing in and where the construction industry has made progress conclusions can be drawn to possible strategies than may resolve those issues and allow for an enhanced humanitarian response to a natural disaster.

Aim

The aim of this paper is to identify the developments that have taken place within the construction industry and research the possibility of applying best practice to organisations involved in relief work in an attempt to increase the combined output of those organisations. Key features from the New Engineering Contract (NEC), which have benefited the construction industry by implementing a cultural shift towards a combined effort, have been investigated for use by Non-Government Organisations (NGOs) and Government during relief work.

Objectives

In order to achieve the overall aim of the dissertation a number of suitable objectives were set. All of the project objectives are listed below and they are listed in chronological order.

- To compare and contrast the working practices of organisations within a construction project to those of organisations taking part in relief work.
- Develop a sound understanding of factors that affect project success rate within the construction industry.
- Research the practices of organisations during post disaster relief work.
- Identify successes and failures in chosen case studies.
- Cross examination of post disaster relief work and major construction projects
- An attempt at cross-industry benchmarking for areas such as project management, risk management and communication.
- Highlight key aspects within the construction industry that can be implemented by NGOs to help develop NGO-Government relations and improve output during relief work.
- Identify constraints and similarities in both fields
- Suggest possible improvements and how they should be implemented.
- Identify areas for further research.

Case Studies

Introduction

Recent history has recorded some of the most devastating earthquakes in recorded history. Scenarios studied were the 2005 Pakistani-administered Kashmir earthquake, 2010 Haiti earthquake, the 2011 Tohoku Earthquake (Japan) and the 2011 Christchurch earthquake (New Zealand).

Successes

Military-civilian cooperation

The combination of military, civil organisations provided quick and effective relief work. There was also collaboration between rival armies (Pakistani and Indian forces) as well as assistance from US forces. There was also collaboration between rival governments through opening of border checkpoints. The collaboration was extended to NGOs which greatly enhanced the relief effort. This paper suggests that the integration, coordination and transparency of intent displayed during the Kashmir earthquake creates a framework which future humanitarian relief work could be successfully executed.

International collaboration and use of technology

Central Asia Institute, a US NGO was the first organization to rebuild earthquake resistant schools in Azad Kashmir in November 2006. They were not only earthquake resistant but the first 3 schools reconstructed after the disaster. Although initial costs are high, by considering the possibility on natural disaster during the design and construction many lives can be saved. Unfortunately resources are often unavailable for such initiatives.

One of the impacts of international collaboration was the development of The International Charter on Space and Major Disasters, which was activated allowing satellite imagery of affected regions to be shared with rescue and aid organisations. The use of technology was extensive during the relief work, he OpenStreetMap community responded to the disaster by greatly improving the level of mapping available for the area using post-earthquake satellite photography provided by GeoEye, and tracking website Ushahidi coordinated messages from multiple sites to assist Haitians still trapped and to keep families of survivors informed. Google Earth updated its coverage of Port-au-Prince on 17 January, showing the earthquake-ravaged city.

Both COGIC (French Civil Protection) and the American USGS requested the activation of the International Charter on Space and Major Disasters on the behalf of MCDEM New Zealand, thus readily providing satellite imagery for aid and rescue services.

Google Person Finder was used to collect information regarding survivors and their locations and The Next of Kin Registry is assisting the Japanese government in locating next of kin for those missing or deceased.

Raising funds

Many countries responded to the appeals and launched fund-raising efforts, as well as sending search and rescue teams. The neighbouring Dominican Republic was the first country to give aid to Haiti, sending water, food and heavy lifting machinery.

Disaster management

In both countries systems were in place to react quickly to a natural disaster and reduce the loss of life. In Japan the earthquake early warning systems (consisting of over a thousand seismometers) sent out warnings of strong shaking a minute before the earthquake was felt in Tokyo and it was estimated to have saved many lives (Japan Meteorological Agency)

In New Zealand a full emergency management structure was in place within two hours of the initial earthquake. The country's relief work was coordinated from the National Crisis Management Centre bunker and regional emergency operations command were established across the country. New Zealand has established a Coordinated Incident Management System and a Civil Defence Emergency Management Act in preparation for a state of emergency.

An account from an experienced international USAR representative described the response as

"The best-organised emergency" he had witnessed.

The level of preparation and the speed of the response justify the comment made by the USAR representative. The establishment of a dedicated project manager is common practice within the construction industry but is often a common oversight during relief work. It is assumed that organisation will be able to carry out their duties with little interference. A dedicated project leader allows to key decisions to be made quickly and increases the likelihood of saving lives.

Failures

Control of Funds

A total of $6.2 billion was pledged and a large amount of the money was delivered in terms of services of international NGOs with high pay scales. The rest of the money pledged, which was given to the Government of Pakistan for reconstruction and development, was used to accommodate the retired military officials. The authority was highly criticized for luxurious non-developmental spending and its false statistics. Organizations from the UN, UK and US came under heavy criticism for focusing on costly training and seminars rather than direct relief work. Basic infrastructure which includes road networks, water supplies and waste management is still underdeveloped and has not reached pre-earthquake status in the region.

All of the quotes mentioned in the full paper paint a damming picture of the relief effort after the earthquake. For a country where the annual average income was US $450 and enough money was raised internationally to give each displaced family a cheque for $37,000, how are its citizens still in a state of emergency over a year after the earthquake? Where did the international community fail and what changes could have been made to avoid such a catastrophe?

Lack of Project Management

There are a number of areas in which this project has failed, from delivery of humanitarian aid, delivery of resources, logistics, stakeholder management, security and financial controls as well as delivery of work. In the author's opinion the lack of decision-making capabilities was the root cause of all the problems. By not forming a project team, which collaborated with all of the necessary stakeholders immediately, difference in opinions tore apart any hope of working relationships between NGOs, government and the UN.

Results

All of the data received from the questionnaires was quantified where possible and graphs/charts were produced to represent the data. The quantified data bears no significance as an individual figure but when compared to other figures trends can be identified and conclusions can be drawn.

	Project Management	Risk Management
1. [You are encouraged to develop your project/risk management capabilities]	3.46	2.91
2. [The management of projects/risk during relief work is essential]	3.58	3.41
3. [There are processes and procedures in place to assist/enforce project/risk management]	3.12	3.14
4. [Relief work projects are undertaken in a structured, well-organised/safe manner]	2.88	3.27
5. [An increased awareness of project/risk management has assisted in the delivery/safety of relief work projects]	3.00	3.32

Table 1 – Project Management versus Risk Management

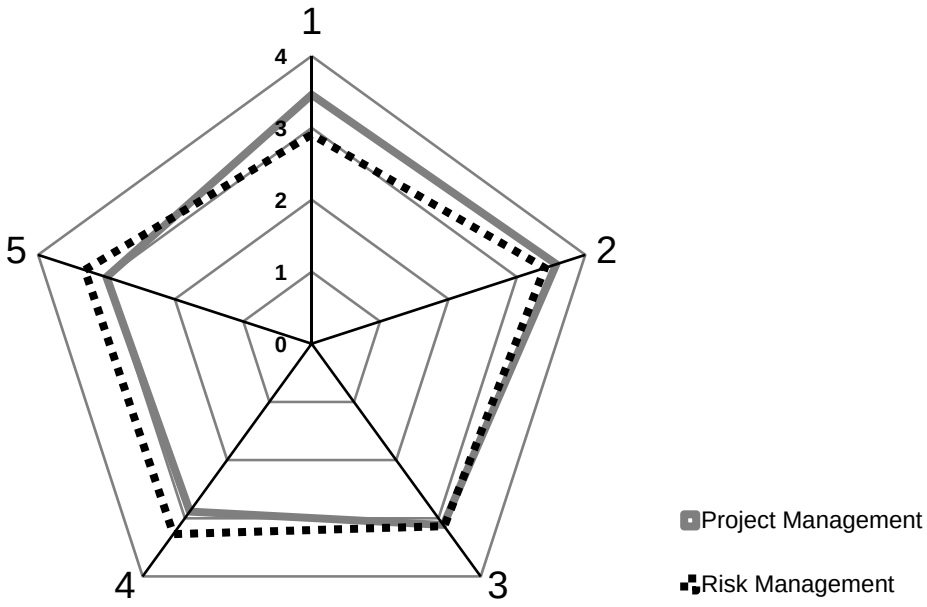

Figure 5 - Project Management versus Risk Management

Figure 3 indicates the perceived importance and output of project and risk management. Sections 1 and 2 indicate importance (personally and from the organisation). Sections 3 indicates how they are enforced and sections 4 and 5 determine the output of implementing project or risk management. The pentagon gives an indication of project strengths and weaknesses and areas that can be improved. The chart indicates that even though greater importance in given to project management the benefits from managing risks are greater.

	Project Management	Risk Management
N/A	0	0
Our priority is getting the work done by whatever means necessary	3	0
it is considered but not important	0	5
it is important but not but not always a priority	14	2
It the driving force behind delivery of any work	9	15

Table 2 – Perception of Project and Risk Management

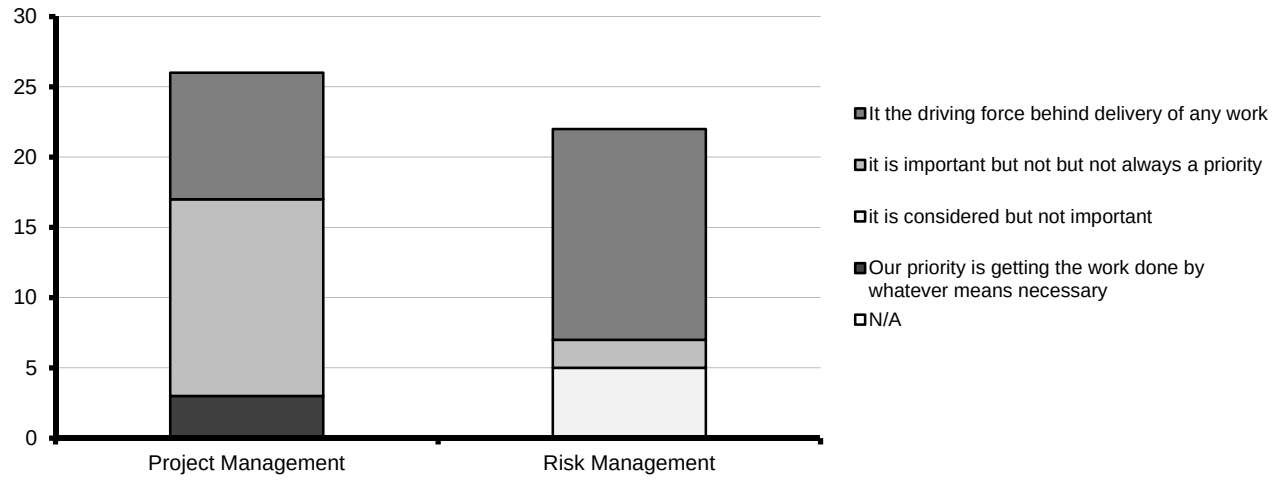

Figure 6 – Perception of Project and Risk Management

Figure 4 indicates the perceived importance of project management and the number of entries indicates the level on competency in each field. Although the average score for project management is lower, a majority of those who filled in the questionnaire understood its concepts. Approximately a third of the completed questionnaire indicated knowledge of risk management but a greater percentage thought it was crucial during relief projects.

	[Between NGO's?]	[Between NGO's and Government?]
Non-Existant	0	0
Poor	3	2
Average	5	15
Good	17	8
Excellent	3	3

Table 3 – Relationship Comparison

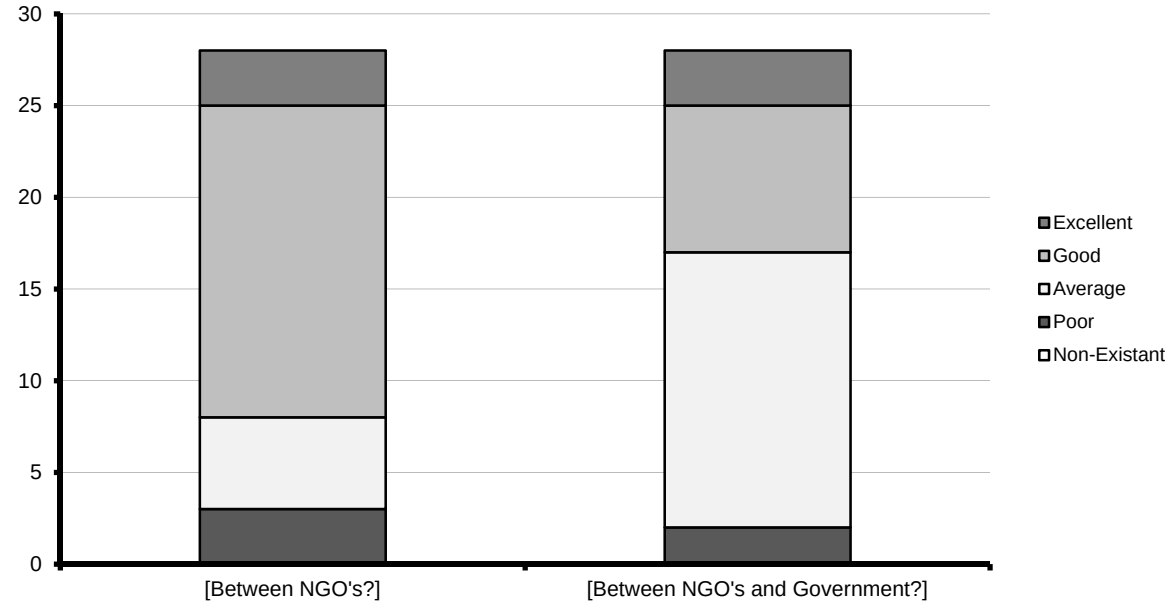

Figure 7 – Relationship Comparison

Figure 5 demonstrates the percived relationships between NGOs and between NGOs and government. Overall the relationship between NGOs is better than that of NGOs and government. The results demonstrate the unpredictale nature of organisational relationships during relief work. This is mainly due to a lack of set working practices. A higher percentage of people rated the relatioship as poor between NGOs which indicates that not only do NGO-government relationship requires improvements but so does the relationshipsd between NGOs.

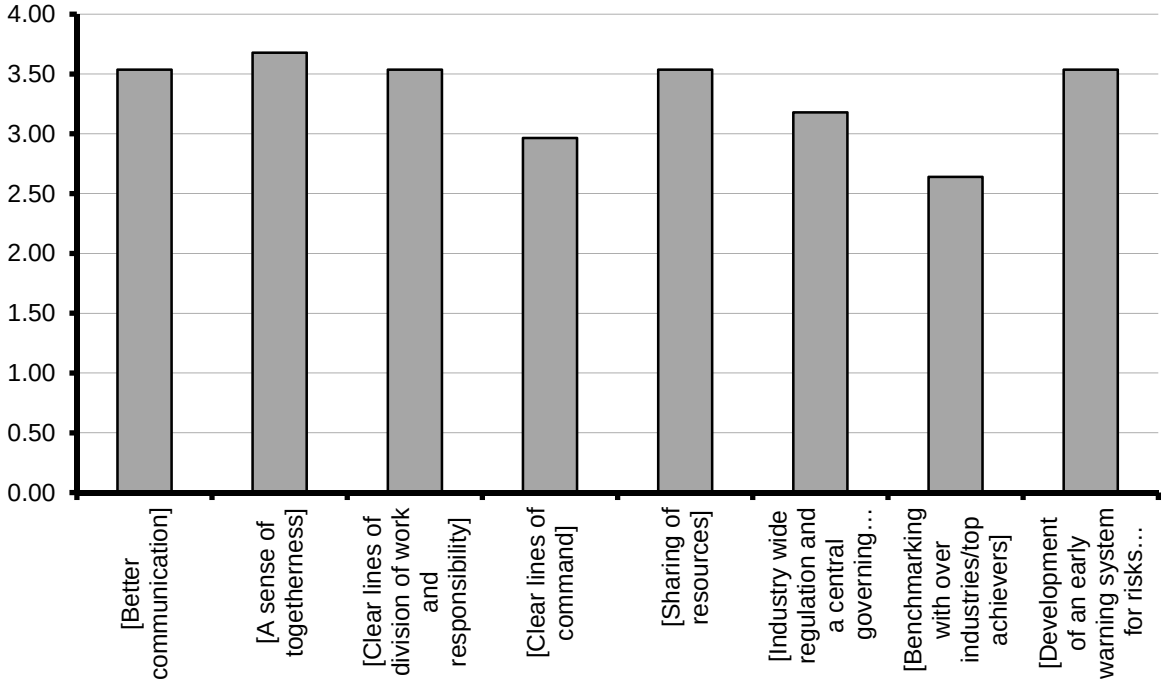

Figure 8 – Suggested Improvements

Figure 6 highlights the improvements that are required and helps identify areas to focus on. Establishing a sense of togetherness gained the highest score closely followed by better communication, clear lines of division of work and responsibility, sharing of resources and finally developing early warning systems.

Two key issues are raised here, inter-NGO and NGO-government communication and the benefits of better communication is highlighted through removal of duplication and being able to reach more people.

Suggested Improvements

Recommendations

Collaborative working involves a number of initiatives. Systems have to be in place to involve stakeholders during project inception through to completion and even during reflection. In the case of NGOs and government agencies involved in relief work a specialised committee must be formed within hours of the incident. In the case on the New Zealand earthquake local authorities formed a committee within hours of the earthquake. This case is a shining example of preparation, plans were in place in the event of a state of emergency and the plan was well executed. The multiple failures that emerged after the Haiti earthquake highlighted the necessity of making well informed and timely decisions and for each of the stakeholders to be involved in the decision making process. By forming a project team stakeholders can quickly form a strategy and decisions can be made quickly. To ensure the project team can be formed utilising competent staff and for it to be representative of all the stakeholders, NGOs should be asked to consider providing a shortlist of candidates suitable for the project team. This act in it's self may assist in a cultural change as NGOs will be required to consult each other in order to provide the shortlist.

The Kashmir earthquake highlighted the potential output of military-civilian cooperation. Opening borders and checkpoints remove many of the barriers NGOs face during relief work. Military-civilian co-operation allowed relief work to be carried out quickly and safely. In the aftermath of the Haiti earthquake the military worked against the NGOs with security issues addressed ahead of humanitarian aid and medical supplies. The delay in humanitarian aid angered NGOs as well as the local population who in the frustration started looting and riots.

To encourage collaboration, organisations should be encouraged to share services. Lines of communication can be quickly established between NGOs and local authorities to allow for a coordinated relief effort. Sharing resources also reduces costs as well as helping relief work progress through development of robust and efficient processes and plans with will help respond to natural disasters faster and more effectively.

Conclusions

There are many parallels between the construction industry and post disaster relief work. Where the construction industry has seen a great deal of technological and cultural advances which have increased the speed and quality of projects while reducing the cost and number of fatalities. Unfortunately NGOs can been reluctant to change and as a result have fallen behind any other industry when controlling costs and implementing current best practice.

Recently the requirement of robust business models and financial regulation has forced NGOs to implement tighter financial controls. Organisations such as REDR have attempted to bridge to gap between industry and NGOs by providing specialist training for project managers and volunteers taking part in relief work. The need to identify and manage risks has been highlighted as well increasing the safety of the staff and controlling costs through better management of the project.

The recommendations from this report are;

NGO's and government authorities should meet annually to discuss a global strategy on international relief work.

Organisations should put forward suitable candidates for formation of an international disaster response team dedicated to one disaster.

The international community should request disaster management plans from each country state identifying the following;

A suitable base of operations.

Organisational command structure for the nation.

An live risk log of potential threats, whether political, technological or natural.

Systems should be in place for the international community and NGOs to meet with 24 after a disaster for selection of a project team and initial assessment.

The above recommendations will help develop communication and allow for resources to be easily shared. Formation of project team consisting of government officials as well as NGOs will develop a sense of togetherness and a coordinated humanitarian response. Formation of a project immediately after a disaster allows for key decisions to be made quickly. This process should be developed and evolve every time there is a disaster. There is a possibility that attempting to form a project team will lead to disputes and inaction, but the risks associated with not setting up a project team are much greater.

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Background Papers

The Global Dimension to Engineering Education Project

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Engineers Against Poverty

Introduction

Engineering education is facing pressure to keep pace with global issues such as sustainability, climate change and inequality. Forward-thinking higher education institutions (HEIs) are adapting courses to equip graduates with the skills, knowledge and attitudes that are necessary to maximise the positive and far-reaching impact of engineering on society and the environment. But constraints exist that must be overcome if these improvements are to be scaled-up and sustained over time. The *Global Dimension for Engineering Education* project brings together for the first time leading organisations responsible for accreditation and professional development in engineering education to work with those involved in global education and poverty reduction to collaborate on activities with an explicit poverty reduction and sustainability focus.

The Project

A Global Dimension for Engineering Education came to life as an education initiative funded by the DFID Development Awareness Fund, and has been in operation since July 2009. The aim of the project is 'to strengthen the commitment and capacity of UK higher education engineering faculties and senior staff to embed global issues within the learning of engineering undergraduates'.

Through various activities, the project enhances knowledge and understanding of the challenges and prospects for development amongst academic staff and enables them, through embedding global issues in the curriculum, to impart this knowledge and understanding to engineering undergraduates. In this way, academics are equipped to help undergraduates understand that for engineering knowledge to be effective, it must be integrated into the social, economic and institutional aspects of development, and that they must join their knowledge with that of other specialists through interdisciplinary approaches.

The Partners

Engineers Against Poverty (EAP) is the grant holder with formal responsibility to deliver the project. However, EAP has implemented the project in association with the Development Education Research Centre (DERC) of the Institute of Education (IoE), Engineering Council UK (ECUK), Engineering Subject Centre (EngSC) and the Engineering Professor's Council (EPC). The project also works with several UK based HEIs, notably Coventry University and Brighton University as partners in curriculum development.

Activities

This project incorporates a range of activities that include:

- A series of professional development seminars where participants work with leading experts and be exposed to examples of good practice;
- The provision of practical support during curriculum review and development;
- Compiling and providing electronic access to case studies and other curriculum development materials;
- High quality publications that capture the key learning from the programme and communicate it in a variety of forms to key audiences;
- A national symposium – *GDEE 2012: Changing Course*

Lessons Learned

There has been a positive response from stakeholders and HEIs regarding the objective of the *Global Dimension for Engineering Education*, as well as recognition of the necessity for improved teaching to maximise the positive and far-reaching impact of engineering on tackling today's most pressing global challenges.

However, during the course of the project some important hurdles have been identified which must be addressed to allow for lasting and positive change in engineering education. In a review of current practice, it was generally reported that although there has been some introduction of the global dimension, much of the existing curriculum content focussed on sustainability, with less emphasis on economic, social, moral, and ethical issues. Importantly, there is often a lack of knowledge of global issues amongst teaching staff and a resistance to what is seen by some as a 'dilution' of core engineering content.[9]

Alignment of the project outcomes with the everyday work of departments and academics would enable the *Global Dimension for Engineering Education* to be used as a catalyst for addressing the global dimension more concretely. As the project life cycle comes to a close, it is of utmost importance that the present strong coalition of stakeholders is maintained and efforts are solidified in translating good intent into meaningful and measurable learning outcomes for future engineering undergraduate students.

[9] See EAP & IoE (2008) The Global Engineer, EAP & IoE, London available at http://www.engineersagainstpoverty.org/_db/_documents/WEBGlobalEngineer_Linked_Aug_08_Update.pdf

Changing Mindsets in International Development - or how did we get to where we are today?

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The concept of "international development" has evolved hugely since the end of the Second World War. In the last sixty or so years, the theories behind international development - and the ways that development programmes are structured and implemented - have been continuously challenged and redefined.

This article aims to outline[10] some of the major developments in international development during this period, ranging from the roots of modern day development and the Cold War, the first large-scale infrastructure projects, the move to appropriate technologies and "human development", participatory involvement and the Millennium Development Goals.

Although international trade and international relations have existed for many hundreds of years, many historians argue that today's idea of "development" emerged in the post-Second World War world - and first came from US President Truman's inaugural address in 1949, where he declared that the benefits of scientific advance and industrial progress must be made available for the "underdeveloped" areas.

1945 to 1950 had seen a period of post-war restructuring and modernisation, notably with the foundation of the United Nations (UN) in 1945 aimed to coordinate international efforts in "maintaining international peace and security, developing friendly relations among nations and promoting social progress, better living standards and human rights" (United Nations, 2012). During this period, the first real instance of large-scale development aid came in the form of the Marshall Plan (also known as the "European Recovery Program" - the large-scale programme whereby the United States gave monetary support to help rebuild European economies after the end of World War II), had been established in 1947 in order to assist rebuilding a war-torn Europe (and to help combat the spread of communism). By 1949, the efforts of the Marshall Plan seemed to be producing successful results, and Truman had felt that something similar could be applied in the rest of the world - with a particular emphasis on supporting those newly decolonised states that were not yet aligned with the Western Allies or the communist East, and with an underlying purpose to consolidate the US influence around the globe[11].

The 1950s marked the beginning of the "golden age" for international development - where the growth for most countries was robust and fairly steady. The 1960s brought in the UN's Decade of International Development, and was the first time where mass media enabled large numbers of people in the West - particularly the radical young - to become first aware of the existence of mass hunger and suffering in large parts of the world. The UN Development Decade had set an unprecedented target for all industrialised countries to donate 1% of their Gross National Product (GNP) to "Official Development Assistance" - or "aid" to be lent to countries needing support to "develop", and many people believed that it would be possible to lift almost all countries and peoples out of poverty.

Sadly, the vision was looking less optimistic by the end of the 1960s. The concept that large amounts of aid would almost automatically lead to improve development - based somewhat on the success of the 1947 Marshall Plan - had not held fast. Whilst the European countries had generally been using aid from the Marshall plan to *rebuild* their countries - and already had political, financial, and administrative systems setup to manage the process - many of the "underdeveloped countries" would be building their infrastructure and systems for the first time.

In one respect the "Development Decade" had been a success - most developing countries had managed to raise their GNP per capita by at least 5% (Black, 2010), but this new wealth had made little impact on the majority. In 1969, the Pearson Committee - a commission setup to conduct a review into the impact of development assistance - noted that "the climate surrounding foreign aid programs was heavy with disillusionment and distrust" (Pearson, 1969).

During this period, the structure of the early development projects - often focusing on physical infrastructure with little thought for sustainability and wider issues - meant that many ventures failed spectacularly. One of the most notorious was an attempt to mechanise agriculture in Tanzania, Uganda, and Zambia - resulting in rapid breakdowns, no spare parts, misuse for private purposes, a failure to recover cultivation costs and endless other problems (Black, 2010). Another example was a development programme in Lesotho aimed to help local people with crop and livestock management, as well as building roads so they could access markets. However, few of the people in the region were farmers, and conditions were not good for farming. Harsh weather destroyed pilot crop projects, and the roads allowed in competitors who drove the existing local farmers out of business (Ferguson, 1994).

In addition, many of the large-scale infrastructure "development" projects were optimistic in their cost-benefit projections, and whilst they were often completed "successfully", the loans used to pay for such project also contributed to the overall debt that the country gathered. As a consequence, any extra national resources were spent on paying back

[10] with an apologetically top-level and Western viewpoint
[11] the term "third world" first came into use during this period of the Cold War - initially as an ideological concept denoting a search for an approach different to that of the capitalist ("first world") or communist ("second world") approaches.

creditors instead of on the health, education, water and sanitation infrastructure and livelihood support that the poorest people need (Black, 2010).

By the 1970s, the maturing development industry had led to the growth of innumerable governmental and intergovernmental institutions, university programmes, specialist researchers, practitioners, and charities, resulting in many debates about the nature of development and the question of what is was truly trying to solve. Whilst the growth of neoliberal and state-centred ideas led to the implementation of structural adjustment programmes into the early 1980s, alternative concepts began to emerge. These included the appropriate technology movement, pioneered by E.F. Schumacher in his book "Small is Beautiful", which encourages the use of "people-centred" technology that is small-scale, labour-intensive, energy-efficient, environmentally sound, and locally controlled (Hazeltine, 1999). The concept of microfinance - providing access to financial services and small loans to directly empower poor people to setup businesses, increase their incomes, and leave poverty behind them - gained its first footholds in the 1970s, and has since become widespread (Rutherford, 1999).

The vision of a whole world development dramatically receded in the 1980s. Recession in the industrialised world impacted on the newly developing countries, such as Mexico, who were dependent on their richer trading partners. In 1982, Mexico suspended their interest payments on an accumulating debt, marking the start of an emerging crisis of developing country indebtedness (Black, 2010). in 1980, the total debt of the developing world stood at $660 billion, by 1990 they had more than doubled to $1,540 billion (UNICEF, 1995) - and during this period, the transfer of resources from rich world to poor went into reverse, with debt repayments from developing countries overtaking the inflow of aid and investment. Over 60 developing countries experienced declining per capita income over the decade, with the worst impacts felt in Africa and Latin America. By its end, the 1980 became known as a "lost decade" for most of the developing world, a decade of development reversal rather than growth (Meadows, 1991).

The 1990s saw a popular movement returning and a growth of decentralisation, with a new emphasis on "human development" - a definition formally combining the criteria of both social and economic advances, rather than solely economic measurements.

The Human Development Index (HDI), devised in 1990, epitomised this trend. The HDI, had the explicit purpose "to shift the focus of development economics from national income accounting to people centred policies"(ul Haq, 1995), and were based on the underlying conceptual frameworks developed by the economist Amartya Sen. The basic HDI measures the health of a population; its educational attainment; and its material standard of living (measured by GDP per capita). It can be argued that even these measures of poverty and development are still overly simplistic and only measure a subset of development indicators, as for example, the HDI does not account for human rights or political freedom.

The concept of sustainable development also become more significant (since the seminal publication of Rachel Carson's "Silent Spring" in 1962, the environmental movement, and the concept of a finite set of resources, had been gradually gaining pace), and Robert Chambers' participatory approaches and policies aimed at putting the "poor, destitute and marginalised at the centre of the processes of development policy" demonstrated how the development projects needed to reassess how it would focus on those most in need of its assistance.

Approaching the millennium, the global development focus moved towards consensus building, particularly with the conception of the Millennium Development Goals (MDGs), aiming to encourage development by improving social and economic conditions in the world's poorest countries. So far, progress on the MDGs has been variable, with often those already nearest the goalpost able to climb over, whilst the hardest to reach are not always benefitting. Duncan Green argued academic literature used to stress the positive potential for inequality to reward "wealth creators" and so encourage innovation and economic growth, but that by 2005, the manifest failure of that approach prompted a number high-profile publications from the World Bank, with the UN arguing that tacking inequality is one of the most urgent tasks of our time (Green, 2008).

Regardless, the early 2000s has seen a number of large scale development aid initiatives that are attempting to consider sustainability, appropriateness, participation, and a rights-based approach. One large-scale programme introduced in Afghanistan in 2003 was a massive effort by the government to reach rural communities across Afghanistan and address their needs using participatory involvement. Through the scheme, programme representatives work with elected village-level councils who reach consensus on development priorities, develop investment proposals and use grants and local labour to meet local needs, and to date, about 17 million rural people in Afghanistan have benefitted from improved water and roads.

New market solutions are also moving into the development sphere. A number of economists argue that low income markets present a prodigious opportunity for the world's wealthiest corporations to "bring prosperity to the aspiring poor" whilst generating a worthwhile profit, and that businesses should see the poor as "resilient and creative entrepreneurs as well as value-demanding consumers" (Hart, 2002). Social entrepreneurship business models, or 'for-more-than-profit' enterprises, use blended value business models that combine a revenue-generating business with a social-value-generating structure or component (Acumen Fund, 2010).

A number of thinkers of the post-development school regard development as having failed and as that the era of development is - or should be - over. William Easterly, author of "The White Man's Burden" argues that the "majority of places in which we've meddled the most are in fact no better off or are even worse off than they were before" (Easterly, 2006), whilst other voices from the 'post-development' school claim that, at best, development has failed, or "at worst it was always a hoax, designed to cover up violent damage being done to the so-called developing world and its peoples" (Allen, 2000).

However, whilst there have been setbacks and failed (and indeed harmful) projects, most scholars would agree that the world as a whole is a safer place, with less poverty and more opportunities for more people - than it was in 1945. Some development approaches so far have been successful, and some have not, with the only certainty that there is no one-size-fits-all for international development. Nonetheless, a great deal of learning and the evolution of ideas have taken place over the last 60 years, and whilst it is impossible to predict the future of international development, its concepts will continue to evolve and, ideally, to enable more people to help themselves to have a greater quality of life for them and their children.

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Notes