Tropical Ecologies: Biomimicry as a Generator for Climate-Responsive Architectural Design

This research project into bio-mimetic climate-responsive architectural design was initiated with an interdisciplinary workshop in Nosara, Costa Rica. Workshop participants included a tropical ecologist and a local Costa Rican architect. The following text presents the research hypothesis and preliminary findings from the workshop.

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INTRODUCTION

In 1971 architect Malcolm Wells put forth the “Absolutely Constant Incontestably Stable Architectural Value Scale.”[1] He was proposing that each building’s environmental performance should be compared against the regenerative capabilities of the wilderness that existed in a particular place prior to human development. This was a radical proposition in the 70s and even today not many buildings would stand up against such a rigorous environmental benchmarking system.[2] However, what is intriguing about Wells’s idea is that it introduces the concepts of regeneration and restoration (i.e., *How to have a positive impact?*) into the sustainability discussion, which to date is dominated by questions of conservation and efficiency (i.e., *How to lessen the negative impact?*). Inspiration for a regenerative approach to design can be found by studying the very thing we are trying to protect—our habitat, the biological ecosystems that surround us.

Plants and animals, over millions of years have developed and perfected adaptation strategies for specific environmental conditions, using renewable energy from the sun while producing no pollution or waste.

In 1997 science writer Janine Benyus coined the term *Biomimicry,3* a new discipline that analyzes nature’s best ideas and adapts them for human use—such as weaving fibers like a spider or gathering energy like a leaf. While many bio-mimetic innovations to date can be found in engineering and material science, architecture has been preoccupied with nature primarily as a source of formal inspiration. In order to arrive at a more performance-based understanding of the architecture/nature relationship, my research

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Figure 1: Top: Dry tropical forest landscape during rainy season, and bottom: dry season

Figure 2: Top: Hacienda La Casona, Santa Rosa National Park—View of courtyard,and bottom: screened ventilation openings

focuses on Biomimicry's potential to inspire climate responsive architectural design strategies. In other words: What can architects learn from natural organisms that have developed extraordinary adaptations to resource-constrained environments (e.g., extreme climatic conditions) and how can this knowledge be used to design buildings that are similarly well adapted, and as a result use a minimal amount of resources? Important is the focus on the local: the potential of the *local* ecosystem to inform a *locally specific* architectural expression—a bio-mimetic architectural regionalism of sorts.

THE LOCAL ECOSYSTEM

The specific ecosystem I am studying is the tropical dry forest (TDF) of Mesoamerica, a unique and extremely rare ecosystem, of which the largest remnants exist in the Area de Conservación Guanacaste (ACG) in Northern Costa Rica. [4] TDF is an ecosystem with extreme seasonal climate variations—it turns from a lush green forest during the rainy season to a leafless desert in the dry season. Although not as species-diverse as tropical rain forest, TDF contains a higher diversity of functional forms than other tropical forest types. The seasonal droughts have great impact on all living things in the forest and many of the characteristic plant and animal species show complex adaptations in their systems of water storage, water conservation, resource capture, and growth form that allow them to persist in this challenging environment. The TDF therefore constitutes an ideal testing ground for finding bio-mimetic solutions to climate responsive architectural design. Furthermore, the remaining TDF in Costa Rica outside of ACG's boundaries is highly threatened by agriculture and tourism[5] and is therefore ideal for a study of alternative architectural practices in Costa Rica, helping to find a balance between human development and the need for conservation and restoration of the existing ecosystem.

COLONIAL ARCHITECTURE TYPOLOGIES

Hacienda La Casona, Santa Rosa National Park—View of courtyard (left) and screened ventilation openings (right)

The drastic seasonal variations in rainfall, solar radiation, and humidity have greatly influenced vernacular and colonial architectural typologies. Just as the local climate can be understood as a seasonal hybrid between the hot-arid and hot-humid climate zones, so does the colonial typology of the region display climate adaptation strategies common to both climate zones. For example La Casona, a historic hacienda building in Santa Rosa National Park has massive solid walls, a heavy terra cotta roof, and is organized around an interior courtyard, just like what one would expect from a building in the desert. On the other hand is has long roof overhangs, exterior shaded walkways, and an intricate system of wood-screened ventilation openings, all passive strategies typically employed in hot humid climates.

FIELD SITE

The field site for the project, a 42-acre property in Ostional, is a very typical stand of remnant TDF surrounded by ecologically degraded agricultural lands. The site is currently undeveloped and representative of many such small properties in Costa Rica's Pacific Northwest. The land owner is supporting the research project by granting unlimited access to the property for analysis and research purposes.

METHODOLOGY

Initially two extensive site visits were conducted: one of the field site, the other of a nearby protected wildland where the full range of dry forest organisms could be observed in their natural habitat. We decided to limit our initial investigation to the study of plants (as opposed to animals or other organisms), because the majority of plants share two fundamental principals with architecture: the inability to move and the resulting necessity to optimize locally available resources. Furthermore we focused our observations on the two most critical adaptations to this particular climate: thermal control and water management.

THERMAL CONTROL: COMPOUND LEAVES AND SELF-SHADING TREE TRUNKS

Many tree species in the TDF have compound leaves (as opposed to single leaves). The leaflets of a compound leaf are able to move independently of one another, which reduces the size of the boundary layer of air formed on the surface of the leaf. A thick boundary layer can reduce convective cooling and raise temperatures on the leaf surface. High temperatures at the leaf surface can lead to photoinhibition, which reduces the efficiency of plant photosynthesis.

While a literal translation of this strategy (independent movement of individual architectural elements) may prove neither feasible nor particularly interesting, it is the underlying principle (subdivision and geometric differentiation of large surface areas to increase convective cooling) that holds promise as an architectural application. The temperature differential between the different surfaces of a staggered roofscape may induce air movement and thus convective cooling. The principle could also be applied on a much smaller scale, for example as the micro-texture of a cladding material, bringing up the question of scale shift when translating biological analogies into architecture.

The trunks of trees such as the Madroño negro (guettarda macrosperma) employ a similar strategy: its deep ribs running up and down the trunk are part of an ingenious self-shading strategy while the temperature differential between areas exposed to sun and those in shadow induces convective cooling.

WATER MANAGEMENT

The lack of water during the dry season is the most defining feature of the TDF ecosystem. Even though the area receives over 70 inches of annual rainfall, effectively all of it happens between May and November, creating lush and humid conditions that are in stark contrast with what is essentially a seasonal desert between December and April.[6]

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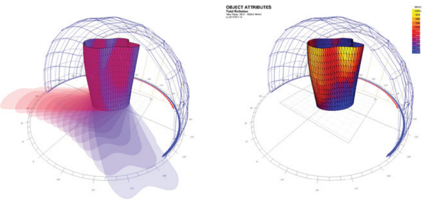

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Figure 3: Top: Compound leaves of carao (cassia grandis). Bottom: Trunk of Madroño negro tree (guettarda macrosperma)

Figure 4: Principle of self-shading: Ecotect analysis model of shading and solar radiation

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Figure 5: Top: Photosynthetic bark of Indio desnudo (bursera simaruba). Bottom: Epiphytic bromeliad on tree trunk

DECIDUOUS TREES

Many plant species in the TDF are deciduous, shedding their leaves during the dry season to reduce water loss through transpiration. Some of these species, such as Indio desnudo (bursera simaruba) have green bark, capable of photosynthesizing even without leaves. What could be the lesson here for architecture?

Again, rather than looking for a literal translation, it is the principle of a total transformation in order to optimize for each of the two seasonal conditions. La Casona, the above-mentioned colonial building, employs a hybrid but ultimately static climate response strategy. What if a building could seasonally transform from a pure desert typology in the dry season to a hot humid one in the rain season? Instead of relying on heavy masonry and small openings for thermal mass —desirable in the dry season but counterproductive in the rainy season—a system of movable lightweight exterior-phase, change material (PCM) wall-panels could be imagined to “switch” on and off thermal mass of the envelope while also controlling the amount of desired cross ventilation.

WATER CAPTURE AND STORAGE

In many bromeliads and other plants, leaves are arranged in a rosette shape. The point of central attachment of these leaves is often modified into a water storage device. In larger examples, known as tank bromeliads, these cisterns may contain entire ecosystems, which help make nutrients more accessible to the plant.[7] Some bromeliads observed on our field site were epiphytic, which means they are growing non-parasitically on trees and derive their moisture and nutrients only out of the air, rain and surface run-off from the host tree’s surface. To abandon soil roots as a source of water and nutrient flow is quite a daring proposition in this climate! Epiphytic bromeliads remind us that even in this seasonally water-deprived climate it may be possible to satisfy our water supply by rainwater alone without having to resort to drilling wells. The sophisticated geometric logic of the bromeliad with its radial V-shaped leaves and central cistern may hold promise as a site planning strategy for rain-water catchment, distribution, and storage.

NEXT STEPS

These findings present only a portion of the bio-mimetic strategies we explored, and the architectural applications at this point are necessarily speculative and preliminary. The ongoing research will further investigate biological climate adaptation strategies for their architectural potential, develop and test passive architectural strategies for site planning, resource capture, and envelope systems. ◆

ENDNOTES

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