Biomimetics: Biologically Inspired Ideas for Construction

Stephen P. Mead Ph.D
Department of Construction Management
Northern Arizona University

This paper discusses the concepts of Biomimetics and describes how natural systems can be used as models for materials and processes that can be used in the design and construction of buildings and infrastructure projects. The paper describes several innovations including smart vapor barriers, bio-inspired wastewater treatment, bacteria catalyzed concretes, termite inspired cooling systems, and carpets that mimic a forest floor. Additionally, the paper discusses how animal and insect behavior can be used to optimize schedules and reduce cycle times in repetitive construction processes. Finally, the paper discusses how Biomimetics may affect construction projects and construction management curricula.

Key Words: Biomimicry, Biomimetics, Bio-Inspired Design, Construction Means and Methods

Background

In 1997, Janine Benyus published a revolutionary book called *Biomimicry*. The word Biomimicry is derived from two Greek words: bios which means life, and mimesis which means to imitate. In her treatise, Benyus describes “a new science that studies nature’s models and then imitates or takes inspiration from these designs and processes to solve human problems, e.g. a solar cell inspired by a leaf.” (Benyus, 1997). A similar term, “biomimetics was coined by Otto Schmitt in 1969 in his article “Some interesting and useful Biomimetic Transforms” (Schmitt, 1969). Schmitt argued that nature provides useful models that can be used in science and engineering to solve human problems. Through the process of evolution, nature has developed a long history of experimentation where the fittest species survive while species that fail to adapt quickly decline and become extinct.

Given the popularity of Benyus’ book, many scientists and engineers have begun to explore this idea of *bio–inspired* products, and increasingly architects and construction managers are adopting some of these ideas in an effort to build better homes, buildings, and infrastructure. As a result, the vinyl-covered boxes we now call homes may soon be replaced with structures that grow, breathe and adapt to changing conditions.

Growing Buildings

William McDonough, the visionary green designer once wrote,“…What if our buildings were alive? What if our homes and workplaces were like trees, living organisms participating productively in their surroundings? Imagine a building, enmeshed in the landscape that harvests energy of the sun, sequesters carbon, and makes oxygen. Imagine onsite wetlands and botanical gardens recovering nutrients from circulating water…In short a life support system in harmony with energy flows, human souls, and other living things." (Zolli,2002).

Would it be possible to grow buildings? While this idea may seem far-fetched, designers at MIT have recently introduced a system that will grow homes from native trees. Developed by the designers at the Human Ecology Design team at MIT, this innovative building system uses an ancient gardening technique called *pleaching* to weave together tree branches. CNC computer templates are used to guide the growth of self-grafting elm, live oak, and dogwood trees to form a lattice of branches that act as the load bearing structure for the building. A dense matt of vines acts as the exterior envelope of the home and provides a substrate to carry the interior finish system of clay and straw. Like the ancient cob houses of England, this matrix of clay, straw, and sand acts as an insulating and waterproofing system that controls internal temperatures and keeps the structure dry. In the words of the designers, "the tree trunks of this design provide the structure of and extruded ecosystem, whose growth is embraced over time" (Joachim, M. et al. 2007). The designers also envision a closed water loop that will help sustain the trees that surround the house and its inhabitants. Water, collected by a roof top funnel, is filtered, and then gravity fed to the building occupants. Plants will help treat the wastewater (see living machines section of this paper), which will then be returned to the roots of the surrounding trees via a gray water irrigation system. As the water moves through the living skin of the house, the plants then generate a unique microclimate that cools the building through evaporation. The sun drives the ventilation (convection) and solar water heating systems. Unlike the extractive process of lumber harvesting and transportation, most of the materials for Green Fab Home are grown on site. This self-replicating process reduces material costs, minimizes transportation impacts, and increases the affordability of the construction. The designers of the tree house see it as a way of replacing the low cost homes currently used by affordable housing groups like Habitat for Humanity.

The major drawback with this system is time. Even under the best circumstances it will take several years to grow and graft a tree in the form of a house. Obviously, growing a house will require some patience, and this may conflict with our societies current ideas of efficient production and instant gratification.

Growing Foundations

While trees provide a macro approach to building houses, scientists are also experimenting with micro sized bacteria as a way to create bio based cements. Jason DeYoung and his colleagues at the University of California Davis have recently developed a technique that uses the bacteria Bacillus Pasteurii to stabilize granular soils. (DeJong, 2006) The bacteria are tilled into granular soil and mixed with urea, a waste product that mammals create when they metabolize protein. This unique combination of biological ingredients generates a chemical reaction that raises the PH of the soil, and one of the products of this reaction is the creation of calcium carbonate. The cement like calcium compound binds the soil particles together into a concrete like mass. Once developed, this bio-engineered solution to soil stabilization may also be used to grow spread footings and drilled pier foundation systems.

Purifying Waste

There is an old expression that goes, "O'er the seven stones the water flows, 'tis pure again the farmer knows". Many ancient cultures understood that plants are remarkably adept at filtering and cleansing water. But more recently, ecologists like H.T. Odum have studied rain forests, coral reefs, and mangrove swamps in an attempt to decode the purification abilities of natural systems. Odum suggested that if we look closely at nature's systems, we can develop ecologically based templates that can help us solve modern problems like wastewater treatment, air pollution, and even economics.

As part of their work Odum and others analyzed how a wetland can remove toxic chemicals from the water and air. A wetland is a tract of land that has wet or moist soil like a peat bog, salt marsh, or inland swamp. Wetlands act as natural filters, where a complex system of aquatic animals, plants, and microorganisms work together to precipitate soil, break down wastes, and generate oxygen and clean water. Interestingly, a large body of research show that wetland plants like bull rushes, cat tails, cranberry seedlings, mangrove and cypress trees and others, will also remove toxic metals or chemicals from their environments. During water uptake, their roots accumulate large concentrations of lead and "immobilize" the toxic metals in the cell walls of the plant. When the plants die, the toxins become imbedded in the peaty sediments of wetland floor, and given enough time, the peat becomes coal through the geologic process.

Using Odum's ideas as a springboard, Dr. John Todd has developed an engineered ecosystem called a *Living Machine* that uses biological processes to treat residential and industrial wastewater. In effect a Living Machine acts like a man made Mangrove swamp or salt water marsh that includes an integrated collection of plants and animals. Collectively, these organisms see our liquid waste as food, and they reduce complex organic substances into simpler components that can then be reused by other plants and animals. Using Todd's invention, waste water moves into a series of tanks that are populated by plants and fish, bacteria and algae. Using only the sun's light as an energy source, these organisms convert waste into potable water at half the cost of traditional mechanical systems. Todd has used Living Machines to treat everything from residential sewage to the industrial waste. (Todd, J. 1994).

Similarly, the Canadian Mortgage Housing Corporation has developed a demonstration home in Toronto called the Healthy House to help promote the possibilities of biological wastewater systems. Here, the home is designed to provide clean water for all household needs without municipal services. Rain and snow that falls on the roof is routed to an underground storage cistern where it is filtered through sand and treated with ultraviolet light. The sand acts like the soil that filters water along the edges of a stream or river. The wastewater, which would usually drain into the city sewage system, is collected and recycled for use in toilets, showers, the washing machine and landscaping. Like the

Living Machine described earlier, the house sized system uses bio-filtration to clean and polish the wastewater. According the CMHC, "Water is recycled up to five times, with a small amount being safely released into the soil each day… water that is generated filters into the ground under the front lawn, where it waters fruit trees and flowers" (CHMC 2001). According to estimates, the house will use approximately 10% of the water of a traditional home.

Buildings that Breathe

In developed countries, people spend approximately 90% of their time indoors, (Leech et al. 2002) but many people live or work in buildings where the air is so poisonous that the buildings actually make them sick. According to a report by the Environmental Protection Agency, 70 million Americans currently live or work in "sick buildings" and many experts theorize that the recent alarming rise in childhood asthma may be due to increasing indoor air pollution (J.P. Deason et al, 1998).

Indoor air pollution comes from several sources: paints, cleaning products, aerosol propellants from your shaving cream, and the glue that holds your countertop and cabinets together all "off gas" volatile organic compounds (VOC's) and other chemicals that can aggravate allergies and cause cancer. At the same time, many buildings are now designed in a way that helps biological pollutants like mold and mildew grow unchecked while hiding behind building assemblies like drywall and carpets.

In contrast, natural systems are continually cleaning house. For instance, a leaf uses the process of transpiration to extract in the carbon dioxide needed for photosynthesis while flushing oxygen into atmosphere. Tiny valve-like stomata cover the skin of the leaf allowing air and moisture to pass through the membrane while excluding larger dust and dirt particles from the process. The elegant design of a stomata is similar to other diaphragms found throughout nature (think of your lips) and could also serve as an efficient model for a new class of mechanical valves and backflow preventers.

Several years ago, researchers in Europe developed a building vapor barrier that acts much like a leaf. The product, which is called MemBrain, is a temperature sensitive vapor barrier that breathes to allow excess moisture to escape from inside your home. In the winter, when the air is cold and humidity is low, MemBrain closes its pores to reduce air infiltration and improve energy efficiency. In summer months, when humidity is high, the pores of the vapor barrier open up and it's permeability increases. In effect, this artificial skin senses climatic conditions, and adjusts its permeability to allow the wall to breathe. (Certain Teed.Com)

Termite Inspired Cooling

Another example of nature inspired building system comes from the African termite mound. The African termite lives in tall mounds so strong that humans use dynamite to remove them when they are in the way. Relative to a termite's size, these mounds are equivalent to a mile-high skyscraper housing the population of New York. But their real genius lies in their remarkable environmental control system. Even in the oppressive heat of African savannah where temperatures vary from 104 F to 34 F in a single day. The design of these termite mounds keep them cool (around 85 degrees) without fans, chillers, or heat pumps. These tall mounds, which can reach 26 feet in height and 10 feet underground, are built like a smokestack, and the termites create small tunnels or openings at the bottom of the mound. These openings are oriented to catch the prevailing breezes, and as the air enters the mound it passes through chambers of wet mud, which lowers the temperature of the air through evaporative cooling. Because warm air rises, the air is drawn through the top of the stack through the "stack effect" of convection.

Archtiect Mick Pearce used the termite idea as the basis for his design of the Eastgate Building in Harare, Zimbabwe. Like the termite mound, the design uses the mass of the building as a "heat sink" that insulates the building from the diurnal temperature swings outside. Working with Ove Arup & Partners, he developed an air-change system that uses a central atrium to passively move air from the base of the building to the stacks on the roof. Along the way, it passes through hollow spaces under the floors and then into each office through baseboard vents. As the air warms, it is drawn out through 48 round brick funnels. During cool summer nights, fans send cooler outside air through the building seven times an hour to chill the concrete mass of the hollow floors. This project, which was completed in 1995, uses only 10% of the normal air conditioning required for similar buildings of its size (Tzonis, A. et al. 2001).

Growing Insulation

Insulation plays an important role in performance of any building's envelope system. In many ways, energy performance and indoor air quality are closely linked with the proper installation and sealing of a building's skin. Curiously, insulation is surprisingly low tech. Fiberglass insulation has been in use for over seventy five years, and Jefferson used cellulous to insulate his Monticello home. While new products like open and closed cell foam products have helped to improve insulation performance, there chemical makeup has been linked to asthma and pulmonary disease problems.

Recently, a new company founded by two students from Rennselaer Polytechnic Institute, has developed a new insulation product that is actually grown from mushrooms. The product, which is called "greensulate" is developed from a petrified slurry of water, mushroom spores, starch, perlite, and hydrogen peroxide. In this case, the materials are placed in a dark environment. The mushrooms feed on the starch and grow around the other insulating materials, binding all of the other materials together. When the process is complete, hydrogen peroxide is added to the mix to neutralize the mushroom spores and prevent unwanted growth in the future. This product, derived from natural products, has a higher insulation value than traditional petroleum based products. Like other natural systems, it can be easily broken down and recycled once it has reached it's useful life. (ecovativedesign.com)

Carpet like a Forest Floor

Carpet is omnipresent in America. It is found in almost every building, and house in our country, and we produce millions of square yards of the material each year.
At the same time carpet is a major part of our growing landfill problem. According to the book Natural Capitalism, we throw away 920 million square yards annually enough carpet to cover the entire island of Manhattan every year (Hawken, Lovins, 1999). Part of the problem is the way that carpet wears. People tend to walk through spaces in the same way each day, and as a result carpet shows wear at doorways and hallways, and in high use areas like dining rooms. Textile designer, David Oakley looked to the forest floor to help solve this problem. Oakley designed a carpet called "Entropy" that mimics the organized chaos of a riverbed or a blanket of fallen leaves. By mimicking nature, Oakley's carpet tiles can be easily replaced without worrying about dye lots or patterns. This allows facilities managers to replace individual tiles, which minimizes waste and reduces the life cycle cost of the product.

Organizations and Processes

Scientists are also studying animals and insect behavior to develop new ideas that can be used to manage and organize projects and processes. Lain Couzin, a mathematical biologist at the University of Washington, is studying army ants to develop mathematical models as to why people, birds, and insects have a tendency to swarm (Couzin et al. 2002). Using high-speed film cameras, ant behavior was analyzed frame by frame to understand why army ants act collectively when they search for food. Typically, the swarm will move in a dense column toward the food source, where two outgoing lines flank an incoming line of ants. During the process, each ant lays down a chemical marker that is used by the other ants to guide them on their journey to and from the food source. Cousin's mathematics demonstrate that ant movements have many of the same patterns that govern the physics of liquids, and that this particular scheme allows the most efficient movement of a large group of individuals.

These studies are already being used to rethink how we move traffic in dense urban locations (American's spend 3.7 billion hours stuck in traffic), and in construction they could be used to improve the efficiency and queuing of earth moving equipment on linear projects like roads, railroads and bridges. Research by El Gafy (2007) Dorigo (1996) and El –Rayes et al (2001) suggest that the study of insect populations like ants can also be used to help optimize resource utilization and reduce scheduling durations for repetitive construction projects like high rises and roads.

Conclusions and Implications for Construction Education

While Biomimetics is a rapidly evolving discipline, the field provides specific opportunities for expanding the depth of construction education. One of the complaints about professional degree programs is that because they focus on professional education, they lack the depth and breadth of a traditional liberal arts education. Whereas a liberal studies student will take classes in humanities, philosophy, sciences, social sciences and mathematics, a construction management student's education focuses on the intricacies of the profession. But in a global culture of rapidly changing technologies, new knowledge is often created when professionals work across disciplines. As a result, new ideas often develop when the chemist talks with the computer scientist, or when an engineers and designers share ideas with a construction managers. Given theses opportunities, many Universities are now encouraging or even mandating interdisciplinary studies within professional curricula.

Voltaire once suggested, “Originality is nothing but judicious imitation”. From ants to trees, nature provides numerous models that can help construction managers develop new solutions to complicated systems and processes. As such, construction educators may be able to enrich their curricula and help nurture the creativity of their students by looking beyond traditional means and methods and embracing the interdisciplinary thinking that will form the ideas of the future.

References:

Canadian Home Mortgage Council (2001). *The Toronto Demonstration Projec t*[WWW Document] URL: http://healthyhousesystem.com/toronto.html

Couzin, L. Krause, J. James, R. Ruxton, G. Franks, N. (2002) *Collective Memory and Spatial Sorting in Animal Groups*. Journal of Theoretical Biology, Vol 218, pp.1–11

DeJong, J.T., Fritzges, M.B., and Nüsslein, K. "Microbial Induced Cementation to Control Sand Response to Undrained Shear" ASCE Journal of Geotechnical and Geoenvironmental Engineering, 2006, Vol. 132, No. 11, pp. 1381-1392.

Deason, J.P. (Ed.) (1998) Sick Buildings:what we have learned and what can be done. Journal of Environmental Engineering and Policy Vol 1, No. 1. July 1998. pp37-48

Dorigo , M., Di Caro, G, 1999. The ant colony optimization meta-heuristic. In: Corne, D, Dorigo, M.,Glover, F. (Eds.), *New Ideas in Optimization.* New York, McGraw Hill.

Ecovative Design (2007). [WWW Document] URL: http//www.ecovativedesign.com

El-Gafy, M. (2007) "Resource Allocation for Repetitive Construction Schedules: An Ant Colony Approach" Annual Proceedings of the Associated Schools of Construction. Flagstaff 2007.

El-Rayes k. and Moselhi O. 2001 "Optimizing Resource Utilization for Repetitive Construction Projects." Journal of Construction Engineering and Management, ASCE 127 (1): 18-27

Joachim, M. (2007) *Fab Tree Hab.* [WWW Document] URL: http://www.archinode.com/bienal.html

Hall, C.A.S. (Ed.) (1995) *Maximum Power: The ideas and applications of H.T.Odum,* Niwot, Colorado. Colorado University Press.,

Hawken, P. Lovins, A. Lovins, L. (1999) _*Natural Capitalism*_ Boston: Little Brown and Company.

Certain Teed (2007). [WWW Document] URL: http://www.certainteed.com/CertainTeed/Homeowner/Homeowner/Insulation/Prodindex/Residential/MemBrainProdIndex.htm

Leech JA, Nelson WC, Burnett RT, Aaron S, Raizenne ME. (2002) It's about time: a comparison of Canadian and American time-activity patterns. Journal Annual Environmental Epidemiology. 2002;12:427–432.

Tchobanoglous, G., Burton, F.L., and Stensel, H.D. (2003). *Wastewater Engineering (Treatment Disposal Reuse) / Metcalf & Eddy, Inc.*, 4th Edition, McGraw-Hill Book Company.

Todd NJ, Todd J., (1994*) From Eco-Cities to Living Machines: Principles of Ecological Design.* Berkley, California: North Atlantic Books

Tzonis, A., Lefaivre, L., Stagno, B. , (Eds.) (2001) *Tropical Architecture: Critical Regionalism in the Age of Globalization* . London: John Wiley and Sons