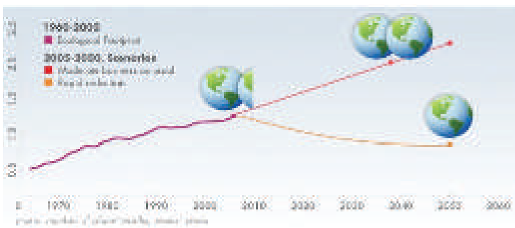
Sustainability Design Principles in Practice

Ir. Prof. Dr Ruslan Hassan

Ir. Prof. Dr Ruslan Hassan *is currently the IEM Vice President and a Fellow of Academy of Sciences Malaysia. Presently he is attached to the Malaysia Institute of Transport (MITRANS) and Universiti Teknologi MARA (UiTM). He researches, consults and teaches Sustainability Design in Practice.*

Sustainability emerged from the "sustainable development" concept. Sustainable development[1] is defined in the Brundland Commission Report (1) as meeting the needs of the present without compromising the ability of future generations to meet their own needs.

At present, the human population is not approaching sustainability. Wackernagel *et al., (2)* provides evidence that our demand for natural resources has rapidly increased in the last few decades. In 1961, demand corresponded to 70% of Earth's capacity for biological productivity; by 1980s, demand began to exceed the biosphere's capacity, and by 1999, we were using 120% of Earth's natural resources. In other words, it would require 1.2 earths to regenerate what was used in 1999. Clearly, this does not meet the test of sustainability.



Source: Wackernagel et al.,[2]

ENGINEERS AND SUSTAINABILITY

Sustainable development must achieve the due balance of environment, economy and the society. Development is the sum of our products and projects, i.e. application of technology. In these applications, engineers carry out, influence or decide on the options evaluated, the decision making criteria as well as the detailed design and implementation/ production.

For the development to become sustainable, engineers must incorporate 'sustainability' into the planning and engineering of products and projects. Sustainability is the ability to maintain to perpetuity or the capability of being maintained whereas sustainable design goal is to produce objects using only renewable resources and which, in operation, will deplete only renewable resources.

SUSTAINABILITY DESIGN PRINCIPLES AND APPLICATION

The design perspectives should be able to achieve the following:

1. Long-term design
2. Use more from less
3. Closing loop

1. Long-term design through Nature-Inspired Algorithms

Through years of evolution, Nature has been surviving. Biomimicry is emulating Nature's best biological ideas to solve human problems. The popularity of the Nature-Inspired Algorithms is primarily influenced by the ability of biological systems to effectively adjust to a frequently changeable environment. Swarm intelligence has been of great interest for many research scientists in the last decade. Bonabeau (4) has defined swarm intelligence as designing algorithms or distributing problem-solving devices based on the collective behaviour of animal societies and social insect colonies. The core of this study is to develop meta-heuristics by adopting the insect problem solving abilities.

Many studies have been conducted on social insects such as termites, bees, wasps and ants. A good example is a beehive. However the logic can also be extended to other insects with similar behaviour. An ant colony and a flock of birds can be categorised as "a swarm". The Particle Swarm Optimisation (PSO) Algorithm was developed based on the social behaviour of flocks of birds or schools of fish. Some of other algorithms developed are Ant Colony, Wasp Nests and Firefly Algorithms. An artificial Bee Colony Algorithm is a population-based swarm intelligence optimisation technique developed by Karaboga in 2005 (5). This algorithm is based on the behaviour of honey bees when foraging for food. The honey bees use different methods such as a waggle dance to locate optimal food sources and reaching new ones (6).

Termite-Inspired Air Conditioning Simply by Architecture

The Eastgate Centre & Office block in Central Harare, Zimbabwe, is modelled after the local termite (*Macrotermes michaelseni*) mounds. It is ventilated and cooled entirely by natural means. Air is continuously drawn from the open space by fans on the first floor and pushed up vertical supply sections of ducts located in the central spine of each of the two buildings. The fresh air replaces stale air which rises and exits through exhaust ports on the ceiling of each floor. Ultimately this stale air enters the exhaust section of the vertical ducts before it is flushed out via chimneys.

Figure 1: Termite-Inspired Building [3]

2. Efficient Design: Use more from less

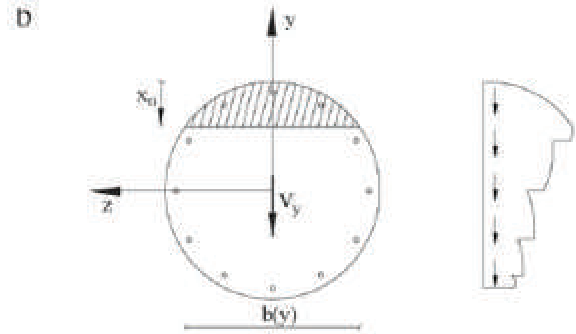
Solid versus Hollow Section/Column

Solid circular columns are very popular for bridge pier designs, due to simplicity of construction and because its strength characteristics under wind and seismic loads, are similar in any direction. Circular elements are also used extensively as columns in buildings or as piles for foundations. Hollow core circular concrete members are used less structurally than solid circular cross sections. However, these can be found in concrete chimneys, concrete pipes and elevated water tanks, as well as in large bridge columns and offshore platforms.

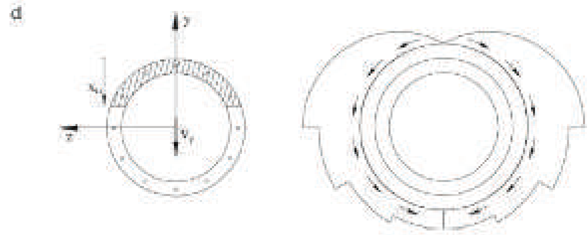
Some savings can be obtained when using hollow core circular columns. The economical convenience in the use of hollow columns is due to the cost saving afforded by the reduced section area (up to 70%). Furthermore, hollow columns are more efficient than solid ones from a structural pointof view. When the weight of the vertical members is relevant in the performance of the entire structure, a significant reduction in the seismic mass may be attained by using this structural type.

Even though shear transfer mechanisms are qualitatively well known, there is no agreement on the quantification of the shear strength of concrete members. Shear stress distributions on solid and hollow core circularcross-sections are very different. Whereas in the first, shear stresses are mainly vertical, in the second, shear stresses are assumed to act parallel with the boundaries of the section. In the former, shear crack pattern will be contained in a plane. In the latter, the crack pattern will not be contained in a plane but willform a helix of constant pitch in the space, and will form a straightline in the surface of the unfolded cylinder.

This statement has been proven theoretically and is experimentally correct (7).



Shear stresses in cracked solid circular cross-section,



Shear stresses in cracked hollow core circular cross-section with approximation-values for maximum shear stresses [7]
Where x_n = depth of compression zone, V = shear force

The fact that shear stresses have a different orientation in both section types, linked to the fact that the shear reinforcement does have the same geometry for both structural types, leads to the evidence that the stirrups or spiral reinforcement are not equally effective in solid and hollow core circular sections. Transverse reinforcement will be more efficient in those section types where shear stresses better align with the shear reinforcement. Circular or spiral stirrups will be more efficient in hollow core circular specimens than in solid ones (7).

3. Closing the loop design through Ecological Engineering

Ecological Engineering Principles.

Ecological Engineering is defined as the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both (8). The design consists of Energy Augmentation Self-organisation/self-design and adaptation (9).

a. Energy Signature: The set of energy sources or forcing functions which determine ecosystem structure and function. Energy Sources that affect an ecosystem are:

- Sunlight as primary energy source of the ecosystem
- Organic inputs, which is detritus concept in stream ecology and estuaries
- Auxiliary energies (apart from sunlight and organic matter) which reduce the cost of internal self-maintenance and increase the amount of other energies which can be converted to production.

The augmentation of energy through design by existing appropriate energy signatures to support the ecosystem being created. The subsidies are water, fertiliser, aeration or turbulence for encouraging wetland species by adding these to the source of water. Stressors can be added, such as pesticides to limit the development of the ecosystem (i.e. adding herbicides to control invasive, exotic plant species).

b. Self-organisation: The selection process through which ecosystems emerge in response to environmental conditions by filtering of genetic inputs (seed dispersal, recruitment, animal migrations etc.). Self-organisation is the process in which species composition, relative abundance distributions and network connections develop over time. The mechanism of self-organisation is a form of natural selection of these species which reach a site through dispersal. The species in the ecosystem has found a set of favourable environmental conditions to support a population of sufficient size for reproduction.

Self-organisation helps to guide self-design by allowing natural selection to organise the systems. The best species can be preferentially seeded into a particular design or Nature can be allowed to choose the appropriate species. Excess seeding of many species is provided and self-design occurs automatically.

c. Pre-adaptation: The phenomenon of adaptation that arises through natural selection for one set of environmental conditions just happen also to be adaptive for a new set of environmental conditions that the organism has not been previously exposed to. Self-organisation can be accelerated by seeding with species that are preadapted to the special conditions of the intended system. It requires the knowledge of design conditions of the ecosystem to be constructed and the adaptation of species. Adaptation by species occurs through Darwinian evolution along environmental gradient.

Pre-adaptation by design is done by taking advantage of the principle of biodiversity prospecting and knowledge of the niche concept. New systems developing with pollution are sources of preadapted species for treatment ecosystems. Invasive exotic species are successful due to preadaptation to human disturbance and the seed sources through ecological engineering.

Application

The principles are then adopted in the design of the ecosystem in the improvement of water quality (10).

The Solar Aerator and the Floating Wetland are now operating fully at Kolam Takungan Banjir Air Leleh [10]

The energy augmentation through solar aerators allows for self-organisation or self-design and the vertiver plants adapted for the present environment thrive in the pond ecosystem.

CONCLUSION

Engineers need to play more active roles in the use of renewable resources of nature for a balance approach to development. There is a need to be resilient and innovative as well as to design for impact-proof and to take the no-regrets options route. Sustainability design will achieve the objectives by adopting the approaches presented, namely:

- Long-term design through biomimicry
- Structural optimisation through using less materials
- A close system, not unlike ecosystem, to be used through ecological engineering for a closed-loop approach. ■

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