Biomimicry Beyond Organisms:

Acting and Informing at a Systems-Level

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Abstract:

Organisms exist, not alone, but as an amazing blend of biotic and abiotic elements guided by physical and energy boundaries we know as Earth's Operating Systems. Using biomimicry as a tool at an organismal level can yield solutions for focused challenges. Utilizing biomimicry at a systems level can allow for an interrelated series of solutions much like an ecosystem does in nature with boundary compliance and potential for increased levels of resilience.

LOGICally LEEDS, an ecological-industrial park with over 1 million square feet of office and industrial space, is close to the central community of Leeds, England. It is an ecologically diverse space wedging through historic and natural assets near an ethnically diverse and socially challenged neighborhood.

By creating a development utilizing biomimicry at a systems level, designers are striving to increase resilience to floods while using water efficiently. This paper conveys the logic and process of designers creating solution pathways borrowing genius strategies from the Elephant Foot plant, European Water Vole and Giraffe to help capture, store and distribute excess volumes of stormwater.

1.0 Introduction

We're all looking for solutions. Unfortunately, in our "want it now" society we likely to embrace the mythology of the silver bullet. Nature does not behave that way. In nature, organisms simply strive for being better. Optimization isn't perfect. It's messy and constantly morphing. With change as a constant in the world, biomimetic adaptation is one of the strongest tools we have at our disposal. Nature is always optimizing – whether for food gathering, transport, self-protection, temperature regulation, or attracting a pollinator. None of this happens without systems and yet, the systems approach in biomimicry generally trails the organismal approach and has yet to reach its full potential.

A plethora of systems exist in the world - ecosystems, structural systems, circulatory systems, chemical systems – but when solving problems in systems "system" must first be defined, its parts and behaviors analyzed and its context paired with the context of the identified problem. Then, solution makers can decide what system model to use in creating solution pathways.

In working with *LOGICally LEEDS,* designers:

- Analyzed the site and existing ecosystems (systems)
- Articulated goals for the project while integrating the parameters of the site and Life's Principles
- Conducted research to identify natural organisms with genius strategies to comply with Life's Principles while achieving the design goals and
- Developed a design solution utilizing three organisms in a systems approach.

Obviously an eco-industrial park is a large and complex undertaking. However; working in systems at any level can potentially increase workability and resilience – especially if combined with the tools of biomimicry.

2.0 Working in Systems

The attributes of resilience revolve around the capacity to prepare for, respond to and recover from disturbance or change while maintaining an organism or system's character, functions & capacity. In order to optimize and become more resilient, organisms change in response to their environment. They adapt. Eventually, changes can take place which affect entire species and ecosystems – but always with the end point working toward optimization and resilience. In nature there is no other choice. Adaptations made in conflict with these systems eventually perish.

Systems are described as a set of things: (people, molecules, biotic & abiotic elements) interconnected in such a way as to produce their own pattern of behavior over time. All systems have elements, relations and functions. (Meadows 2008, 2) Elements can be the digestive tract parts of a frog or the parts of a plant. The elements in an ecosystem can include the frog and all the plants and organisms as well as abiotic elements like rain and temperature surrounding them. Each of these relationships has a function – grass serves as support for the frog. The soil below serves as a support for the plant, both in physical and nutritional terms. So, what isn't a system? Random items with no particular purpose in relation to each other … are not systems.

It is a system if:

- You can identify the parts
- The parts affect each other in some way
- In combination, the parts create an effect they wouldn't without each other.
- The effect/behavior persists over time. (Meadows 2008, 12-13)

2.1 System Types

As we look further at systems we discover there are three basic system types:

- Isolated – With no exchange of energy or matter outside the system (These seldom, if ever, exist.)
- Closed – With an exchange of energy but not matter outside the system (Examples include pressure cookers, solar ovens etc.)
- Open – Energy and matter can cross boundaries. (This describes the majority of systems on Earth and is the systems described in this paper.) (Skinner and Murck 2011, 10-11)

Open systems are subject to Earth's Operating Conditions: sunlight, water, gravity, limits and boundaries, cycles and dynamic non-equilibrium. (Biomimicry 3.8. 2012. "Earth's Operating Systems." Last modified 2012. http://biomimicry.net/about/biomimicry/biomimicry-designlens/lifes-principles/)   This is the baseline for solution development. Earth operates in cycles. Everything on Earth is affected by gravity. Life requires sunlight and today's sunlight can be a free source of power (passive). All life needs water which has conditions of its own (cycles, watersheds, saltwater intrusion, etc.). Limits & boundaries look and act differently depending on the organism and/or the abiotic element or group of elements – but they exist in every circumstance. Dynamic non-equilibrium, as Alberti noted, is neither continuously gradual nor consistently chaotic. It's episodic. So, the sphere in the bowl is, in most cases, more of a slow building and then release (Alberti 2008, 21) than a constant rolling from state to state. These operating conditions at their most basic levels form the "context" for living. They affect work, play, eating, sleeping, waste … not only at an organismal level, but at a systems level as well.

2.2 System Behaviors

In addition to complying with requisite operating conditions, designers must take into consideration the fact that nothing is static. Life, systems and businesses operate with flows and feedback loops. In Life's Principles, developed by Janine Benyus, Dayna Baumeister and the staff of Biomimicry 3.8; balancing feedback loops are sometimes illustrated in the example of a hungry baby bird opening its mouth which triggers regurgitation feeding by the parent. This, in turn, can lead to a reinforcing feedback loop which triggers growth (or collapse). Most systems have multiple flows and feedback loops with dominance between the two constantly shifting.

Knowing a little of what a system is and how it operates still may not answer (for some) the question of why working in systems is beneficial. Working in systems enhances resilience, fosters self-organization and optimizes hierarchies. (Meadows 2008, 75.) Businesses are managed for solutions which yield stability but increasingly, because of economic and climate shifts among others, for resilience as well. Working at the nexus of biomimetic systems, reshuffled information creates different sub-species or sub-solutions. In biomimetic system solution pathways one notes replication of strategies that work (redundancy) but with enough variation so that if one goes down – another strategy continues the solution. Self-organization, moving toward greater complexity from individual mechanisms (like metamorphosis) to behaviors of group action (like migration) is efficient and supports large loads of information, products, or in the case discussed here - stormwater. Hierarchies optimize based on sub-systems in combination to yield a "higher functioning" organism/product/group. The circulatory system is elegant; but when combined with other systems to form a human body the result is staggering.

2.3 System Relations Models

When working in biomimetic systems it is useful to work in, what Farnsworth terms Biomimetic System Relations Models including intra-system, adjacent systems, unrelated systems and whole ecosystems. Working in systems with biomimicry can become thorny because of deciding how and where to draw boundaries. The key to deciding can reside in determining what "function" is being solved for; then moving forward with building a solution by picking the most applicable system with which to work in a specific context.

If the function of *slowing, moving and storing liquid* is identified the models could be differentiated in the following ways:

Intra-system: Using a plant system as an example: The xylem directs concentrated flow. Leaves disperse flow. Roots transport liquid between ecosystems. Each of these strategies within a single organism can be mimicked at the challenge site.

Adjacent Systems: Many times grasslands or farmed areas with grass-like crops (wheat, rye, barley) are adjacent to shrubby or wooded areas. Grasses and shrubs have different growing habits and mechanisms which might make them a more productive organism to mimic to solve the aforementioned problem. Grass roots can filter & infiltrate to a deep level. Shrubs' leaves slow flow. Roots of both serve as transport. If those can be mimicked – either in man-made planting patterns (bio-utilization) OR through biomimicry, a positive outcome can be gained.

Unrelated Systems: Sometimes the best answers reside in using organisms from unrelated systems but with complementary strategies such as the Elephant Foot plant, water vole burrows and giraffe necks which will be discussed later in this paper. Although they reside in completely different ecosystems, their combined strategies can serve as solution pathways for specific functions.

Whole Systems or Ecosystems: The Whole Ecosystem model is the most complex. If all the elements, functions and interrelationships are combined to form something new that has its own functions and survives over time it is termed a "whole system". Antarctica is a very large "whole system" but size doesn't determine whether something is a system or not. A person is also a "system". We have other organisms functioning and interrelating within our bodies – up to 100 trillion good bacteria according to the Human Microbiome Project. So, size doesn't determine whether something is a whole system. Working in "whole systems" one must pay attention not only to the context of the challenge, but the context of the solution, Earth's Operating Systems, Life's Principles, the swings in dominance, the particular stocks present, materials and energy being used in order to keep the system operational. Other models are seen as "parts" of an operation as opposed to a "whole" operation.

2.4 Circular Economy

Finally, it is also important to note in Biomimetic System Relations Models were conceived with the intent to be used in conjunction with Dame Ellen MacArthur's Founding Principles for Circular Economy:

- Waste = Food
- Diversity is strength
- Energy must come from renewable resources
- Thinking in terms of systems is key
- Prices must tell the truth

As solution pathway developers solve problems, it is intended they do so using a design brief for disassembly and reassembly. The circular economy, an industrial economy created to be restorative, utilizes material flows which include biological nutrients, designed to reenter the biosphere safely, and technical nutrients, which are designed to circulate at high quality without entering the biosphere. (MacArthur Foundation 2013)

3.0 Applying Systems-Thinking

This project's aim is to apply systems-thinking to a case study site. As an entry for the Biomimicry Design Challenge run by Biomimicry 3.8, the designers chose a location in close proximity to their place of study, Leeds; and a site that could offer both water management and sustainable urban design challenges.

The chosen site is a 110 acre (45 hectare) parcel of farmland, 2 miles from Leeds city centre. The site is 25% flood plain with a small culverted river, the Wyke Beck, running along the western edge. The farmland slopes steeply from the northeastern corner with an elevation change of approximately 40 metres (131 feet). At the southwestern tip of the site surface water pools due to the flat topography and compact soils.

The local authority, Leeds City Council, have earmarked the site for the creation of industrial development. This is due in part to the close proximity to central Leeds and the motorway network.

The site location, topography, hydrology and geology is the reason it was chosen as a case study site for the design competition.

3.1 Analysis

Before being able to apply the biomimetic systems approach it was relevant to complete an extensive analysis of the area identifying the range of ecosystems. The combination of biomimetic and systems-thinking approaches necessitated the identification of the three components of the system, in this case, the ecosystem. This is important in urban design/planning given the complexity of the urban fabric.

Some of the questions asked relating to systems-thinking were:

- What nonliving (sun, wind, etc.) and living (predation, cooperation, nutrients, etc.) challenges do you think your functions are affected by in this setting?
- Is your subject unique in its approach to responding or do you see other organisms responding in similar ways? How is the system your organism is a component of responding to these pressures?
- What implications do these patterns have for sustainable community design?
- How do the functions of this organism interrelate with other organisms? How do they interrelate with the system? In each ecosystem (or indeed, any system) elements,

interrelationships (or interconnections) and functions are repeated in an array of different numbers and scales at the individual organism level, between organisms and between groups of organisms. When one designs a *biomimetic system* one must make sure to pay attention to all three as well as how the multiplicity of these exist and complement each other.

The analysis work identified a range of organisms ranging from a number of types of moss, tree roots, mosquitoes, fresh-water shrimp, fungus, fruiting berries and water-based plants, to large willow trees.

Additional information on the ecology of the site was provided by the developer. From this report, "Extended Phase 1 Habitat Survey by White, Young and Green (2011), European water vole droppings and burrow entrances were identified.

The analysis work identified two local ecosystems, historic woodlands and riparian habitats along with ecotones (natural edges) of each. These ecosystems managed fluids in differing ways. Yet, each complies with Life's Principles. As an example, we can look at the riparian habitat:

- Evolves to survive - Successful riparian trees create offspring and spread along the riverbanks.
- Is resource efficient - The ecosystem breaks down nutrients to produce food for others.
- Adapts to changing conditions - As flooding becomes more prevalent in East Leeds, surviving organisms are becoming more water tolerant in terms of moisture, flow, volume or some mixture of the three.
- Integrates development with growth - The ecosystem is self-organizing.
- Is locally attuned and responsive – The food web and nutrient network is an example of this.

- Uses life-friendly chemistry - Life builds and grows in the ecosystem using life-friendly chemicals, compounds and mixtures.

This led to answering the question ‘How could people use the strategies you’re observing?’ The designers thought of developing a closed-loop network based on how a riparian habitat deals with water volumes and flows. This could be a more effective water management system; and could even possibly clean water polluted from industrial use. This led to setting the goal for the design.

3.2 Objectives

Having carried out the analysis of the local ecosystems, a goal and design brief was developed to allow the design team to keep the focus of the project. Through the careful incorporation and emulation of nature’s strategies, the designers worked to incorporate forms, systems and processes from nature in the design to achieve the following goals:

1. Modify physical state of water
2. Protect from abiotic factors
3. Provide ecosystem services
4. Capture, absorb, filter + store water
5. Distribute water
6. Expel water.

Commercial analysis of the LOGICALLY Leeds site earmarked it for development as an industrial estate. By combining this with the project analysis, the concept was to design an Ecological Industrial Park based on biomimicry principles in a system to achieve the six goals. An additional feature was to provide social amenities for the neighboring residential area by deculverting the Wyke Beck and providing a network of open spaces linking both the riparian habitats and historic woodlands through careful selection of plants and materials.

The key brief was to ensure that a biomimetic systems approach was used to consider the overall site while creating a closed-loop water management system. "By introducing a surface stormwater and hydrologically and ecologically functioning landscape, making combined structural and natural drainage infrastructure and landscape is far more resilient to extreme meteorological events," states Novotny et al (2010, 103).

3.3 Organisms and Ecosystems

The fieldwork and site analysis found a number of organisms and ecosystems that could be used for inspiration for this project. Each of these could form part of a complex system within the site. The goals were simplified to three stages of the system:

1. Water Capture
2. Water Storage
3. Water Distribution

As previously mentioned, the European Water Vole (*Arvicola amphibious*) is a successful organism in the riparian habitats in the vicinity. The water vole's burrow is made to limit water ingress and protect the vole from predators. The question was asked 'Can this element be used for the function of capturing water instead?' Obviously, directly emulating this strategy would not work. What if the inspiration from the water vole burrow was reversed? By designing a capturing system that is a reverse of the burrow, water ingress is optimized with the vole's chambers providing additional storage. This was the element that design team took.

What organism can be emulated to store water? In this instance, it was necessary to look to a different biome, the semiarid desert, for the inspiration. Elephant Foot Plants (*Discorea* *elephantipes*) have swollen bases for water storage and can store water from six months to a year. It does this by retaining water within its root structure and base of the stem. The root structure does this by expanding and contracting according to the amount of water stored through the transfer of water from the soil.

The final goal of the system was to then distribute the water throughout the site. Again, by looking to another biome, in this instance the grass savanna, inspiration came in the form of the Giraffe (*Giraffa camelopardalis*). In the upper neck, the rete mirabile prevents excess blood flow to the brain when the giraffe lowers its head. The jugular veins also contain several (most commonly seven) tricuspid valves to prevent blood flowing back into the head from the inferior vena cava and right atrium while the head is lowered. The form of the valves and the mechanisms that the giraffe anatomy employs to regulate blood flow provides the perfect inspiration to regulate the distribution of water within the site.

3.4 Developing the system

The system that has been developed is a combination of features of the water vole burrow; elephant foot plant and giraffe neck. The next stage was to show how these specific strategies would work together to provide the Ecological Industrial Park with a closed-loop water management system better than products and processes already on the market.

By mimicking the reverse of a water vole burrow it should be possible to increase the capacity of the water flow significantly by designing pipes with chambers running off to the sides. This would have the beneficial effect of storage for large levels of storm water running onto the site.

The elephant foot plant collects and stores water through the roots structure in times of plentiful water supply in the semiarid deserts where the plant is found. With standing water posing potential hazards from both bacteria and insects, having a flexible storage system that expands and contracts dependent on water levels, potentially minimizes these risks. The *Discorea elephantipes* has a water capacity of 97% in its fibrous tubers (Eggli & Nyffeler, 2009).

Giraffe neck veins are complex systems that regulate blood flow throughout the neck ensuring that this fluid does not cause damage to the heart and brain whilst the giraffe lowers and raises it head. Mitchell et al (2009) studied the necks of numerous giraffes and found them to contain both bicuspid and tricuspid valves. Their findings state that there is a low correlation coefficient between the length and number of valves, but the spacing of the valves is important. Specifically, this relates to controlling the flow near the head and the heart. By extracting this research, into the design of a distribution pipeline, it will be important to ensure that valves are positioned near the connection with elephant foot plant system and the outlet. This will ensure that the water capacity is managed most effectively.

A riparian habitat is the interface between land and stream habitats. These are important natural bio-filters, protecting aquatic environments from excessive sedimentation, polluted surface runoff and erosion. They are characterized by hydrophilic plants which are a natural means of mitigating fluvial flooding by slowing and absorbing excess water. In this project, reintroducing the planting of white willow (salix alba), abundant both up and downstream, will not only relieve the pressure on the vole/elephant foot/giraffe system, but provide bank stability for the de-culverted river.

3.5 Systems

The key to the development of these solutions will be linking the unrelated organisms into a system. Each of the organisms has a key function and achieves the goals set out within the challenges, to capture, store and distribute fluids. These elements will be working together to meet the challenge of creating an industrial development site that manages fluids, in this case water, to minimize the residual effects on site and also secondary effects downstream.

4.0 Conclusions and Recommendations

In biological cases, there are millions of contributors to the system, no unemployment and numerous opportunities for nature's equivalent of entrepreneurship – species that evolve into a wide variety of ecological niches (Pawyln 2011, 54).

This case study looks beyond biomimicry at the single entity-level and develops an understanding of the how that tool can also reflect the genius of natural systems or partial systems. A system is characterized by the presence of elements (parts), effects of said elements on other portions of the system, and the existence of an effect not otherwise present which exists over time. Open-loop systems, the most common type, are governed by what Biomimicry 3.8 terms Earths' Operating Conditions.

The study is an example of a biomimetic unrelated systems model being used to manage water within a specific site. The 'Biomimetic System Relations Model' defined by Farnsworth includes Intra-, Adjacent, Unrelated and Whole systems or ecosystems. By defining the functions and system boundaries needed for the solution pathway, the appropriate biomimetic relations model can be selected; thus simplifying somewhat, the very complex array of choices found in nature.

For this study, the goal of minimizing negative effects of storm water to a potential industrial development site and accompanying ecosystems by capturing, storing and distributing water was identified. By focusing on these functions, a site analysis revealed opportunities to apply the unrelated systems model by abstracting water capture strategies of the European Vole burrow design and combining that with the storage capabilities of the Elephant Foot plant and the distribution and flow regulation found in the neck of a Giraffe. The components of this system were designed to work in conjunction with the local riparian habitat. Although two of the organisms are not found in the case study site biome, combining the successful strategies of organisms from the local biome, semi-arid desert and savanna provided designers with a more effective solution. These three organisms and the riparian habitat form an unrelated system with great potential for optimizing storm water management on site.

Integrating biomimicry with a systems approach offers greater challenges, but it does allow for observation and implementation of more varied strategies and interconnectivity to replicate “The Circle of Life”. It has the potential to offer insights and benefits by using both across a range of professional disciplines. This methodology will make connections within and between organisms as well as across ecosystems and between unrelated ones - underscoring that Life’s Principles are not isolated but also interconnected systemically.

In this research, MacCowan and his team examined a number of organisms and ecosystems related and unrelated, to find solutions to the water challenge. More detailed research is needed to develop this project further and take the systems-thinking approach to each business sector from transport management and the business office, to the supply and distribution of resources and energy.

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