The Fourth 'E'

Efficiency, economy, and elegance have often been referenced as the defining characteristics of structural art.[1] Within the constraints of material and budget, engineers have created structures that are both elegant and timeless. As environmental concerns become more prominent, however, a central priority in the mind of structural engineers and designers should be sustainability and therefore 'environment' must be added as a fourth criterion for a successful structure. While these four characteristics can be implemented in a variety of ways, it is the creativity and ingenuity of the engineer that ultimately sets a structure apart. This essay aims to explore the different approaches in addressing the relationship between aesthetics and sustainability within structural engineering.

Architecture at Present

There are currently two major movements in the world of architecture. The first, as seen in recent buildings by architects Frank Gehry or Zaha Hadid, consists of using complex shapes to create a visually exciting aesthetic, often with disregard to environmental impact. The second major movement is towards low-carbon, or "green" buildings. Within these environmentally-friendly buildings sustainability is the focus, while attention to aesthetics can fall to the wayside, leading to a perception that green architecture is unattractive. I believe, however, that both of these trends can and must be combined to create successful structures. This presents a challenge to engineers as we must re-educate ourselves to include both aesthetics and the environment as important priorities.

Structural Engineering at Present

In many building designs today, the structural engineer is used only as the enabler of the architect's vision. Instead, the engineer should be part of the creative inspiration, playing a dominant role in the form of the building to ensure its efficient structural design. This includes environmental efficiency and the decisions made concerning sustainability strategies. It is easy to think that a building

[1] Billington, D.P. (1983). *The Tower and the Bridge: the New Art of Structural Engineering.* Basic Books, New York.

needs expensive technologies to make it environmentally-friendly, such as photovoltaics. While these are helpful, the first step in designing a structure should be the implementation of passive strategies, which take advantage of the orientation, form, and air flow in a building to lower cooling, heating, and lighting requirements. Lifecycle thinking should also be incorporated from the beginning of the design process. In some cases, decisions made by the engineer may lead to higher initial construction costs but could end up being more economical due to savings in energy use throughout the operation of the building. Also, just as a limited budget provides a challenge that can result in a more creative design, placing a limit on the environmental impact can create unique solutions that have benefits both aesthetically and economically. If the architect and engineer work side-by-side, along with the client, an efficient, economic, elegant, and environmentally-friendly structure can be achieved.

Buildings at the Intersection of Sustainability and Aesthetics

There are many ways for structural engineers to successfully design buildings that incorporate efficiency, economy, elegance, and the environment. Sustainable solutions in one region and for one type of building are not always appropriate in another situation, requiring structural engineers to devise creative solutions depending on the context. Below are three visually striking structures that achieve sustainable designs in entirely different ways.

Eden Project, Cornwall, UK (2001)[2]

The Eden Project is a plant biome designed by architect Nicholas Grimshaw and engineer Anthony Hunt together with Arup. Winner of the Royal Institute of Chartered Surveyors' (RICS) Building Conservation Award in 2001, it was built over an abandoned mine to reclaim a post-industrial brownfield site. The aim was to create low-

Figure 1. Close-up of the Eden Project domes[2]

[2]*The Eden Project: The Biomes*. Accessed 26 Jan 2012. < http://grimshaw-architects.com/project/the-eden-project-the-biomes/>

impact greenhouses that would educate people on sustainability and the environment, while housing the world's largest collection of plants. Structurally, it required extensive spans with no interior supports. The solution is an elegant geodesic structure made of light-weight steel hexagons and ETFE membranes, which provide both the glazing and envelope. This innovative design is extremely light and therefore does not require heavy foundations, minimizing its impact on the area. The full glazing aids in the heating of the domes and maintenance of the climates while the operable vents allow for passive natural ventilation, both of which reduce energy requirements.

Mapungubwe Interpretation Centre, Mapungubwe, South Africa (2009)[3,4]

The Mapungubwe Interpretation Centre was designed by architect Peter Rich and engineered by Henry Fagan and Partners, along with John Ochsendorf and Michael Ramage. It is an elegant building with soaring masonry vaults made of soil-cement bricks pressed on site by the hands of locally-trained and previously unemployed masons. It is not only built of environmentally sustainable materials, but it also contributes to the social sustainability of the surrounding region by providing new training in masonry construction, contributing to the poverty relief efforts in the area. The use of the vaulting clearly shows the efficient flow of forces in the structure and was built with minimal formwork and no steel reinforcement, lowering the cost and environmental impact of the building. The center blends with its natural surroundings, in a world heritage site, and stays true to the culture of the area. Mapungubwe has won many awards that attest to its beauty, including a 2008 Holcim Award for Sustainability and the World Building of the Year in 2009.

Figure 2. Mapungubwe interior vaulting[3]

[3] Saieh, Nico. "Mapungubwe Interpretation Centre / Peter Rich Architects." 21 Apr 2010. *ArchDaily*. Accessed 26 Jan 2012. <http://www.archdaily.com/57106>

[4] "Mapungubwe Interpretation Centre – Project in Detail." *World Buildings Directory*. Accessed 26 Jan 2012. < http://www.worldbuildingsdirectory.com/project.cfm?id=1634>.

Swiss Re Tower, London, UK (2004)[5]

Figure 3. Swiss Re Tower[5]

The Swiss Re tower, designed by Norman Foster + Partners and engineered by Arup, is one of the most sustainable skyscrapers in the world. The building was designed to use almost 50% less energy than similar structures.[5] The tower uses its aerodynamic shape to reduce wind loads and the diagrid structure provides a visually expressive exterior. The building utilizes a double-glazed façade which traps air in-between two layers of glass, providing insulation, and improved energy performance. Extensive glazing, along with slots in the exterior, allow for natural lighting and ventilation. This use of passive technology reduces cooling loads and lowers operating costs for the client. The winner of the 2004 Royal Institute of British Architects' (RIBA) Stirling Prize, this unique building has become a new landmark for London and is fondly referred to as the "Gherkin."

Toward an Aesthetic of Sustainability

These award-winning buildings embody the potential of the structural engineer to create both aesthetically compelling and environmentally-friendly buildings. Due to the rising concerns about climate change and decreasing natural resources, the focus on sustainable building design will become increasingly prevalent in the twenty-first century. An emphasis on the ability of aesthetics and sustainability to intersect is crucial in the promotion of green buildings to designers and clients alike. Structural engineers have the potential to make an immense contribution in helping our environment, as buildings can only be truly sustainable when their materials and geometry are carefully considered. The study of a variety of environmentally-friendly buildings that are also visually and structurally interesting will help to demonstrate how simple design decisions can result in buildings that are not only efficient, economic, and elegant, but also better for the environment.

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[5] "The rise of the green building" (2004). *The Economist: Technology Quarterly* (Q4). Accessed 26 Jan 2012. < http://www.economist.com/node/3422965?story_id=3422965>.

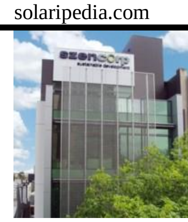
Criteria for Developing Itinerary

The structures selected for study are innovative buildings that are environmentally-friendly in their design as well as structurally and visually compelling. They have been selected because the structural engineers and designers focused on implementing passive strategies, such as natural ventilation and daylighting, to achieve their sustainability goals, while maintaining an interesting and appealing overall design. Traveling to multiple countries allows for the study of different sustainability strategies depending on region and climate. Through the exploration of these buildings I hope to answer a number of questions. What is the role of the structural engineer in the realization of green buildings? What are the primary areas of green buildings that should be emphasized and incorporated into a structural engineer's education? How do approaches change in different climates and cultures? Green buildings are the future of both architecture and structural engineering and we should study and celebrate those buildings that achieve a sustainable design without compromising their aesthetic vision.

Building Itinerary

Europe (Weeks 1-4)		
Icelandic Institute of Natural History (2010) Garoabaer, Iceland *Structural:* Almenna Consulting *Architect:* ARKÍS	Natural ventilation; daylighting strategies; green roof	 ark.is
Eden Project (2001) Cornwall, UK *Structural:* Anthony Hunt; Arup *Architect:* Nicholas Grimshaw & Partners	Extremely lightweight; primarily passive solar heating; built on brownfield	 grimshaw-architects.com
Wales Institute for Sustainable Education (2010) Wales, UK *Structural:* Buro Happold *Architect:* David Lea and Pat Borer	Combined with existing building; circular rammed earth lecture hall	 architectsjournal.co.uk

Europe (continued)		
Brighton Jubilee Library (2004) Brighton, UK *Structural:* SKM Anthony Hunt *Architect:* Bennetts Associates	Wind towers on the roof for ventilation; thermal mass benefits	 bennettsassociates.com
School of Slavonic & East European Studies, University College (2005) London, UK *Structural:* Martin Stockley Associates *Architect:* Short & Associates	Passive ventilation year-round; daylighting strategies	 shortandassociates.co.uk
Swiss Re (2004) London, UK *Structural:* Arup *Architect:* Foster + Partners	Natural ventilation; double-skin facade; aerodynamic structure	 greatbuildings.com
London City Hall (2002) London, UK *Structural:* Arup *Architect:* Foster + Partners	Minimized surface area to reduce heat losses/gains; natural ventilation	 architectureweek.com
Pines Calyx (2006) Kent, UK *Structural:* Scott Wilson Group; John Ochsendorf *Architect:* Conker Conservation	Unreinforced brick vaults; low-carbon, passive design; green roof, rammed earth	 pinescalyx.co.uk
Helicon (1996) London, UK *Structural:* Arup *Architect:* Sheppard Robson	Triple-glazed double-skin facade; adjustable shading; displacement ventilation	 skyscrapernews.com
McLaren Production Center (2011) London, UK *Structural:* Buro Happold *Architect:* Foster + Partners	Rainwater collection; natural ventilation	 designboom.com © mclaren
Downland Gridshell (2002) Sussex, UK *Structural:* Buro Happold *Architect:* Edward Cullinan	Lightweight, wooden, low-energy structure	 edwardcullinanarchitects.com
Great Glass House (National Botanical Garden) (2000) Carmarthenshire, UK *Structural:* Anthony Hunt Associates *Architect:* Foster + Partners	Lightweight structure, rainwater collection; passive solar heating	 habitables.co.uk

Europe (continued)		
Open Academy (2010) Norwich, UK *Structural:* Ramboll *Architect:* Sheppard Robson	Laminated timber structure; required minimal labor and construction time	 architectsjournal.co.uk
Africa (Weeks 5-6)		
Eastgate Center (1996) Harare, Zimbabwe *Structural:* Arup *Architect:* Mick Pearce	Thermal chimney; thermal mass	 wired.com
Mapungubwe Interpretation Centre (2009) Mapungubwe, South Africa *Structural:* Henry Fagan & Partners; John Ochsendorf; Michael Ramage *Architect:* Peter Rich	Local materials; unreinforced structural earthen vaults	 peterricharchitects.co.za
Australia (Weeks 6-8)		
Port Phillip Estate (2009) Red Hill *Structural:* Arup *Architect:* Wood/Marsh	Rammed limestone walls; integrated water filtering system	 woodmarsh.com.au
Scottsdale Forest Ecocentre (2001) Tasmania *Structural:* *Architect:* Robert Morris-Nunn	Low-impact local materials; natural ventilation	 solaripedia.com
40 Albert Rd (1987/2005) South Melbourne *Structural:* Connell Mott MacDonald *Architect:* SJB Architects	Refurbished building; independent from city water and electricity; zero GHG emissions	 sydney.edu.au
60 Leicester Street (2002) Melbourne *Structural:* AEC *Architect:* Spowers Architects	Thermal chimney; water conservation	 acfonline.org.au
Campus Reception Building, AUT Akoranga (2001) Auckland, NZ *Structural:* Gandy and Roberts *Architect:* JASMAX	Naturally ventilated; thermal mass; shading strategies	 *Sustainable Buildings in Practice* – George Baird

Canada (Weeks 8-10)		
NK'Mip Desert Cultural Centre (2006) Osoyoos, BC *Structural:* Terra Firma Builders *Architect:* HBBH	Rammed earth walls; green roof; partially buried to reduce temperature extremes	 nkmipdesert.com
CIRS Building, University of BC (2011) Vancouver, BC *Structural:* Fast + Epp *Architect:* Perkins + Will	Thermal chimney; rainwater collection; grey water system	 perkinswill.com
Bridge of Dreams (2009) Princeton, BC *Structural:* StructureCraft Builders *Architect:* n/a	Locally-sourced materials	 en.urbarama.com
National Works Yard (2004) Vancouver, BC *Structural:* Omicron *Architect:* Omicron	Fly ash concrete panels; shading strategies	 architecture.uwaterloo. ca
Liu Institute, University of BC (2000) Vancouver, BC *Structural:* Bush Bohlman & Partners *Architect:* Architectura; Arthur Erikson	Natural ventilation; shading strategies; daylighting; salvaged materials; high volume fly ash concrete	 architecture.uwaterloo. ca

Approximate Budget

Air	**Room and Board**	**Local Travel**
Boston to Iceland to London: $500 London to South Africa: $700 South Africa to Melbourne: $1000 Auckland to Vancouver: $1300 Vancouver to Seattle (end): $100	Iceland: 3 days at $55/night England: 4 weeks at $65/night South Africa: 1.5 weeks at $65/night Australia: 2 weeks at $65/night Canada: 2 weeks at $65/night	Iceland: $50 England: $500 South Africa:$100 Australia: $400 (includes flight to NZ) Canada: $200
$3600	$4520	$1250
		Grand Total : $9370