Journal of Mechanical Design

Guest Editorial

Why the Developing World Needs Mechanical Design

The dramatic and often unjust difference between life in the developed versus developing parts of the world is striking. For example, roughly 3 billion people still burn biomass to cook their meals; more people in the world have a mobile phone than have a toilet; Dallas Cowboy Stadium (AT&T stadium) requires three times the electrical power than the entire country of Liberia can produce; and a 73 s shower (using an EPA approved low-flow shower head) uses *all* of the daily clean water available per person in Rwanda. These conditions and others have given rise to an interesting area of design and research that spans multiple engineering disciplines and is called Engineering for Global Development (EGD). Work in this area is also often referred to as design for the developing world, design for development, and humanitarian engineering.

There are tremendous research opportunities for the *Journal of Mechanical Design* (JMD) community within the EGD space. Simply consider the billions of people facing life-or-death situations around the technical challenges of health, water, and energy, and the fact that these problems have persisted for generations with no viable solutions; what more compelling foundation for high-impact design and research could you ask for? Solutions to these problems have existed in developed countries for decades, but due to the extreme economic, social, political, technical, environmental, and geographical differences in poor countries, they have not been successfully adapted into the developing world. Take, for example, providing reliable sanitation to a village. Although the pumps and pipes required to make a reliable sewage system were developed years ago, this technology has yet to make it to the developing world for reasons including cost, or that it cannot be repaired, or that there may be no power system available to run it, or that it is incompatible with the culture or governmental policy. Unfortunately, the constraints and requirements imposed by the market are fundamentally different than those for which the technology was originally designed.

Governments, industry, and academia have failed in solving innumerable development challenges because we as a community have not ascertained the specific socioeconomic and technical differences between rich and poor markets. This lack of knowledge has planted seeds for failure, such as solving the wrong problem, believing that the problem is simple and that a solution is intuitively obvious, incorrectly assuming that there is no money to be made from poor people, or that a western solution may be easily adapted or naturally trickle down to the developing world. We need to reframe our mindset. To satisfy the performance and price requirements imposed by the developing world, we need technological revolutions rather than incremental change—on the scale of leaping from vacuum tubes to transistors. The academic community has the brainpower to create these breakthroughs, even if many of us do not have a background in "development." Louis Pasteur would not have thought of himself as an engineer for global development, but pasteurization prevents millions of children throughout the developing world from drinking spoiled milk. Engineers possess many of the qualities required to solve the greatest challenges in global development. In fact, we believe that nearly all the mechanical engineering subdisciplines can be reimagined to successfully serve resource poor individuals in all parts of the world.

Consider the following, to name just a few:

Design theory and methodology (*DTM*)*:* A concept fundamental to this subdiscipline is that of gathering and interpreting customer and stakeholder needs. There is nothing simple about this in a developing world setting. Differences in culture, language, expectations, upbringing, and gender roles are extreme. These and other factors such as a community's previous experience (positive or negative) with engineering and nongovernmental organizations cause conditions that are new and unexplored in research and practice. The DTM community is ideally suited to help remove one of the greatest barriers to lasting impact: misunderstanding developing world contexts. Empathic inquiry, ethnographic research, and human-centered design experiments are all areas worthy of advancement for use in a developing world setting. Joint and collaborative design, with designers/engineers from developing countries, is also a potential enabling framework that merits further research into effective product development with extremely diverse team members.

Machine design: Mechanization—the kind that causes industrial revolutions—has fueled the great disparity between the rich and poor parts of the world. If revisited and tailored to the unique conditions of the developing world, mechanization also has the potential to erase that disparity. An essential part of considering machine design in this way, however, is to understand that the constraints of the developing world often lead to radically different solutions than those found in resource-rich parts of the world. Articulating the unique physics-based parametric relationships of new technologies will generate new machine design theory. We have seen this in our own design work on low-power, off-grid drip irrigation systems and passive, high-performance and low-cost prosthetic limbs. If ever there was an impetus to push the boundaries of our machine design capabilities, this is it—designing for the extreme, unfamiliar, often life-threatening conditions faced by so many in the world today.

Design optimization: Every additional bit of performance is highly valued in the developing world, be it better functionality or lower cost. JMD's optimization community is one of the most vibrant, and with a strong connection to mechanical design, it is poised to maximize a new product's impact to humanity. This is no small challenge, since these are different problems with different constraints than the optimization community has grown up around. For example, how does one model "impact to humanity"? While the community may not know the answer to this now, it is indeed a core tenet of mechanical engineering as a discipline. It is possible that the evolutionary path that optimization techniques have taken has been shaped by the kinds of first-world problems they are designed to solve. Consequently, new paths may be needed to solve developing world challenges or at least be researched and explored. The design optimization community is better suited than any other to carry out that research and realize the benefits.

Uncertainty quantification: There is an unprecedented amount of uncertainty when modeling and working in a developing world setting. These uncertainties range from common manufacturing capabilities, to the relatively unexplored impact of financial and political stability, physical security, cultural acceptance, and methods for measuring long-term societal benefit. These uncertainties are akin to those encountered in many engineered products in the modern world but they involve a large, complex, and often-irrational system that has not been encountered in the developed parts of the world alone. At the center of these uncertainties is an extreme cross-cultural human element, which is most often made more complicated by disparate livelihoods and diverse value systems. New research in quantifying and mitigating these uncertainties represents the significant opportunities that exist in this space for the JMD researchers.

Many other areas familiar to the JMD audience could easily be described in the same light: Systems design, decision-making theory and modeling, design of experiments, product family design, combustion and thermal sciences, and more.

For those who engage in EGD, it is important to recognize that there are at least four different types of opportunities/activities and corresponding impact levels as described below. We know of multiple people working in each of these areas and value the contributions offered therein.

(1) *Product development opportunities:* These are opportunities to design and distribute products, such as the mobile phone, rough terrain wheelchairs, human-powered well-drilling machines, and in-home reverse osmosis water purification systems. Successful products in this space are both profitable *and* humanitarian in nature and are largely the result of a professional product dissemination effort. Such products can result from academic research when good partnerships with industry are in place. When done at an industrial scale, these opportunities have the potential to lead to large impact for those living in poverty.
(2) *Service projects:* Various professional groups, such as Engineers Without Borders (EWB), organize service projects for practicing engineers seeking to use their expertise to help those in poverty. Because of the service nature of the work, the impact is personal, but generally not scalable in the same way the distribution of a mass-produced product is. The impact is significant for the engineer engaging in the work, and if done well it can also be significant for the person living in poverty. The latter often manifests itself in the development of relationships, the sharing of knowledge, and in the development of an engineered product that alleviates poverty for that individual.
(3) *Service learning opportunities:* These take place as part of an academic course and involve a short service project. These opportunities have a significant impact on the students involved as it exposes them to impoverished conditions and challenges them to use their engineering to make a difference. Because of factors such as little design experience, minimal international experience, and the challenges of academia (the influence of letter grades and the certainty of end-of-semester deadlines), the largest impact is most often felt by the student themselves—not the communities with which they engage. In some cases, the impact to the community can be significant, though it is not realistic to assume this will be the case for most service learning opportunities. The larger impact is in training future engineers who will eventually do product development at an industrial scale, serve with professional organizations such as EWB, or carry out research in this area.
(4) *Research opportunities:* As discussed above, there are many opportunities for research in this space—simply because there are many unknowns and uncharacterized phenomena. There are seemingly countless opportunities for the JMD community to look at development challenges with a scientific and innovative eye. This will inevitably lead to new understandings in systems design, uncertainty analysis, design thinking, optimization, machine design and reliability, and more. As with most fundamental research, the impact is expected well after the research has taken place. The research appearing in the archival literature has the potential to influence product development, service projects, and service learning opportunities, if individuals managing those opportunities seek to understand the current state of the literature.

For those engaged in research related to EGD, some principles should guide the publication process:

(i) For research papers, the research contribution should be clear. As a test, the authors should be able to remove the paper's reference to "the developing world" and still see a worthy research contribution.
(ii) For design innovation papers—which are defined in JMD as archiving outstanding work in mechanical design that is concept-oriented and does not necessarily require detailed theoretical or experimental development and analysis—the authors should be clear about what the design artifact is, how and where it was tested, and how well it does what it is required to do.
(iii) The authors should be transparent in the research reporting. It should be very clear what research questions were pursued, what experiments were designed and where they were carried out, and how impact was measured, if at all.
(iv) The authors should recognize that failed projects have archival value and that an open and honest discussion of failure helps others avoid the same traps.
(v) As long as transparency is present, the authors should not feel expected to have finished, tested, and adopted products in order to publish their work, as it has never been expected for any preceding discipline, such as aerostructures.

Within the ASME community, there is a swelling of interest in EGD, which is a definitive part of ASME's strategic initiatives. ASME now has an EGD executive committee and is a founding partner in Engineering for Change,[a] which provides examples, teaching materials, and short courses related to development technology. ASME's EGD committee has sponsored forums at the 2013, 2014, 2015, and 2016 ASME International Design Engineering Technical Conference (IDETC) as well as forums at ASME's International Mechanical Engineering Conference and Expo (IMECE). The IDETC has now had 6 years of special sessions on the topic. Last year's Design Automation Conference (DAC) Keynote was focused on this topic with speakers from Africa (Professor Mugendi M'Rithaa), Pakistan (Dr. Mohammad Bilal Khan), and with lightning talks from industry (Dr. Stephen Harston), new faculty (Dr. Jesse Austin-Breneman), and researchers (Dr. Briana Lucero). Importantly, the JMD has now published multiple papers in the area of EGD.

We invite the JMD community to consider how their engineering knowledge and skills can be used, reimagined, or blended with someone else's to help more people in the world benefit from engineering. For those who carry the responsibility of funding, reviewing, and editing the archival literature, we invite you to consider the need for research in this area, its relative infancy, and the global value it can bring when it is done well.

The disparity between life in the developed versus developing parts of the world, though striking, *can be* bettered by the JMD community. The last industrial revolution was catalyzed by the contributions of engineers like James Watt and Thomas Edison; we will need to make similar contributions—which we can do—as we apply our research, engineering, and design skills to the technical challenges of global development.

[a]www.engineeringforchange.org

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