

BIOMIMICRY FOR CONSTRUCTED WETLANDS

Looking To Nature For Solutions On Water Treatment

"Making knowlege work for us"



December 2013



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What Is Biomimicry?

"Bios" means life, "Mimicry" means imitate. Biomimicry is the practice of learning from and then emulating life's genius to solve human problems and create more sustainable designs. Biomimicry is a branch of science, a problem-solving method, a sustainability ethos, a movement, a stance toward nature, and a new way of viewing and valuing biodiversity.

Why Biomimicry? Why now?

Organisms and ecosystems face the same challenges that we humans do, but they meet those challenges sustainably. The premise of biomimicry is that Life has been performing design experiments in Earth's R&D lab for 3.85 billion years and what is flourishing on the planet today are the best ideas – those that perform well in context, while economizing on energy and materials. Whatever the design challenge, the odds are high that one or more of the world's 30 million creatures has not only faced the same challenge, but has evolved effective strategies to solve it.

The selective pressure placed on all natural life forms minimizes and removes failures. Organisms are the consummate physicists, chemists, and engineers, and ecosystems are economies beyond compare. They can provide us with innovative and progressive solutions to the design, engineering and other challenges that we now face: energy, food production, climate control, benign chemistry, transportation, packaging, and more. The vision is to create products, processes, organizations, and policies—new ways of living—that are well-adapted to life on earth over the long haul. "Doing it nature's way" has the potential to change the way we grow food, make materials, harness energy, heal ourselves, store information, and conduct business.

Source: BIOMIMICRY SOUTH AFRICA - <http://biomimicrysa.co.za/about/about>

1.INTRODUCTION

Biomimicry is the practice of learning from and then emulating natural forms, processes and ecosystems to solve human design challenges and create more sustainable designs. The Water Research Commission has initiated a five year research project on Biomimicry and constructed wetland design. The overall aim of the project is to demonstrate the Biomimicry methodology and to evaluate the effectiveness of this methodology in the design, construction and maintenance of constructed wetlands. If successful, this methodology can then be implemented on other systems and processes.

The first phase of the research project was to compile a literature survey on the biomimicry methodology, as well as natural and constructed wetlands. This included identifying organisms, systems and/or processes that could potentially be mimicked for water treatment technologies, i.e. "Champions in Nature", organisms, systems or processes that have been or can be mimicked for water treatment technologies.

The findings of that phase of the project are presented in this publication.

2.METHODOLOGY

While the concept of nature inspired designs is not new, the Biomimicry Institute have developed a procedure where-by biologists and designers can work together to identify and emulate natural solutions in their design challenges:

The key steps in the methodology (Biomimicry Guild, 2009) are:

- **Identify – The first step is to identify the function.**

- ☐ What is the core problem that needs to be solved?
- ☐ What do you need to achieve?
- ☐ What do you want your design to do?

- **Interpret – Biologise the question.**

- ☐ As an example, consider a design problem whereby the designer is required to treat water containing high concentrations of sulphate. Typical questions would be:
 - ☐ "How does nature remove sulphates from water?"
 - ☐ "How does nature survive under high sulphate conditions?" – understanding the mechanism where-by the organism is able to adapt and survive under these conditions can lead to a solution to the design challenge.

- ☐ “What natural processes require high sulphate conditions?”
 - ☐ Understand the overall context.
 - ☐ Climatic conditions, social conditions, temporal conditions, etc.
- **Discover – Find solutions in nature. Brainstorming between designers and biologists.**
 - ☐ Identify nature's models which meet the functions identified in step 1.
 - ☐ Select the champions by considering the context and identifying the organisms whose survival are dependent on the function.
- **Abstract – Understand the principles and context and selecting a short-list of champions.**
 - ☐ Look for repeated successes and the principles that achieve this.
- **Emulate – apply lessons learnt in nature.**
 - ☐ Mimic form – understand and mimic the structure/ shape.
 - ☐ Mimic function – understand and mimic the principle, process, strategy or mechanism.
 - ☐ Mimic ecosystems – understand and mimic the interactions between different organisms to meet the function.
- **Evaluate – evaluate against life's principles (The Biomimicry Group, 2011) and identify areas of improvement to the design. These principles include:**
 - ☐ Be resource efficient.
 - ☐ Use life-friendly chemistry.
 - ☐ Integrate development and growth.
 - ☐ Be locally attuned and responsive.
 - ☐ Adapt to changing conditions.
 - ☐ Evolve to survive

Biomimicry Solutions To Water Treatment Technologies

In order to understand natural water treatment processes, the project team posed the following questions:

- How does nature purify water?
- How does nature filter water?
- How does nature remove dissolved salts from water?
- How does nature create a homogenous mixture?

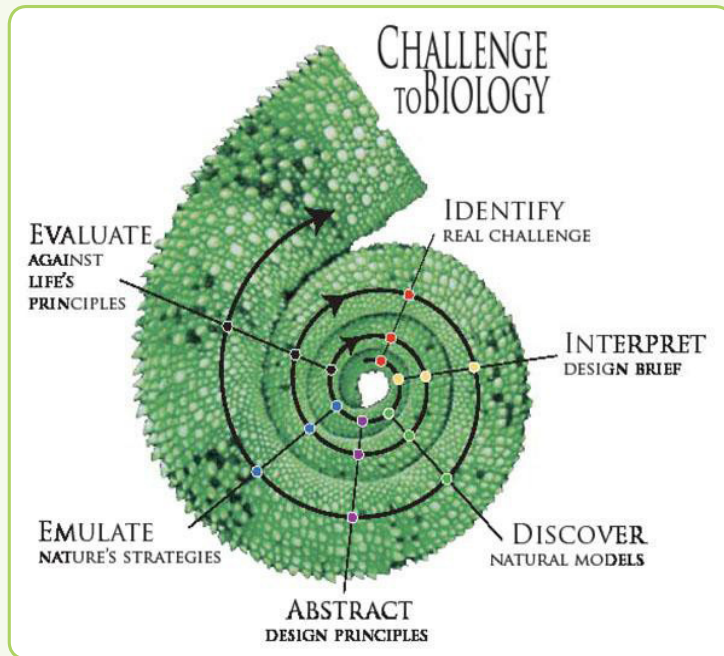


Figure 1: Biomimicry Methodology
(Biomimicry Guild, 2009)

3. Findings

The results obtained were classified under the following sub-sections

- Ecosystem solutions.
- Filtering technologies.
- Desalination.
- Flow technologies.
- Surface protection.

3.1 Ecosystem solutions

The most common method for obtaining clean water for most organisms is to rely on the ecosystem that they inhabit to sustain life. Animals, for example, rely on the action of a diversity of plants, trees, algae, fungi and bacteria to capture rainwater, filter sediments and toxins, and store water in leaves, lakes, ponds, etc. where they can have access to it.

3.1.1 Wetlands

The Bright Water Company mimicked wetlands in their Biohaven Floating Islands project (Floating Island International, 2012). A polymer based island, constructed with recycled material is used. Plants are inserted into pre-cut pockets which are designed such that the roots can be submerged into the water. As the vegetation grows,

microbes cling to the roots and the floating Island, removing excess nutrients from the water in conjunction with the plants.

The Living Machine, invented by John Todd, is a form of wastewater treatment inspired by wetlands (Todd & Todd, 1994). The systems are modular, involving a series of tanks/islands/reactors that are connected, each with their own "ecosystem" design performing a particular water treatment function. Instead of chemicals as cleaning agents, aquatic living creatures like snails and small fish, together with different vegetation species are brought together in different combinations to perform specific tasks (Patsalides, 2010).

3.1.2 Forest Litter

The manner in which Forest Litter decomposed was mimicked by Dean Cameron in his design of the Biolytix Biopod, which treats raw sewage and food waste to a water quality suitable for irrigation (Biolytix, 2008). The system makes use of a selection of worms, beetles and microscopic organisms which feed on the nutrients in the water.

3.2 Filtration technologies

A wide range of organisms perform bulk filtration of water to filter out nutrients for feeding. The filtration is achieved through various principles. At the time of the study, the Baleen Filter was the only successful biomimetic filtration application identified, however it is envisaged that further investigations on the principles discussed in this section can lead to innovation filter designs in the future.

3.2.1 Filtration using keratinous filaments

Baleen whales which feed on krill have no teeth, instead they have developed a keratinous row of fibres known as a baleen to filter out organisms from the sea water. The keratin sheath of each baleen plate encapsulates hair-like strands that become evident as the sheath is worn down and splits open. Upon closing its mouth, the whale's lower jaw distends, creating pressure against the baleen. This forces water through the keratin fibres, but retains all organic material. Once all water is forced out the whale's tongue rises and sweeps the organic material off the baleen and swallows it (Attenborough, 1979). The principles of Baleen whale filtration have been emulated in existing biomimetic technology, called Baleen Filters. In the Baleen Filter, water runs through the filter, causing visible solids and particles to remain behind in the filter. Hereafter, a second high-pressure, low-volume spray of water dislodges the solids and carries it away. As a result, there are two output streams; one which is filtered, and another which is a concentrated solids stream (Croll, 2008), (Brodie & Vikingsson, 2009).

The basking shark is the second largest living shark, after the whale shark and uses filtration to feed on Plankton < 1 mm. It is a slow moving and generally harmless filter

feeder. It has anatomical adaptations to filter feeding, such as a greatly enlarged mouth and highly developed gill rakers (Sims, 1999).

Flamingos feed on crustaceans and algae > 0.5 mm. The bill of a Flamingo is lined with numerous complex rows of lamellae, which filter out the various small crustaceans, algae and unicellular organisms on which flamingos feed. The feeding process requires a series of tongue movements and opening and closing of the beak, which allows food items to be filtered by the lamellae and eventual ingestion. Unwanted items such as mud and saltwater are pushed out by the tongue. Swinging the head to and fro allows water to enter the beak and the tongue moves back and forth acting as a pump, sucking the water in and forcing it out up to four times a second (Erich et al, 1988). The Lesser Flamingo has such a dense filter that it can sift out single cell plants (Biomimicry institute, 2010) (Jenkin, 1957).

3.2.2 Filtration using partial pressure

The Bladder Wort is a plant that uses a partial pressure method of feeding on water fleas and small fish, which are between 1µm – 1mm. The water plants are found in wetlands in many parts of the world. Their traps, the bladders from which they get their name, are tiny transparent capsules. Glands on the inner surface of the traps are able to absorb water and in doing so create a partial vacuum within. Each trap has a tiny door fringed with sensitive bristles. If a small water creature, such as a mosquito larva, touches one of these, the bristle acts as a lever, slightly distorting the edge of the door so that it no longer fits tightly on the rim. Water rushes in, sweeping the door inwards and with it, the little organism that touched the hair. The swirl of water within the capsule pushes the door closed again and the prey is imprisoned. The whole action is completed within a fraction of a second (Laakkonen, Jobson, & Albert, 2006).

3.2.3 Filtration using small cilia

The sea squirt has two openings, the inhalant and exhalant apertures. The water enters through the inhalant aperture and comes into contact with the basket-like interior of the sea squirt, which is covered with tiny gill slits with hair-like structures called cilia. This helps to propel the water, as well as to filter out food from the water current. The food then attaches to the mucus lining on the inside of the sea squirt and flows into the esophagus at the lower end of the body. The remaining water exits through the exhalant aperture (Dales, 2008).

Daphnia are small, planktonic crustaceans, between 0.2 and 5 mm in length. Daphnia possess bristle-equipped appendages. These creatures swim with such appendages, using them as paddles - with semi-stagnant water around each bristle, an appendage can serve as a paddle. The creatures also use such appendages as rakes, filtering edible particles from the water around them. The principle behind the alternate paddling and filtering is based on the speed at which an appendage

operates. The size of the appendage and speed of movement decide what function the movement will have. According to Vogel (2003), large and fast result in a rake or filter and small and slow allows for movement.

3.2.4 Filtration using mucus lined appendages

Salps, which feed on algae < 1 mm, are small free-swimming marine creatures with gelatinous, semitransparent bodies that move around by means of jet propulsion, drawing in water through an aperture at one end of the body and then forcing it out through another aperture at the opposite end. Small food particles are gathered by a mucous net of varying complexity (depending on species). It was found that organisms as small as 0.5 microns also get caught and eaten, since they stick directly to the mucus (Woods Hole Oceanographic Institution, 2012). The mucus net which captures the food particles rolls into a strand and goes into the gut, where it is digested. It is then released in the form of pellets, which sink to the bottom of the ocean. The net, or “house”, is discarded when clogged, and a new one is quickly formed. An individual may produce up to 10 or more nets in a single day.

The Peacock worm feeds on detritus, bacteria and plankton between 0.2 and 100 μm and is a marine polychaete worm. Tiny hair-like structures or cilia on the mucus lined tentacles, filter suspended particles from the water. These particles are then sorted according to size; small ones are eaten, large ones are discarded and medium-sized particles are added to the top of the tube with mucus, in order to increase its length.

3.2.5 Sediment trapping in wetlands

While this is not a feeding mechanism, constructed wetlands also have an upfront screening/filtration step in the form of sediment trapping. Factors influencing sediment trapping include:

- Vegetation – upright vegetation in the flow path tends to slow down the flow of water and trap suspended solids.
- Hydrogeomorphology – topographic features resulting in the slowing down and spreading of water result in sediments settling to the floor of a wetland.
- Geomorphology – The ratio of wetland size to drainage area, where a larger ratio results in improved sedimentation.

3.3 Desalination

Desalination technologies are fast becoming a popular choice for water treatment. These technologies are however expensive, both from a capital investment point of view and an operational point of view. Several natural processes where-by dissolved salts and impurities are separated from water are being investigated.

3.3.1 Aquaporins

Aquaporins are proteins found in cellular membranes, which contain pores in the shape of an hour-glass, made of crystalline material and used to transport water in and out of cells. These proteins transport the water through the membrane at a rate much faster than diffusion and with increasing hydrostatic pressure this rate can be further increased. Aquaporins can be used to filter out ions, including hydronium (H_3O^+) and hydroxyl (OH^-) ions, all the while maintaining a high water permeate rate and without requiring extreme pressures to force the water through. Since the discovery of aquaporins in 1992, an almost complete atomic-level understanding of the aquaporin water channel function has been

reached (Chakrabarti, Tajkhorshid, Roux, & Pommès, 2004). NASA tested Aquaporin technology in October 2011 and found this membrane to come closest to the requirements of a small, lightweight system which can convert the body fluids of astronauts into drinkable water. Larger scale testing is to be done in 2012 (Aquaporin, 2011). Aquaporin marketing, sales and licensing of the final membrane technology is expected in 2013.

3.3.2 Mangroves

The mangrove draws sea water up capillaries via transpiration and filters the sea water through membranes which do not allow the salt through. Salt build-up is dangerous for living tissues and other internal structures and needs to be prevented. As a prohibition to salt build-up, the red mangrove pumps the salt into the tissue of old leaves which are about to drop off. The black and white mangroves secrete the salt through glands onto the leaves.

3.4 Flow technologies

Flow technologies rely on shape to move water in ways that dissipate or avoid the forces of friction. By creating different flow environments water is oxygenated, suspended particles are removed and/or nutrients are distributed. The literature survey into existing biomimetic flow technologies identified two relevant existing technologies, some additional relevant research and some inspiring organisms that could yield further fruitful research on this subject.

3.4.1 Spiral Flow

Inventor Jay Harman developed the Pax Lily impeller after studying fluid flow efficiencies in natural systems, such as air and ocean currents. He observed that nature never moves in a straight line and tends to flow in a spiraling path that he called nature's Streamlining Principle. PAX technology replicates nature's most energy-efficient and effective path of mixing fluids – spiral geometry. The Lily takes advantage of nature's flow pattern – a low resistant and effective method of mixing fluids – to significantly

improve the performance and energy usage of water mixing technology. With this natural design, the PAX Water Mixer can mix up to 10 million gallons with the same energy footprint as three 100 watt light bulbs (PAX Scientific, 2008), (Biomimicry Institute, 2010).

3.4.2 Vortex Generator

The Watreco Vortex Generator was inspired by the trout's ability to remain steady in the current of a river or stream. Water rushing into the trout's mouth is forced into ever-tightening vortices as it passes through the gills and back into the current. This allows the trout to remain steady even in inconsistent or violent currents. The system essentially works by causing water to quickly swirl down an ever-tightening coil of channels. This forces contaminants and/or air bubbles (depending on the application) into a column in the center of the swirling water. At the end of the process a vacuum quickly sucks this column out, leaving water with the desired properties behind (Watreco, 2011).

The Limeteq product uses the Vortex Generator to change the structure of lime crystals in water from calcite to aragonite. Aragonite is a polymorph of calcite, i.e. it has the same chemistry but different structure and therefore different properties and physical characteristics. One can expect significantly less lime scale build-up with aragonite, leading to longer-lasting pipes and reduced usage of harmful cleaning chemicals.

3.5 Surface protection

Biofilm formations and scale build-up in piping and equipment of collection and distribution networks, as well as water treatment plants are a common reason for down-time at these facilities. Anti-fouling and/anti-scaling technologies can help to manage this.

3.5.1 Anti-fouling surface

Microscopic investigations on shark's skin revealed that the shark skin denticles are arranged in a distinct diamond pattern, with tiny riblets that discourage micro-organisms from settling. This inspired the design of the Sharklet Surface Technology. The pattern is manufactured onto adhesive backed skins that can be applied to surfaces to prevent biofilm build-up (Sharklet, 2010).

3.5.2 Anti-scale surface

Thermal polyaspartic acid (TPA) is a mimic of a biopolymer originally discovered in oyster shells. In addition to participating in the formation of oyster shells, TPA inhibits the formation of calcium carbonate, calcium sulfate, barium sulfate, and mineral scale, as well as limiting the oxidation of metals. TPA is a polymer made of polyaspartate,

with an active carboxylate chemical group attached to it that gives TPA its function. The polyaspartate of TPA is unique as its polymer backbone is made of chains of amino acids (peptides) instead of the hydrocarbon chains that make up the backbone of polyacrylate. TPA's polymer is therefore degradable by bacterial action (Nanochem Solutions, 2005).

4. CONCLUSION

The literature survey identified several success stories, as well as potential champions that can be mimicked to produce sustainable water treatment technologies. One of the key findings was that whilst an abundance of information is available on natural processes and constructed wetlands, the information is not in a format that can be easily converted into bio-inspired designs. The project team, together with the research sponsor and reference group, has thus decided to embark on phase two of the project which is to compile an information bank of organisms/plants/animals and processes in nature which can be mimicked in the design of water treatment technologies.

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