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Bio-Inspired Design: What Can We Learn from Nature?

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Bio-inspired design, as it will be developed in this essay, draws heavily on E.O. Wilson's concept of biophilia and related work in environmental aesthetics. There are other valuable approaches to bio-inspired design, particularly those stemming from a consideration of the functions and processes of nature as so eloquently described by Janine Benyus in *Biomimicry*. My focus here, in contrast, is on the forms and sensory attributes of nature that hold special psychological significance.

Wilson defined biophilia as "the tendency to focus on life and life-like processes." This fascination with life propels scientific inquiry as well as our aesthetic sensitivities. Wilson and others argue that because the brain evolved in a biocentric world, we should be especially tuned to features and attributes of nature that have had consequences for survival and reproductive success. As Steven Pinker writes in *How the Mind Works*: "The brain strives to put its owner in circumstances like those that caused its ancestors to reproduce." As well, the brain strives to avoid circumstances that reduce the chances of survival and reproduction. Thus, our minds have evolved both to seek out beneficial! ! ! places and things and to avoid the harmful. This includes living organisms as well as the natural processes that sustain life (especially light, water, and fire).

Understanding what it is about nature that attracts or repels is at the core of bio-inspired design, as developed in this essay. Although we tend to equate design with the sense of pleasure and enjoyment, design also must confront hazards and dangers in the environment in ways that intuitively evoke avoidance behaviors. Mr. Yuk stickers are used to warn about harmful substances, just as smiling faces are used to convey pleasure with a desirable object. It is this link to emotions that we need to better understand, because design strives to evoke particular kind of emotional experiences, either as ends in themselves or as motivations for other behaviors, such as consumption, entertainment, and avoidance of hazards.

Bio-inspired design is relevant to a wide array of applications – including places (communities, landscapes, buildings, rooms), toys, furnishings, tools, technologies, and vehicles. There are obvious connections between bio-inspired design, Kansei engineering, and emotion centered design, all of which aim to connect emotional experience more explicitly to the sensory and perceptual qualities of spaces and products.

Bio-inspired Place Design.

For most organisms, being in “the right place” is an important determinant of survival and well-being. There is no reason why this should be different for humans. The central adaptive pressures facing all animals, including humans, are protection from hazards (both animate and inanimate) and access to high quality resources and spaces.

Positive affective states of interest and pleasure, associated with preference, signal that an environment is likely to provide resources and supports that promote survival and well being, while negative affective states serve as warnings of potential harm or discomforts.

Drawing on habitat selection theory, ecologist Gordon Orians argues that humans are psychologically adapted to landscape features that characterized the African savannah, the presumed site of human evolution. Although humans now live in many different habitats, our species long history as mobile hunters and gatherers on the African savannahs should have left its mark on our psyche. If the “savannah hypothesis” is true, we would expect to find that humans intrinsically like and find pleasurable environments that contain key features of the savannah that were most likely to have aided our ancestors’ survival and well being. These features include:

- A high diversity of plant (especially flowers) and animal life for food and resources.
- Clustered trees with spreading canopies for refuge and protection.
- Open grassland that provides easy movement and clear views to the distance.
- Topographic changes for strategic surveillance to aid long distance movements and to provide early warning of approaching hazards.
- Scattered bodies of water for food, drinking, bathing, and pleasure.
- A “big sky” with a wide, bright field of view to aid visual access in all directions.

Savannah “mimics” are obvious in many of our modern built spaces including shopping malls, department stores, golf courses, and parks. Research on the design of retail settings shows how the manipulation of space and artifacts influences purchasing behaviors. Many of these manipulations -- light, décor, sounds, food, flowers, smells, visual corridors -- are consistent with the savannah hypothesis and other research on environmental preferences.

Geographer Jay Appleton independently developed a prospect-refuge theory of landscape preferences that is closely related to the savannah hypothesis. Appleton argues that people prefer to be in places where they have good visual access to the surrounding environment (high prospect), while also feeling protected and safe (high refuge). Conversely, high negative reactions are expected when one can be seen without the ability to see into the environment. An overview of research on children’s environments by Heerwagen and Orians (in *Children and Nature*, MIT Press cited below) shows strong ties between spatial qualities of children’s environments, especially the provision of prospect and refuge features, and play behaviors. Young children are more likely to engage in creative play in refuge-rich environments that afford the protection and safety necessary for imaginative exploration. Natural settings also provide a rich array of artifacts that serve as pretend play props.

Architectural historian Grant Hildebrand argues that the manipulation of prospect and refuge and the integration of nature and naturalistic features is a hallmark of many buildings of enduring appeal. Although Hildebrand did not gather any empirical data, others have, including a study by Suzanne Scott of interior environments. She found that built spaces with nature, moderate degrees of complexity, and a sense of refuge coupled with high prospect were more preferred than spaces lacking these characteristics. People especially liked spaces with vertical and horizontal expansiveness that were subdivided into smaller zones. Scott suggests that zoned spaces provide users with the potential to survey the surroundings, but still enjoy partial concealment. Many of the preferred settings also had soft, rounded forms and irregular layouts. Institutional spaces with minimum décor and embellishments were especially disliked, as were vast empty spaces.

Nature is not always benign, however. The natural world is rife with hazards that create fear and anxiety. These include animal fears (especially snakes and spiders) as well as environmental anxieties (darkness, enclosed spaces, heights, loud noises, storms, being in the open without protective cover and being alone in a strange place). Horror movies and fun houses do a masterful job at manipulating emotions through the design of space and the introduction of hazards.

Health Impacts of Connection to Nature

Studies by Roger Ulrich have consistently found that passive viewing of non-threatening nature stimuli through windows, videos, or photographs reduces the physiological indicators of stress and increases positive moods. Rachel Kaplan reports similar results in a field study of office workers. Kaplan found that workers who had window views of nature felt less frustrated and more patient, and reported more overall life satisfaction and better health than workers who did not have visual access to the outdoors or whose view consisted of built elements only. Russ Parsons suggests that positive effects of nature may extend to the immune system, thereby directly affecting human physical health. In keeping with these findings, research also shows that people working in windowless environments decorate their rooms with more nature pictures and décor than people in windowed spaces, perhaps as a way to enhance their psychological comfort.

Our evolved responses to landscapes are also apparent in the design of video games for children. Video games feature places, stimuli and events with strong roots in our evolutionary past – predators, prey, ominous strangers, natural hazards, scary places, poisonous foods, and a safe home base. Researchers have also found that the most appealing games have a cluster of motivating features, including dynamic visual imagery, randomness, action, dynamic hazards, spatial and visual complexity, audio effects, and interactivity. These aspects of nature will be addressed in the final section of this essay. But first, I turn to another natural element that is fundamental to life on earth and which plays a strong role in our response to the environment – sunlight and the diurnal change in light.

Bio-inspired Lighting Design.

The strong preference for nature extends to daylight and views to the outdoors. Research on windowless spaces shows that people complain most about the loss of daylight and not

having access to time and weather data. Why should people care about these losses when we have clocks, radios, and other technologies that can provide instantaneous time and weather information?

To understand the psychological relevance of daylight in modern built environments it is useful to consider how natural light aided adaptive behavior in ancestral habitats. The high, consistent preference for daylight and views suggests that evolutionary pressures are likely to be influencing our responses. Although all of our sensory systems acting together were important to survival, the visual system is our primary mode of gathering information. Thus, light must have played a powerful role in information processing. In ancestral environments, light was likely to have had several key functions that are relevant today. These include:

- *Object identification.* Light provides information about color, shape, edges, and distance of objects in the environment and thus aids in detection and movement. Sunlight is especially good at providing contrast and edge information. Light bouncing off of water, creating a sparkle effect, is also highly attractive and may be associated with water quality.
- *Indicator of time.* Natural light changes significantly over the course of the day, providing a signal of time that was crucial to survival throughout human history. Being in a safe place when the sun was setting was not a trivial matter for our ancestors, and it is still important to human well-being.
- *Indicator of weather.* Light also changes with weather, from the dark, ominous color of storms to rainbows and beams of light as clouds break up and recede. Attending to the variability in light and its relationship to changes in weather would have been highly adaptive.
- *Signal of prospect and refuge.* The sense of prospect is signaled by distant brightness and refuge is signaled by shadow. Brightness in the distance aids assessment and planning because it allows for information to be perceived in sufficient time for action to be taken. As noted previously, high prospect environments include open views to the horizon and a luminous sky ("big sky"). A sense of refuge is provided by shadows from tree canopies, cliff overhangs, or other natural forms. Judith Mottram and other researchers suggest that allowing the eyes to rest on infinity (which the horizon represents visually) may be beneficial, even if the view is perceptually manipulated through visual images rather than actual distant views. Thus, our natural attraction to the horizon could be satisfied in many ways through the manipulation of imagery applied to vertical surfaces which is what Mottram did with textile design.
- *Signal of safety, warmth, and comfort.* Although we usually think of the sun as the primary source of light in the natural environment, fire also served as a source of light and comfort, both physical and psychological. Anthropologist and physician Melvin Konner suggests that the campfire served important cognitive and social functions in developing human societies. The campfire extended the day, allowing for people to focus their attention not on the daily grind of finding food and avoiding predators but on thinking about the future, planning ahead, and cementing social relationships through story telling and sharing the day's experiences.

- *Peripheral processing aid.* Light also provides information about what is happening beyond the immediate space one occupies. It illuminates the surrounding environment that impinges continually on our peripheral processing system. The importance of peripheral light is evident from the discomfort many people feel when they are in a lighted space with low lighting at the edges, leading to a perception of gloom. Lighting researchers suggest that negative responses to gloom may be associated with its natural function as an early warning signal that visual conditions are deteriorating.
- *Synchronization of bio and social rhythms.* As a diurnal species, light plays a critical role in our sleep-wake cycles and it also synchronizes social activities. Although we can now alter our activity cycle with the use of electric light, research evidence nonetheless shows that night work is still difficult and often results in drowsiness, difficulty sleeping, mood disturbances, and increased cognitive difficulties at work. Some night work facilities are using bright interior light to shift biological rhythms and increase alertness. There is also evidence that people who experience seasonally-related depression prefer to be ! ! ! in brightly lighted spaces.

To summarize, light provides information for orientation, safety and surveillance, interpretation of social signals, identification of resources, and awareness of hazards. Whether it is the changing color of light associated with sunset or storms, the movement of fire or lightening, the brightness in the distance that aids planning and movement, or the sparkle of light off of water – all of these aspects of light have played a role in helping our ancestors make decisions about where to go, how to move through the environment, what to eat, and how to avoid dangers.

High quality lighting, especially when it is intended to evoke a sense of place and positive mood, draws intuitively on these features of natural light. Yet many places regularly occupied by people do not benefit from high quality lighting. Offices, hospitals, and schools are often blandly lighted, with many spaces devoid of windows and outdoor contact. It is worth asking whether electrical light design or more creative daylighting design can overcome the deficiencies of our current building interiors.

General Features of Nature as Candidates for Bio-Inspired Design

The previous sections of this essay deal primarily with design inspired by preferred landscape settings. Other features and attributes of nature also have much to offer for design. What might these features be?

Although there is less research evidence on this topic, it is reasonable to look for general characteristics of living organisms and life-like processes that could form the basis for bio-inspired design. These include, but are not limited to:

- *Movement.* Movement is characteristic of all living organisms as well as life supporting systems, such as the sun, clouds, fire, and water. Movement may be self generated or aided (for instance, by the wind, water, or by attachment to a moving organism). Aaron Katcher hypothesizes that certain kinds of movement patterns may be associated with safety and tranquility, while others indicate danger. Movement patterns associated with safety show “heraclitean” motion that is “always changing, yet always saying the same.”

Examples are aquarium fish or the pattern of light and shade created by cumulus clouds. In contrast, movement patterns indicative of danger show erratic movement and sudden change, such as changes in light and wind associated with storms, or birds fleeing from a hawk

- *Growth and development.* As a result of reproductive processes, all living organisms exhibit patterns of development that unfold over time from some simpler form to a more complex one. Some life-like processes, such as storms and the diurnal cycle of light, also may be said to show developmental sequences. Many sustainable design strategies are beginning to incorporate developmental thinking, with an emphasis on how products are created and then returned at the end of their “life” as useful input into another product.
- *Complexity.* All living organisms and life-like processes display complex design or adaptive complexity that may not be apparent at first glance, but which is discovered through sensory exploration. The desire to know more about a space or object with increased exploration is considered by many to be at the heart of learning: the more you know, the more you want to know and the deeper the mystery becomes. In contrast to living forms and spaces, most built objects and spaces are readily knowable at first glance, and thus do not motivate learning and exploration. Although complexity is a desirable feature, spaces and objects that are too complex are difficult to comprehend. The key may be the combination of ordering and complexity that allows comprehension at higher levels first and then at lower levels with successive exploration. In *Origins of Architectural Pleasure*, architect Grant Hildebrand provides extensive commentary on this topic.
- *Fractal patterning.* Fractal growth processes and probabilistic events determine the forms and patterns of living organisms, systems, and natural processes. This gives rise to patterns that have a basic similarity at different levels of scale, but are not exact replicates. Some refer to this as “rhyming” – similarity coupled with difference. In contrast, many human designed patterns are exact repeats of the same form, perhaps in different colors or sizes. Peter Stevens, in *Patterns in Nature*, provides a masterful overview of the archetypal patterns and themes that underlie the immense variety of natural forms.
- *Organic shapes.* Nature is not rectilinear. The shapes of natural objects are determined by fractal growth patterns, as noted above, and by the limitations imposed by the conditions of life on earth, especially sunlight and gravity. Although there is not a great deal of research on this topic, there is some indication that people respond positively to organic shapes and curvilinear spaces in buildings, landscapes, and artifacts.
- *Multi sensory.* Living organisms are sensory rich and convey information to all human sensory systems, including sight, sound, touch, taste, and odor. Life supporting processes such as fire, water, and sun also are experienced in multi sensory ways. Although the vast majority of research in environmental aesthetics focuses on the visual environment, there is growing interest in understanding how design appeals to multiple senses. Both Kansei engineering and emotion centered design are grounded in links between sensory perception and emotional responses to artifacts and to specific features of products.
- *Abstract informational characters.* Stephen and Rachel Kaplan have written extensively on the visual qualities of environments that have high psychological appeal and which,

they argue, are fundamental to information processing. Two of these qualities (coherence and legibility) aid environmental understanding, and two aid exploration (complexity and mystery). Decades of work by the Kaplans and their students have shown these qualities to be robust in predicting preference patterns. Although their findings have been applied primarily to landscapes, they may be fundamental to many other designed spaces and even products.

There is much still to learn about bio-inspired design. There are many approaches and processes and many topics not discussed here. The perspective provided in this essay draws on evolutionary psychology and habitability theory, the special provinces of this author. Those interested in the ideas presented here can find further details in the articles and books listed below.

There is much more to be provided by others from diverse backgrounds and interests. Let the discussion and debate begin.

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Dr. Heerwagen is psychologist whose research and writing focus on habitability theory, workplace ecology and the human factors of sustainable design. She has written and conducted research on environmental aesthetics with Dr. Gordon Orians, an ecologist at the University of Washington. She has a BS in Communications from the University of Illinois (Champaign-Urbana) and a Ph.D. in Psychology from the University of Washington focusing on behavioral ecology and decision making. She currently has her own research and consulting business in Seattle. Her consulting work centers on the psychological and social aspects of work and their links to environmental design. Prior to starting her own business, she was senior research scientist at the Pacific Northwest National Laboratory and a principal with Space, LLC. From 1982 to 1992, she was a research faculty member at the University of Washington, College of Architecture and Urban Planning. Dr. Heerwagen has been an invited participant at a number of national meetings on workplace productivity sponsored by the National Academy of Sciences, the General Services Administration, and the American Institute of Architects.

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