LESSONS FROM NATURE

DEREK CLEMENTS-CROOME
UNIVERSITY OF READING

CIBSE Intelligent Buildings Seminar November 19th
2014 at Arup

WWW.DEREKDCROOME.COM
Characteristics of Nature

- runs on sunlight;
- uses only the energy it needs;
- fits form to function;
- recycles;
- rewards cooperation;
- banks on diversity;
- demands local expertise;
- realises the power of limits.

Benyus (2002)
Biomimetics

The abstraction of good design from Nature
Biophilia – How we connect with Nature

First described by Erich Fromm in the 1960’s Biophilia is the Love of Life or Living Systems.

Edward O. Wilson --- we don’t just love all things in the natural world --- we are genetically connected to them. Humans have a deep desire to connect with Nature.

Our subconscious desire to be close to Nature in our everyday lives continues even in the workplace.
The Artificial Leaf

Research groups have been trying to create artificial leaves to try and mimic natural processes. Dan Nocero then at MIT now at Harvard had success in 2011.

An Artificial Leaf splits water to produce oxygen and hydrogen, use hydrogen either as a fuel or to reduce carbon dioxide to produce organic fuels.

Biomimetics, Design and Intelligent Buildings

BOTH ORGANISMS AND BUILDINGS HAVE TO SURVIVE IN THEIR ENVIRONMENTS

- ADAPTATION (Shape, Materials, Structures,…), MODULATION
- SENSING, ACTUATION (Passive, Active)
- INTELLIGENCE (Choices, Responses)
- ENERGY MANAGEMENT

Jeronimidis, G, 2007, The University of Reading
The Fish (Peix) at Vila Olimpica Barcelona 1989-1992 by Gehry

H. Alderney-William, Zoomorphic 2004, (Lawrence King)
Milwaukee Art Museum, Wisconsin, USA, 1994-2001 by Santiago Calatrava is like a Bird
Scottish Exhibition and Conference Centre by Norman Foster like an Armadillo
Organic architecture promotes harmony between human habitation and the natural world through design. Sympathetic and integrated into its site so that buildings, furnishings, and surroundings become part of a unified, interrelated composition. 

Fallingwater by Frank Lloyd Wright
Animal and Human Technologies

Spider’s webs, devices for catching food;

Spider’s web in detail hardened forms of viscous thready masses.

Otto –Rasch 2001
Bubble and net formation in a living cell (radiolaria)
We mimic Nature, but have yet to come up with anything to match its technical and aesthetic ingenuity, its ability to adapt to its environment and change over time.

Nothing beats a spider's web or for example the human skin.
SPIDERS WEBS

Linyphia

Cyrtophora
Bower birds collect and arrange by size brightly coloured objects with which to lure the females and stimulate a sexual response.
Reed Hut Weather Shelter

Primeval House

More highly developed building technology for woven reed hut.
Primeval House
Integrated Sensing

WOOD CRICKET (15 mm long)

Cerci organs (about 2mm long) carry about 2000 hair-type sense organs each act as:

- air-flow sensors
- chemical sensors
- acceleration sensors
- deformation sensors
- contact sensors

Jeronimidis, G, 2007, The University of Reading
Digital Botanic Architecture

The idea is not to make buildings look like botanic organisms. It is to interlace Nature and architecture enabling the design of hybridized, biological structures. The overall aim is to create new architectural typologies incorporating natural attributes ordered in performance, materials, mechanics, communications, and form.

*Dollens 2009*
The *Podhotel* copies leaves and pods from a flower stalk, the leaves being transformed into solar and shading panels and the pods being prefabricated rooms.
Magnetic or Compass termitaries near Darwin, Australia.

Attenborough, D, 2005, Life in the undergrowth, BBC Books p.228
Compass termites in Australia

Evolved orientation of termitary for preferred maximum temperature level of about 32°C

Von Frisch 1975
The Ultima Tower - a Human Termite Nest by Eugene Tsui
Eastgate Office Building in Harare, Zimbabwe inspired by termites nest
Biomimetics: Early Examples

Giant Water lilies – Kew Gardens-inspires the rib vaults at Crystal Palace

Crystal Palace 1851

Jeronimidis, G., 2007, The University of Reading
Fractal topology of extruded leaf wax

Physical principle = Surface tension affected by wax

Droplet collects particles and clean leaf

Jeronimidis, G, 2007, The University of Reading
Bioluminescence is the production and emission of light by a living organism. Its name is a hybrid word, originating from the Greek bios for "living" and the Latin lumen "light". Bioluminescence is a naturally occurring form of chemiluminescence where energy is released by a chemical reaction in the form of light emission.
Fireflies, anglerfish, other creatures and some mushrooms glow due to bioluminescence.
Alberto Estévez’s Bioluminescent Tree

Experiments in bio-illumination with implications for architecture, industrial and environmental design.

Digital Walls
Digital Walls with Embedded Sensors

Dye sensitised solar cells with titanium oxide layers on a surface with light absorbing dye molecules adsorbed on surface which can generate electricity
Gilder’s proposed photovoltaic cell over the membrane absorbing sunrays from all directions inspired by Moths Eye

Microscopic view of a schematic membrane with impregnations on its outer surface created for increasing its exposed surface area.
A virtual analysis of the model for this project showing the encapsulated routeings of the heating and cooling network within the base material of the structure.
Lessons from Nature

Although human ingenuity makes various inventions it will never discover inventions more beautiful, appropriate and more direct than in Nature because in her nothing is lacking and nothing is superfluous.

Leonardo Da Vinci
Some examples from Nature
Crab eyes may be either large or reduced.

Having eyes mounted on stalks helps to increase field of view and range.

Light is limited or absent in the deep sea.

Reduction or loss of eyes is common in some deep sea decapods.

A giant red hermit crab collected from the shallow continental shelf near the Charleston Bump shows off his large eye stalks.

Photo by Project Oceanica Jeronimidis, G, 2007, The University of Reading
Basis of Velcro

burs from woollen materials and dog’s coat have spines tipped with tiny hooks

Mueller T, 2008, Biomimetics Design by Nature, National Geographic, April,
Velcro: George de Mestral, 1948 - Seed pods

Galium aparine (Stickywilly)

Jeronimidis, G, 2007, The University of Reading
The hooks on a piece of Velcro brand fastener

Tiny hooks on a Burdock (Arctium lappa) (detail)

hooks (left) and loops (right).

The loops on a piece of Velcro brand

http://en.wikipedia.org/wiki/Velcro
Contours of the sleek boxfish promotes low drag

Contours of car give low drag

Mueller T, 2008, Biomimetics Design by Nature, National Geographic, April,
Shark-Skin Effect: Drag Reduction

Jeronimidis, G, 2007, The University of Reading
Sharks tooth-like denticles reduce befouling and drag

Fast Swim suit

Mueller T, 2008, Biomimetics Design by Nature, National Geographic, April,
Mollusk-inspired Fan
Whale-inspired wind turbine blades

Mueler T, 2008, Biomimetics Design by Nature, National Geographic, April,
MEMS fabricated hair array, produced by MESA at the University of Twente.

Fig. 1a Mechanosensor hair array on cercus (image has been artificially enhanced for better visualisation of hairs)

MEMS fabricated hair array, produced by MESA at the University of Twente

Jeronimidis et al, Customised Intelligent Life-inspired Arrays, The University of Reading
Microelectromechanical (MEMS) system longhairs sensors for airflow and acoustic measurements also photonics e.g. crickets, gecko
Thorny devil lizard

Sipping through a foot, the thorny devil lizard wicks water to its mouth via channels between its scales. Scientists hope to mimic the mechanism to develop water-capture technologies for dry regions.

Mueller T, 2008, Biomimetics Design by Nature, National Geographic, April,
The sticky toe pads of tree frogs and crickets have inspired Indian researchers to create an adhesive tape that is both strong and reusable.

Tree frogs, lizards and bush crickets have now inspired a team of Indian researchers to create a super glue—an adhesive which is highly elastic, strong and can re-stick up to 25 times without weakening.

After studying how these creatures use their sticky toe pads to cling on to surfaces, Dr Animangsu Ghatak, an assistant professor at the Indian Institute of Technology, Kanpur, and colleagues have made an adhesive tape by running air or oil filled microchannels through a soft, elastic material, making it stickier than conventional glues.

The frog-inspired adhesive tape is 30 times more sticky, report researchers (Image: iStockphoto)
Tokay Gecko

Gecko’s feet have spatula-tipped hairs (some 6.5 m per toe) that adhere to surfaces at the molecular level, allows nimble footing on vertical and horizontal surfaces.

Mueler T, 2008, Biomimetics Design by Nature, National Geographic, April,
Gymnodactylus mimikanus Blgr.
Praeanal and femoral pores × 3.
Synthetic gecko is composed of millions of mushroom-shaped hairs. One metre square of a new super-sticky material inspired by gecko feet could suspend the weight of an average family car.

Geckos inspire 'super-adhesive', BBC News 26.07.06.
Geckos, glue and sticky tape

Scanning electron microscope image of a 1cm² section of the Gecko-sticky tape.

Spiderman toy hanging from a glass plate, attached using the tape with a contact area of approximately 0.5cm².

Bunching of the hairs is a problem that reduces the adhesive properties of the tape.

Pooley, B. Biomimetics: Borrowing from Biology Thenakedscientists.com
Mollusk Inspired Epoxy

The mussel foot produces an epoxy with adhesive properties that rival any "super-glue" on the market.
Survival of Animal and Plants Depends on Sensing to Capture Information from their physical and Chemical Environments

- Defense Against Predators
- Capture of Prey
- Adaptation
- Navigation
- Communication

One particular characteristic of biological sensing is its unique capacity to extract “meaning” from noisy environments.

Jeronimidis, G, 2007, The University of Reading
Adult male Gryllodes sigillatus cricket
Example: Sensory filiform hairs of crickets: detection of predators (air flow)

The filiform sensing hairs are located on the *cerci* (from a few tens in young, up to 1000+ in adults)

Filiform hair length varies between 100 and 1500 μm
Diameter typically 4-10 μm

Jeronimidis, G, 2007, The University of Reading
Cerci organs (about 2mm long) carry about 2000 hair-type sense organs each:

- air-flow sensors
- chemical sensors
- acceleration sensors
- deformation sensors
- contact sensors

WOOD CRICKET (15 mm long)

Jeronimidis, G, 2007, The University of Reading
Sensory filiform hairs of crickets

(Seidel, 2004)

(Dangles et al., 2004)
SEM of cricket cerci at 257x mag
Prey localisation in desert scorpions – vibration-based triangulation

Jeronimidis, G, 2007, The University of Reading
Insects, Spiders and Crustacean-sensory information from

- Strains in the exoskeleton (campaniform)
- Infrared detectors (modified campaniform)
- Air flow and pressure detectors (hairs)
- Vibration detectors (slits & lyriform)

Jeronimidis, G, 2007, The University of Reading
Shape Change

Leaf folding in *Mimosa pudica* (1-3 seconds)

Stimulus:
- mechanical contact
- vibration
- light
- temperature
- humidity

Jeronimidis, G, 2007, The University of Reading
Smart adaptive shape change

Differences in fibre orientation
+ layering

Jeronimidis, G, 2007, The University of Reading
Bio-inspired shape

Roof-supporting “trees” – Stuttgart Airport

Jeronimidis, G, 2007, The University of Reading
The underside of the Red Abalone (Haliotis Rufescens) shell shows a remarkable iridescent ceramic that is twice as tough as our high-tech ceramics. Mother-of-pearl – nacre- is composed of alternating layers of calcium carbonate (in a special crystal form called aragonite) and Lustrin-A protein.
The key to functional integration in biology is the use of fibre architectures for designing structures, incorporating sensors and providing actuation.