A Field Guide to Generating Architectural Species

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The question posed by this session topic, of how architecture may begin to draw from the tools, techniques, and concepts of ecology, is of critical importance to the future of our discipline. Examining the overlaps between these two fields in an effort to extract useful insights from the rapidly developing science of ecology and put these to work in the context of architecture in a meaningful way, going beyond mere metaphor, will require a clear understanding of the levels of organization with which ecology is concerned. The science of ecology is a relatively young field and, like the discipline of architecture, has experienced rapid growth in recent years with the development of sophisticated computational techniques, specifically in the area of theoretical ecology. While it is tempting to apply the metaphor of an ecosystem as a complex set of interacting components and feedbacks directly into the realm of architecture, it may be even more productive to examine the specific mechanisms that ecologists study at various scales and levels of organization and ask what parallels may exist in architecture and urbanism. Both architecture and ecology are concerned with the articulation of form, structure, and pattern emerging at multiple scales in response to environmental conditions.

We may begin by asking, why has ecology suddenly become such a fertile area of inquiry for architects in recent years? Certainly, the easy answer is to draw the obvious connection between the now omnipresent concern with sustainability in the built environment, and a simplistic understanding of the field of ecology, as one that is primarily concerned with conservation of the Earth's natural systems. However, ecology is in fact a quantitative science concerned with the myriad interactions between organisms and their environment, which uses a well-developed arsenal of theoretical models in conjunction with experimental studies at multiple scales to understand these complex interactions. A more useful and productive understanding of the connections between these two diverse fields requires us to abstract things a bit, and understand both ecology and architecture as disciplines that are primarily concerned with problems of pattern, scale and complexity, and with comprehending complex interactions of material and energy that operate across many nested levels of organization. In combination with advances in computational power and an increasingly sophisticated understanding of complex systems, architects have begun to mine the field of ecology in all its manifestations for useful metaphors, mechanisms, processes, and tools. In the following paper, I will explore a handful of concepts drawn from the science of ecology that may be useful for further speculating on the increasingly productive overlap between these two disciplines.

In 1989, on the occasion of his receipt of the MacArthur Award, theoretical ecologist Simon Levin published a paper entitled "The Problem of Pattern and Scale in Ecology" (1). The themes discussed in this article represented some of the fundamental questions confronting the field of ecology at that point, and many of these remain to this day important areas of inquiry. Generally, Levin discussed the problem of scaling up from observations of behaviors or phenomena at one scale to the outcomes that these interactions produce at higher levels. A key factor in understanding these dynamics is to ascertain how information is transferred from one scale to the next, and how large-scale patterns feedback upon and inform local interactions. Understanding the emergent properties of dynamic systems is of great interest to a number of fields, of which architecture and ecology are two examples, but there are certain overlaps between these two areas that make them more relevant to one another than might first be apparent. The complex systems studied by ecologists may be more productive for architecture than, say, purely physical systems which may exhibit similar properties, due to the inherent agency embedded in ecological interactions. New methods of architectural production enabled by computation have endowed architecture, too, with myriad degrees of agency. No longer is architecture a process of sculpting inert matter, but for a growing number of practitioners it has become an exercise in designing responsive and robust systems that are imbued with a set of behaviors specified by their designers and set into motion. The question of agency has risen to the forefront of the discussion, and the designer occupies a distinctly different role in these new modes of production. Agency is now distributed throughout a project, and the role of the designer is as much about assigning this agency to various elements than anything. Systems of interacting components behave fundamentally differently when individuals possess some internal motivation, and are no longer simply responding to external forces. The systems being deployed by practitioners working with agent-based models are thus fundamentally different from earlier digital modes of production that simulated physical forces to deform a surface or vector field, and are also distinct from parametric systems which have a fixed number of possible outcomes. Designers working with generative self-organizing systems require a set of tools and a language for dealing with the outcomes of their design experiments. The discipline of ecology offers an extraordinarily useful framework for understanding these complex interactions because of the multiple levels of nested organization with which it is concerned. In his paper, Levin described every organism as an "observer" of its environment, each operating according to its own spatial and temporal logic. Strategies such as seed dispersal or dormancy may alter the spatial scale that an organism effectively occupies. The process of defining which entities within an architectural project play the role of the observer, and at what spatial and temporal scales these agents observe and operate on their environment, will become more and more important as agent-based design methodologies continue to mature and develop.

NICHE THEORY

The theory of the niche is one of the fundamental concepts of modern ecology. Generally described as the role a species plays in a given ecological community, the concept has undergone several distinct understandings. First described by Joseph Grinnell in 1917, the original sense of the term referred to the specific set of habitat conditions within which an organism was typically found. As a linguistic construct, we may even trace the connection between architecture and ecology under discussion here back to this initial deployment of an architectural metaphor designating the position of a species as a "recess." This definition allowed for the existence of "empty niches" within a community. Later, Charles Elton refined the working definition of the niche to indicate the role that an organism plays. This definition persists as the "recess-role" niche. Competition between species is one of the most fundamental mechanisms in ecology, and one of the primary concerns of niche theory. These early concepts of the niche were supported by the competitive exclusion principle, which states that two species cannot coexist when competing for the same resource, but one species will always win out. In a series of well-known experiments, Georgy Gause demonstrated this by pitting two species of paramecia against one another. When competing for the same resource, one species always won out as the competitive dominant.

However, while this principle is apparent in highly controlled laboratory settings, it is difficult to identify in the natural world. In recognition of this conundrum, G. Evelyn Hutchinson published a paper in 1959 entitled "*Homage to Santa Rosalia, or Why Are There So Many Different Kinds of Animals?"* (2). In this lecture, he outlined his revised conception of the niche, as an n-dimensional hypervolume.

Each axis of this hypothetical volume represents some quantity such as temperature or food size, and the area contained within the volume, or the "niche space" indicates the range of those quantities within which a species can survive. This approach went a great deal further in explaining the rich diversity of forms in nature, as it allowed for the differentiation of resource use according to qualities such as food size, as opposed to the relatively limited number of species that would be predicted by the competitive exclusion principle. In the context of architecture, such a framework may be useful in imagining how we might begin to generate a wide diversity of forms and entities. Hutchinson's concept of the niche would be further refined by MacArthur and Levins in 1967, who proposed the Resource-Utilization niche, focusing on a few critical niche axes instead of the practically infinite variety allowed by Hutchinson. MacArthur and Levins's framework also allowed for the identification of points of limiting similarity, where species became too similar to coexist, and demonstrated the possibility of convergence and divergence of coexisting species. When we consider the breeding and cultivation of new architectural species through the use of evolutionary algorithms, identifying such points of limiting similarity may prove useful in determining what differentiates the novel architectural species that inhabit the synthetic ecologies we develop.

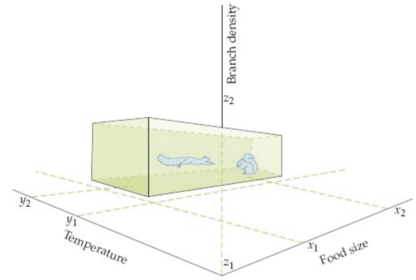

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Figure 1: Hutchinsonian niche in 3 dimensions, from (7).

As in ecology, the concept of the niche as a driver of architectural production may be understood in several ways, but Hutchinson's description of the n-dimensional hypervolume seems relevant to any discussion of niche space in architecture. Just as individual species evolve a suite of adaptations in both physiology and behavior to thrive under a specific set of environmental conditions, so too must any architectural intervention respond to its local environment. Thus, at the scale of the building, the typical concerns of sustainable design such as solar radiation, outside temperature, precipitation, and water availability would all seem to be easy starting points as potential niche axes in selecting for massing and large-scale building forms that are responsive to local climatic conditions. An ecological redefinition of architecture, while not confined merely to concerns with sustainability, would nevertheless certainly build from these as an initial framework. This is merely a recognition that environmental factors shape the development of morphology and behavior at all scales. However, environmental factors alone do not determine the plethora of forms and organizations found in nature, and thus designers may begin to articulate a whole slew of additional niche axes. The niche concept may also be useful at smaller scales, integrated into the design process at earlier stages as designers evolve a series of species that compete for some resource and begin to differentiate into a number of forms, each specializing on one particular invented resource. The process of designing with evolutionary algorithms is still in its infancy, but will begin to take on a more significant role as designers working with agent-based generative tools seek to differentiate more and more novel forms, patterns, and organizations. The most productive aspect of agent-based design approaches lies in the ability to invent any number of possible narratives for how and why agents interact with one another, and how these interactions are translated into form.

PARASITISM / MUTUALISM

Ecological concepts need not be deployed only in the service of form generation in architecture. Associations such as parasitism and mutualism offer the potential for reframing power relations between entities that may prove to be useful as well. New, parasitic forms of architecture might serve to disrupt power structures by feeding off of the excess or waste products generated by the powerful. Parasitic architectures may be deployed that are capable of co-evolving with their hosts, receiving some information, and responding in real time. Of course, these are merely speculations but the important point is that, as architecture operates within a distinct sociopolitical milieu, the operational lessons that the discipline draws from the study of ecology may be applied to these forms of relations and interactions as well. Such reframing of power relations through strategies of parasitism may in fact play out at the scale of urbanism more so than in an explicitly architectural context. These strategies are already in use and do not necessarily require the intervention of a designer, as can be seen in the increasingly common practice of stealing electricity from the "host" power grid that occurs in any number of slums around the world. Like these parasitic interventions, strategies of mutualism may also be applied to the power relations mediated by architectural and urban forms. Some of the most well-studied examples of mutualism in nature involve the interactions between Acacia trees and the ants that inhabit them. These ants are provided with shelter in the hollowed-out thorns of the trees as well as food in the form of nectar and specially manufactured protein-rich nodules. In return, the ants provide defense to the plant from herbivores as well as other insects, and even go so far as to clear out new seedlings around the trees that might grow to compete with the Acacias for light and other resources. One could imagine a number of iterations of how such a system might play out architecturally, with some proto-architectural robotic species inhabiting the exterior of some larger structure, and providing services for its host such as cleaning, maintenance or processing of waste products in exchange for the provision of energy and shelter. In a more bucolic version of this type of mutualism, perhaps a plant community could be given a series of nooks on a façade in which to take root, being provided with stored rainwater in return.

SPATIAL PATTERNING AND SELF-ORGANIZATION

Some of the most relevant examples of ecological interactions for architecture take the form of self-organizing processes that form discernible patterns at larger scales. While the rules governing interactions between individuals may be local and relatively simple, the patterns that emerge from these interactions are coherent and legible at much larger spatial scales. Typically, these local interactions take the form of short range activation combined with long range inhibition, as described by Alan Turing in 1951 (3). Positive feedback dominates interactions at short distances, while negative feedback takes over at longer distances. Such patterns can be observed in a number of biological and non-biological systems, from the development of spots and stripes on animals to patterns on seashells. In spatial ecology, as well the interactions between individuals can generate striking patterns at higher levels. An ecological example of one such system involves mussels, which move incrementally across the floor of tidal flats. Individual mussels benefit from aggregating together, decreasing their risk of predation and attaching to one another to prevent being carried away by tidal forces. However, these benefits are outweighed once a certain level of density is reached, beyond which levels of competition between individuals for food particles become too great. Thus when clusters become too large, negative feedback kicks in and some portion of the cluster begins to disperse (4). These types of self-organizing processes underlie systems that display pattern formation at multiple scales, and could be a useful organizing principle for new forms of planning, incorporating self-organized development where individuals cluster together to maximize access to resources such as water or transportation hubs but where the benefits of aggregating cease once a certain level of density is reached.

In addition to merely responding to the local environment, many organisms actively modify their environments as well. While the entire enterprise of architecture is essentially the process of humans modifying their environment in such a way, we might also imagine individual buildings or components taking a more active role in the modification of their local environment. *Wendy*, the recent installation by HWKN at PS1, offers one intriguing possibility for how this type of local environmental modification might occur at an architectural scale, as buildings may begin to actively clean the air in their immediate environment, but we can imagine more and more responsive and active types of

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environmental modification as technology continues to advance and intelligence becomes embedded in increasingly smaller entities. Well known examples of such environmental modification in the natural world include termite mounds and beaver dams, feats of ecosystem engineering that are permanent or semi-permanent, but interesting examples exist of more provisional and temporary constructions as well. Much of what we have discussed so far remains in the realm of design processes, however we might also look to insights from behavioral ecology to speculate on the ways in which an architecture reconceived according to ecological principles might become more open and responsive to its environment, capable of adaptation and reconfiguration.

COOPERATION AND SELF-ASSEMBLAGES

The army ant *Eciton burchellii* represents one of the most striking examples of cooperation found in nature. Living in massive colonies of hundreds of thousands of individuals, these ants are capable of dramatic feats of engineering and coordinated activity, even though each individual is essentially blind. In their daily swarm raids across the rain forest floor, these predatory ants flush out small arthropod prey, forming a complex dendritic trail network by which prey items are returned to their nest site. High levels of traffic flow are maintained along this trail network and highly coherent traffic lanes emerge spontaneously, generated solely through the local interactions between individuals (5). This system was one of the earliest examples of self-organization in nature to be investigated with computational models, in a study from 1991 in which the authors implemented a simplified agent-based model to capture the process of positive feedback that occurs when an individual ant responds to a pheromone deposited by another, and in turn lays down more pheromone, thus reinforcing the trail to a food source (6).

This simple mechanism has powerful consequences, as these repeated interactions can lead to the development of large-scale patterns in the characteristic branching form of the army ant raiding-network. The authors further showed that for different distributions of prey, alternate macro scale patterns would emerge corresponding to the food sources and trail patterns of different species of army ant.

In addition to the compelling self-organized patterns created by their trail networks, and the optimized traffic flow maintained across these networks, *Eciton burchellii* possesses a unique morphological adaptation that allows them to literally form structures out of their own bodies. A set of hook-like claws at the end of each leg allows these ants to join themselves together in various configurations, allowing the ants to quickly construct provisional architectures in response to environmental conditions. While these structures take many forms, two of the most interesting in the context of architecture are bridges and bivouacs. These structures, described as self-assemblages, are dynamic and responsive, and may be considered as a kind of living architecture. The bridges created by army ants are used to cross over gaps in the heterogeneous landscape of the forest floor. They serve to optimize the flow of traffic along the raiding trail, speeding the transport of prey items back to the bivouac, a temporary nest structure.

Figure 2: Network patterns emerging from different prey distributions, from (6).

Figure 3: Army ant bivouac

The truly amazing thing about these bridges is that they are self-regulating, meaning that ants within a bridge can sense the flow of traffic crossing over them, and dismantle a bridge when it is no longer required. At the scale of the entire swarm raid, the numerous bridges along the trail act as a kind of responsive terrain-smoothing system, forming and breaking apart as traffic conditions change. Again, these bridges are entirely self-organizing as individual ants respond to bottlenecks and traffic flow, measured at the local scale by the increasing or decreasing number of contacts from neighbors. This phenomenon has sparked great interest in the field of swarm robotics, and has quite interesting implications for the development of new models of architecture based on the interactions of simple autonomous agents capable of attaching themselves together into larger structures.

Like the bridges created by *E. burchellii,* the bivouac, or temporary nest structure that they inhabit is also formed entirely out of the bodies of individual ants, linked together into long chains which then further link to form curtains, walls, and floors. Perhaps even more impressive because of their sheer size, these structures are highly organized and may consist of hundreds of thousands of individuals.

As a consequence of the sheer quantity of food required to sustain an entire army ant colony, these colonies cannot remain in one fixed nest site but must be nomadic, and so have evolved the capacity for building an entire nest structure out of their own bodies, one which is dismantled and constructed anew in a different site each day when the colony is in its nomadic phase. The architectural implications of such a nomadic, distributed system capable of dismantling and reassembling in different configurations, able to adapt to local site conditions, are profound. In addition to the appealing concept of responsive, self-assembling architectures, we might also draw from the army ant example the concept of a distributed sensing network, wherein components of architectural subsystems may disperse out into the environment, or search across or within portions of a structure in response to human or environmental inputs.

We have described some of the building blocks of ecological systems, the basic interaction rules that determine the distribution and abundance of species, as well as the morphology and function of individuals through the mechanisms of natural selection. The big question, of course, remains: how do we make these concepts operational in the context of architectural production? Clearly there is no simple answer to this question, and numerous strategies will be developed by practitioners in the coming years as tools, techniques, and insights drawn from the study of ecology continue to infiltrate into the design studio. To use these concepts in a productive way in the context of architecture, we need to speculate about what constitutes an architectural species or an individual, what defines a community, and at which scale and what point in the design process we are proposing to incorporate these concepts. Most of the general concepts discussed here are scale independent, allowing architects the luxury of inventing any number of narratives for how such interactions may play out, at scales ranging from the component to the building to the city. ◆

ENDNOTES

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