How should we measure sustainability in Humanitarian Engineering?

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“Humanitarian Engineering’ refers to the use of science to invent, create, design, develop, or improve technologies which promote the well-being of fast growing, poor, marginalised, disaster hit or under-served communities.” Dr. Georgia Kremmyda.

So, how do we, engineers, fit in? And, if we do fit in how do we fit in, in a sustainable way?
<table>
<thead>
<tr>
<th></th>
<th>Scientist</th>
<th>Engineer</th>
<th>Artist</th>
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<tbody>
<tr>
<td>Answers the question</td>
<td>Why?</td>
<td>How?</td>
<td>Who?</td>
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<tr>
<td>Purpose</td>
<td>Explains the existing</td>
<td>Invents the non-existent</td>
<td>Stimulates the emotions</td>
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<tr>
<td>Models</td>
<td>Rational, complex, statistical</td>
<td>Rational, simple, mathematical</td>
<td>Irrational, psychological, aesthetic</td>
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<tr>
<td>Scale</td>
<td>Large, general, wide-reaching</td>
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<td>Discovery-based (Hypotheses)</td>
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Outline

1. The framework - Sustainable Development
2. The engineering mindset
   • My personal journey - Finding a voice
   • Lessons learned in Mexico and Kenya
3. The methods and the tools
   • Life Cycle Cost Assessment (LCCA)
   • Life Cycle Assessment (LCA)
   • Social LCA
   • Industrial Ecology (Cradle-to-Cradle/Circular Economy /Eco-Technology)
   • Design for Sustainability
4. Putting it all together
Sustainable Development

Our Common Future (1987), Brundtland Report, UN.

I. The Concept of Sustainable Development

1. Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

   • the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and

   • the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs.
Sustainability Today – Brown Agenda

UN Sustainable Development Goals (2015)

• No Poverty
• Zero Hunger
• Good Health and Well-being
• Quality Education
• Gender Equality
• Clean Water and Sanitation
• Affordable and Clean Energy
• Decent Work and Economic Growth
• Industry, Innovation and Infrastructure - Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
• Reduced Inequalities
• Sustainable Cities and Communities - Make cities and human settlements inclusive, safe, resilient and sustainable
• Responsible Consumption and Production
• Climate Action
• Life Below Water
• Life on Land
• Peace, Justice and Strong Institutions
• Partnerships for the Goals
The Fifth Assessment Report (AR5) is the most comprehensive assessment of scientific knowledge on climate change since 2007 when the Fourth Assessment Report (AR4) was released.
My Personal Journey

Why is this relevant?

• Because I have had an engineering mindset for most of my career.
• Because I believe that engineers have an inferiority complex when dealing with global and humanitarian issues.
• Because it shows a path to enlightenment for an engineer.
A 20 year Chronology

1985-1998 – NSF-funded engineering research on FRP composites leads to research in crashworthiness and explicit finite-element methods (DYNA, ABAQUS)

1998 – NSF Building Vulnerability Science and Technology Center Proposal with social scientist led thrusts - $50M

2001 – 9/11 attacks

2004 – DHS CREATE (Center for Risk and Economic Analysis of Terrorist Events) research on terrorism using system dynamics modeling tools (Stella, AnyLogic)

2004 – AEC Global Project based course at Stanford University LEED (Leadership in Energy and Environmental Design)

2007 – BIM (Building Information Modeling) course offered - REVIT + Green Building Studio (paper on pedagogy at ASEE)
2007 – EPA P3 (People, Prosperity and the Planet) Student led Design Competition
2009 – NSF Program Director for $25M EFRI-SEED (Science in Energy and Environmental Design) Initiative
2009 – Rockefeller Foundation, EWB (Engineers without Borders), E4C (Engineering for Change), Extreme Affordability, CEB, LCA workshops funded
2012 – NSF Sustainable Cities Research Coordination Network
2012 – NSF PIRE (Partnerships in International Research and Education) proposal – $5M led by social scientist
2014 - NSF EAGER research on sustainable indigenous materials in Mexico and Kenya led by social scientist
2014 – Is Structural Engineering Sustainable? First tiny article on Sustainability!
2016 - RAE Dist. University Prof. tour of UK institutions
2017 – Humanitarian Engineering Engineering Symposium
… and the People (that’s what really counts)

- Prof. Jeffrey Russell, Vice Provost for Continuing Education, UW-Madison
- Prof. Vicki Bier, Chair, Industrial and Systems Engineering, UW-Madison
- Dr. Benjamin Thompson, former graduate student, UW-Madison
- Dr. Renate Fruchter, Director, AEC Program, Stanford University
- Dr. Sohi Rastegar, Senior Advisor, Engineering Directorate, NSF
- Dr. Bruce Hamilton, Environmental Sustainability Program Director, NSF
- Dr. Diana Bauer, EPA then US Department of Energy
- Prof. Nimmi Gowrinathan, International Studies, CCNY
- Prof. Matt Jelacic, Architectural Design, UC Boulder, USAID
- Ms. Noha El-Ghobashy, Founder, Engineering-for-Change
- Prof. Mahesh Daas, Dean, Architecture, University of Kansas
- Prof. Esther Obonyo, Interim Director, Humanitarian Engineering and Social Entrepreneurship (HESE), Penn State University
- Prof. Anu Ramaswami, Humphrey School of Public Affairs, U of Minnesota
- Prof. Jim Biles, Executive Officer, Earth and Environmental Sciences, CUNY
- Prof. Fabio Matta, Civil Engineering, U. South Carolina
- Dr. Georgia Kremmyda, Warwick University
- and the many, many undergraduate and graduate students I have worked with.
Lessons from research in Mexico and Kenya

“Overcoming Barriers to Adoption of Sustainable Building Materials to Mitigate the Effects of Climate Change and Natural Disasters in Coastal Areas of Southern Mexico.” NSF, Bank, Biles, Obonyo (2013-17)

“Catalyzing Transformative Scale-Ups for Impact in Extremely Affordable, Sustainable and Resilient Housing through Social Enterprise.” NSF, Obonyo, Bank (2014-17)
Survey 628 households in seven coastal communities in Yucatán, Mexico
Celestún (n=161), Chelem (n=98), Chuburná (n=44), Chicxulub (n=139), Telchac (n=41), Río Lagartos (n=98), San Felipe (n=47)
IVEY 2 BR house demonstration on pilings in St. Clara
New area of Fraccionamiento Flamboyanes, about 10 km from Progreso
Engineering a possibility
Lessons Learned

• Public and private organizations are grasping at straws and are over-whelmed, under-informed, and prey to commercial forces.

• People are exceptionally resilient – but their resilience is often not well-informed. We do not often “Build Back Better.”
The Methods and the Tools
Life Cycle Cost Analysis (LCCA)

“Life-cycle cost analysis is a process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future costs, such as maintenance, user, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment.”

Source: Transportation Equity Act for the 21st Century


Life Cycle Assessment (LCA)

“Life Cycle Assessment (LCA) is a tool for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle.” UNEP - UN Environment Program 1996 - Present
Environmental management — Life cycle assessment — Principles and framework

**Key Concepts of Life Cycle Assessment (LCA)**

- Boundaries
- Functional Unit
- Life Cycle Inventory (LCI)
- Life Cycle Analysis (Midpoints)
- Life Cycle Impact Assessment (LCIA) (Endpoints)
Social Life Cycle Assessment (S-LCA)

Child labour;
Forced labour;
Excessive working time;
Wage assessment;
Poverty;
Migrant labour;
Freedom of Association,
Right to Strike, and Collective
Bargaining Rights;
Health and Safety;
Human Rights;
Governance;
Community Infrastructure

Industrial Ecology (Cradle-to-Cradle/Circular Economy /Eco-Technology)

Industrial ecology systematically examines local, regional and global materials and energy uses and flows in products, processes, industrial sectors and economies. It focuses on the potential role of industry in reducing environmental burdens throughout the product life cycle.

- material and energy flows studies ('industrial metabolism')
- life cycle planning, design and assessment
- design for the environment
- extended producer responsibility ('product stewardship')
- eco-industrial parks ('industrial symbiosis')
- product-oriented environmental policy
- eco-efficiency

1997 - Present
Putting it all together

• Be engaged – write a joint-proposal for funding a Humanitarian Engineering research project. Volunteer to teach a course, lead a group.
• Be open – look for non-traditional research collaborators.
• Be thoughtful – listen and learn from others.
• Be flexible – pivot when needed. Don’t dig in.
• Be educated – read the “great books” of sustainability and international development.
• Be mindful – it’s about people, after all.
Extra Slides
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<th>Science plus</th>
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US Bridges 2015

- All Bridges: 611,845
- Deficient Bridges (23%): 142,915
- Structurally Deficient (41%): 58,791
- Functionally Obsolete (59%): 84,124
Early-Period Sustainability

Aldo Leopold – *A Sand County Almanac* (1949) – “A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise.”

Rachel Carson – *Silent Spring* (1962) - “Only within the moment of time represented by the present century has one species -- man -- acquired significant power to alter the nature of his world.”

Early-Period Sustainability

Garrett Hardin - The Tragedy of the Commons (1968) – “The population problem has no technical solution: it requires a fundamental extension in morality.”

Donella Meadows et al – Limits to Growth (1972) - The book used the World3 model to simulate the consequence of interactions between the Earth's and human systems.

Late-Period Sustainability


Cradle to Cradle: Remaking the Way We Make Things (2002) - Michael Braungart and William McDonough


The End of Poverty (2005) - Jeffrey Sachs

Green to Gold - How Smart Companies Use **Environmental Strategy** to Innovate, Create Value, and Build Competitive Advantage (2006) - Daniel C. Esty and Andrew S. Winston

An Inconvenient Truth (2006) - Al Gore
The Liberal Arts

- the Trivium
  - grammar
  - logic
  - rhetoric
- the Quadrivium
  - arithmetic
  - geometry
  - music
  - astronomy

- The liberal arts are those subjects or skills that in classical antiquity (8th BC-5th AD) were considered essential for a free person (a citizen) to know in order to take an active part in civic life.
- Together the Trivium and Quadrivium (5th AD) constituted the seven liberal arts of the medieval university curriculum.
A circular economy is one that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles.

2. Optimise resource yields by circulating products, components and materials in use at the highest utility at all times in both technical and biological cycles. ResOLVE levers: regenerate, share, optimise, loop.

3. Foster system effectiveness by revealing and designing out negative externalities. All ResOLVE levers.
Techno-Ecological Synergy: A Framework for Sustainable Engineering
Estimated Number of Awards: 5 regular and 5 early-career awards
Anticipated Funding Amount: Approximately $7 million total for all awards
Potential Funding per Award: Up to a total of $800,000 for regular awards and $600,000 for early career awards, including direct and indirect costs, with a maximum duration of four years.
ALTERPAVE - USE OF END-OF-LIFE MATERIALS, WASTE AND ALTERNATIVE BINDERS AS USEFUL RAW MATERIALS FOR PAVEMENTS CONSTRUCTION AND REHABILITATION (www.alterpave.eu)

The overall aim of the ALTERPAVE project is the demonstration of an innovative and integrated approach for the sustainable construction of roads considering the whole life cycle of the infrastructure by:

1. Enhancing the resource and cost efficient use of alternative materials,
2. Ensuring the recyclability of the roads developed with the alternative green materials (Design for Reuse) and
3. Implementing a “circular economy approach” by taking advantage of the actual by-products and waste produced by the regional industries.
Design for Sustainability

Four innovation levels:

- Product
- Product-Service System
- Spatio-Social
- Socio-Technical System

Durability and Service Life

Table 1
STV targets and rationale.

<table>
<thead>
<tr>
<th>Environmental indicator</th>
<th>Life cycle target</th>
<th>Base data (US DOE, 2009)</th>
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<tbody>
<tr>
<td>Global Warming Potential</td>
<td>$2.29 \times 10^3 \text{ kg CO}_2\text{e/m}^2$</td>
<td>$1.33 \times 10^2 \text{ kg CO}_2\text{e/m}^2\text{-yr}$</td>
</tr>
<tr>
<td>Primary Energy</td>
<td>$5.42 \times 10^4 \text{ MJ/m}^2$</td>
<td>$2.35 \times 10^3 \text{ MJ/m}^2\text{-yr}$</td>
</tr>
<tr>
<td>Potable Water</td>
<td>$9.88 \times 10^4 \text{ L/m}^2$</td>
<td>$2.63 \times 10^3 \text{ L/m}^2\text{-yr}$</td>
</tr>
<tr>
<td>Ozone Depletion Potential</td>
<td>$0.00 \text{ kgCFC11e}$</td>
<td>NA</td>
</tr>
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<tr>
<th>Percent reduction from base</th>
<th>Reduction basis and source</th>
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<tbody>
<tr>
<td>70% below 1990 levels by 2050</td>
<td>IPCC AR4 (IPCC, 2007)</td>
</tr>
<tr>
<td>60% below 1990 levels by 2050</td>
<td>IPCC AR4 (IPCC, 2007)</td>
</tr>
<tr>
<td>NA</td>
<td>1997 Montreal Protocol (UNEP, 2012)</td>
</tr>
</tbody>
</table>

Sustainable target value design: integrating life cycle assessment and target value design to improve building energy and environmental performance Russell-Smith, S.V., Lepech, M.D., Fruchter, R., Meyer, Y.B. JOURNAL OF CLEANER PRODUCTION 2015; 88: 43-51
“The lack of limit state analysis in sustainability design is partly due to the perceived similarity between life cycle economic cost (LCC) methods and life cycle economic, social, and environmental sustainability assessment (LCA) methods. In the case of infrastructure, design and management methods that minimize economic costs while maintaining minimum structural safety requirements (i.e. PONTIS, BRIDGIT, etc.) prima facie meet “economic sustainability” goals by minimizing economic cost or maximizing economic value.”

Probabilistic design and management of environmentally sustainable repair and rehabilitation of reinforced concrete structures Lepech, M.D., Geiker, M., Stang, H., CEMENT & CONCRETE COMPOSITES, 2014; 47: 19-31
“Environmental impacts associated with infrastructure design and management strategies that are environmentally sustainable must comply with local, regional, and global natural ecosystem carrying capacities. While minimization of environmental impacts of infrastructure moves closer toward environmental sustainability of infrastructure systems, it does not necessarily meet ecosystem carrying capacity constraints. Only when evaluated against a science-based limit state can efforts of environmental impact reduction be assessed as environmentally sustainable. Similar arguments could apply to meeting fundamental social metrics of sustainability that include equity, literacy rates, etc.”

Probabilistic design and management of environmentally sustainable repair and rehabilitation of reinforced concrete structures Lepech, M.D., Geiker, M., Stang, H., CEMENT & CONCRETE COMPOSITES, 2014; 47: 19-31
“The adoption of one-dimensional transport of chloride ions as the deterioration mode and electrochemical depassivation of reinforcing steel as the failure limit state are simplistic models upon which to base decade-long repair and rehabilitation decisions associated with environmental sustainability.

Research in the development and validation of fundamental models for determining reinforced concrete service life is needed to support the sustainability design framework and reduce uncertainty captured within this approach.”

Probabilistic design and management of environmentally sustainable repair and rehabilitation of reinforced concrete structures Lepech, M.D., Geiker, M., Stang, H., CEMENT & CONCRETE COMPOSITES, 2014; 47: 19-31
“Significant opportunities exist in the reduction of environmental impacts associated with concrete infrastructure repair, rehabilitation, and use. In line with recently proposed probabilistic sustainable design requirements in the fib 2010 Model Code, the sustainability design framework presented [in this paper] integrates probabilistic life cycle assessment with probabilistic reinforced concrete service life models to provide a foundation for more rational design, construction, and operation of concrete infrastructure that meets science-based environmental sustainability targets.”

Probabilistic design and management of environmentally sustainable repair and rehabilitation of reinforced concrete structures Lepech, M.D., Geiker, M., Stang, H., CEMENT & CONCRETE COMPOSITES, 2014; 47: 19-31
Infrastructure – Sustainable Design

Environmental and Economic Consequences of Permanent Roadway Infrastructure Commitment: City Road Network Life-cycle Assessment and Los Angeles County A.Fraser & Chester, Journal of Infrastructure Systems, 2016, 22(1)

Fig. 2. Historical road construction, reconstruction, resurfacing, and surface treatment in Los Angeles
Environmental and Economic Consequences of Permanent Roadway Infrastructure Commitment: City Road Network Life-cycle Assessment and Los Angeles County A. Fraser & Chester, Journal of Infrastructure Systems, 2016, 22(1)
“Embedded energy use and GHG emissions resulting from:
• **Initial construction** - 260,000 TJ and 21,000 GgCO2eq.
• **Periodic reconstruction** - 390,000 TJ of energy and 30,000 GgCO2eq.
• **Periodic resurfacing** - 158,000 TJ of energy and 12,000 GgCO2eq.
• **Surface treatment** - 43,000 TJ and 2,500 GgCO2eq.
• **General maintenance** - 3,600 TJ and 190 GgCO2eq.
• **Total** - 850,000 TJ of energy use and 66,000 GgCO2eq.”

Environmental and Economic Consequences of Permanent Roadway Infrastructure Commitment: City Road Network Life-cycle Assessment and Los Angeles County A.Fraser & Chester, Journal of Infrastructure Systems, 2016, 22(1)
“In 2010, yearly vehicle travel in Los Angeles resulted in 38,000 Gg of CO2 emissions, approximately 60% of the total embedded in the entire roadway network. Since 1950, the road network has enabled environmental impacts that are approximately 27 times larger than those generated from the construction and maintenance of the network.”

Environmental and Economic Consequences of Permanent Roadway Infrastructure Commitment: City Road Network Life-cycle Assessment and Los Angeles County A.Fraser & Chester, Journal of Infrastructure Systems, 2016, 22(1)
“The deployment of a permanent infrastructure can create a lock-in scenario through which future costs and environmental impacts are unavoidable. The historic inability to understand this commitment and appropriately allocate future resources has led to a situation in Los Angeles in which costs have escalated and environmental impacts have become unacceptable, yet an urban form has grown around this transportation network that makes alternatives challenging and potentially infeasible.”
“The environmental and economic effects are highly sensitive to the maintenance schedules associated with surface treatment and resurfacing. … For new construction, the additional upfront investment to design and build a more durable surface, such as Superpave, has the potential to reduce long-run environmental and economic impacts. The current paradigm in which transportation infrastructure investments are made based on minimum requirements may lead to greater lifecycle costs.”

Environmental and Economic Consequences of Permanent Roadway Infrastructure Commitment: City Road Network Life-cycle Assessment and Los Angeles County A.Fraser &Chester, Journal of Infrastructure Systems, 2016, 22(1)
Climate Change - IPCC predictions

GHG emission pathways 2000–2100: All AR5 scenarios

Representative Concentration Pathway (RCP)
Under the high greenhouse gas concentration scenario, the annual mean sea level in Hong Kong and its adjacent waters in 2081-2100 are expected to rise by 0.63 - 1.07 m relative to the average of 1986-2005.

Projected changes in the mean sea level in Hong Kong and its adjacent waters relative to the average of 1986-2005 under the high (red) and medium-low (orange) greenhouse gas concentration scenarios (solid line plots the mean value while dashed lines show the likely range of projection results). Historical observations are shown in black.
http://www.chinafile.com/infographics/submerged
Vulnerable Property in the Eastern United States

Residential real estate sales have grown less quickly in the last five years in areas where flooding from hurricanes is more frequent.

Some areas that flood the most from hurricanes...

...have had slower real estate sales in the last five years.

The risk of flooding from hurricanes is high along the Carolina Coast. The real estate markets in many counties there have slumped in the last five years.

Along the Gulf Coast, most counties are at a high risk of flooding from hurricanes.

The risk of flooding from hurricanes among counties in South Florida is consistently high. Real estate sales declined slightly in Miami-Dade, Collier, Hendry and Lee Counties, while sales in other counties there have barely grown.

November 25, 2016, New York Times
With profound sympathy
Conclusions

• To be sustainable Humanitarian Engineering should follow a Design for Sustainability philosophy
• Life Cycle Assessment + must be included.
• A product market analysis is need to determine the true need for products in Humanitarian Engineering.