I n the Chronicle of Higher Education this spring, there was an article about Patrick Dougherty, a sculptor who creates large, outdoor installations from saplings and tree branches (Ingalls 2001). He was pictured with "Paradise Gate," a three-story piece he was constructing at Smith College. It looked very much like the work of an overly ambitious bowerbird. Not only does Dougherty use the building materials that birds use, but also their techniques for weaving the branches together. I thought this sculpture was a perfect way to introduce a column on the relationship between architecture and biology, a subject that has several related aspects. There are a large number of animal builders like the bowerbirds who in some cases create works even more ambitious than Dougherty's—termites and beavers come immediately to mind. Humans are also builders, and in many cases, take their designs from nature; this seems to be happening more these days as architects abandon the straight lines of much modern architecture and move to greater use of organic curves. There is also increasing evidence that our biology influences our architecture, that we have an innate attraction to particular architectural forms. Finally, the term "building biology" can be taken quite literally in the sense of creating buildings to house research facilities and natural history collections. This column provides a quick tour through each of these aspects of the biology-architecture link, and as you will see, each area is receiving attention from biologists and architects today.

**Bird Nests**

I think the best place to start this survey is with those species that are among the most obvious of builders, the birds. Mike Hansell (2000) recently published a book that deals exclusively with bird nests. He was originally interested in insect structures, and he begins with some basics of animal construction in general. Then he discusses how he began to tackle what was for him the new area of the bird nest by working out a classification system based on a few key characteristics including dimensions, shape, site, and method of attachment. Hansell sees the nest as having four zones: the area of attachment, the outer—and perhaps decorative—layer, the structural layer, and the...
lining. From there he goes into an analysis of materials, from the inorganic such as mud, through animal materials such as caterpillar silk, feathers and the mucus of swifts, to plant materials, and finally other substances such as human-made materials like paper that often show up in the nests of birds in urbanized areas.

Hansell then goes on to analyze construction methods, and one of the best pictures in the book shows what is involved in a village weaver (Plceus cucullatus) weaving a single strip of elephant grass into its nest—14 steps in all. The illustrations are one of the strengths of this book, but its excellence also stems from the thoroughness of Hansell's coverage of his subject and the obvious passion he has for it. I can't even begin to mention all that he discusses, but he manages to touch upon everything from the use of snake skin as building material and the many ways nests are camouflaged by decorative material such as lichen, to the many relationships between bird nests and insect colonies. A book that might be a useful companion to Hansell's is Alexander Skutch's (1989) Birds Asleep, which doesn't just deal with nests but obviously discusses them; this is another book that is worth going to for the illustrations.

**Arthropod Building**

Hansell notes that most complex and diverse building behaviors in animals are found in only three classes: the arachnids, insects, and birds. At first I took exception to this sweeping statement, and he does qualify it by saying that there are "a few outbursts of virtuosity with talented displays of skill occurring sporadically across the animal spectrum" (p. 12). His point is that in these three classes building is more than an isolated "outburst"; particularly among birds and spiders, it is the rule rather than the exception. William Shear (1986) has written a great book on spider webs and their evolution. This is a book that made me appreciate the work of the spiders that call our basement home, though I do from time to time have to destroy some of their more elaborate constructions. Now at least I study them for a few minutes before I take the vacuum cleaner to them.

Those other arachnids, the mites, are the subject of a chapter on leaf galls in J. Scott Turner's The Extended Organism (2000). Though I wouldn't call this an easy read, this is the kind of book I love: one that forces me to consider a biological idea that I'd never given any attention. Turner's thesis is that animal-built structures are better viewed as parts of the animals themselves rather than as external to them. He cites Richard Dawkins's (1982) related idea of an extended phenotype, the continuation of the action of genes beyond the boundaries of the organism. Turner wants to consider in more detail how animal-built structures can be seen as organs of physiology, "no different from, and just as much a part of the organism as, the more conventionally defined organs such as kidneys, hearts, lungs, or livers" (p. 2). To make his point, he uses a number of examples, most involving invertebrates. Turner presents his cases in detail and isn't afraid to use math and modeling to support his ideas. This is not the kind of book I would recommend to most of the non-science majors I teach, but it's a great reference to show biology majors how physiology and ecology are related to each other.

As to the mites, Turner examines how alterations in leaf shape with the formation of leaf galls induced by mites or midges, lead to an increase in leaf temperature and thus in the rate of photosynthesis and in the amount of sugar available to the arthropods. In another chapter, he deals with the singing burrows created by mole crickets. The burrow acts as a musical instrument, or what might be considered an extended larynx, with different species producing differently shaped "horns." The cricket sings while building the burrow, so the sounds change as the burrow enlarges and as the cricket "tunes" the structure. For Turner, the burrow "is as much a part of the physiological process of communication as is the cricket's muscles, nervous system, and body" (p. 178). This and all the other examples Turner investigates are fascinating, but I want to mention just one more: the burrowing of lugworms and how the chemical changes the worms produce in the walls of their burrows encourage the growth of bacteria. The microbes are eaten not by the worms, but by diatoms and nematodes that, in turn, are worm food; so the lugworms are making an important change in underground ecology.

**Other Animal Architects**

The influence of animal-built structures on ecosystems is now receiving more attention not only from zoologists like Hansell and physiologists like Turner, but also from ecologists who are investigating a field they call "ecosystem engineering" (Alper 1998). They see organisms as responsible for two distinct types of habitat alternation. In autogenic engineering, the organism, such as a coral, alters the ecosystem by its own growth and is an integral part of that system. In allogetic engineering, the organism alters the environment and then moves on, leaving behind the structures it has built. An obvious example of this is a beaver dam, which may continue to block the flow of a stream long after it's abandoned by its builders. Another example involves not an animal, but a
microorganism, and is a reminder that biological architecture can involve more than just the animal world. In the Negev desert in Israel, there are several bacterial and cyanobacterial species that secrete long-chain sugars that bake in the sun, binding soil and sand together to form a black crust. This protects the damp microbial colonies beneath the crust from desert heat. When it rains, the crust, which is like asphalt, doesn’t absorb water, thus increasing runoff into pits dug by desert porcupines and beetles. Seeds germinate in these pits, forming tiny oases that often shelter a dozen plant species.

It should be obvious by now that the field of animal architecture is much too large to be covered in a brief article; I haven’t even mentioned beehives or bears’ dens. Two of the best surveys of the field were published years ago: Karl von Frisch’s (1975) Animal Architecture and David Hancocks’s (1973) Master Builders of the World. Von Frisch is, of course, the Nobel Prize-winning animal behaviorist and approaches his subject from an evolutionary viewpoint. Hancocks, on the other hand, is an architect who has worked in a number of zoos. As the note on the author states on the book’s cover: “His original intention had been to specialize in housing for people, but he found that the problems of designing for animals—the need to think in terms of basic behavioral requirements—were so challenging and so little studied that he now devotes most of his time to zoological architecture.” His book, however, is not so much about zoos as about what Hancocks has learned about the structures animals create for themselves.

Architects & Biology

Having introduced the subject of human architects, it’s now time to move on to an examination of what these builders have learned from the builders of other species. At the moment, biomorphic forms—curves and blobs—are big in architecture. As a review in The New York Times last year noted, the Venice Biennale’s Seventh International Architecture Exhibition was full of curved shapes (Muschamp 2000). A group of UCLA students designed something called “Embryological House” that looked very much like a large cell filled with vacuole-like spaces. Another group from UCLA was inspired by x-rays of seashells, specimens of animal architecture I haven’t mentioned yet but ones that keep coming up in modern architecture (Ruark 2000). Of course, it isn’t just the youngest architects who look to nature for inspiration; that great architect/engineer Buckminster Fuller, the creator of the geodesic dome, was a lover of beehives and other animal-built structures and was impressed by the frugal use of materials by animal builders (Kenner 1973).

The Barcelona architect Antonio Gaudi was famous for his biomorphic forms, many of which are related to the sinuous forms of turn-of-the-last-century Art Nouveau. The German architect Frei Otto also used biomorphic forms and drew on nature not only for inspiration but for construction techniques. His columns were formed from vertebra-like disks in compression, held in place by muscles and tendons in the form of guylines. Even an architect like Mies van der Rohe was more influenced by nature than his designs might indicate. In the 1950s, he created the quintessential modernist skyscraper, Lever House, on Park Avenue in New York. Like many of his designs, it is essentially a rectangular box with large windows and absolutely no curves; every angle is a right angle. But van der Rohe’s reading indicates that despite his output, natural form was on his mind. In a recent retrospective of his work that was held at the Whitney Museum of American Art in New York, a collection of books from his personal library was displayed, and a number of the volumes, which looked well-used, dealt with form in nature, particularly plant form. He also had several works on evolution.

In The Monumental Impulse: Architecture’s Biological Roots, George Hersey (1999) argues that in architecture and ornament, humans design forms that reflect those found in the body, from the molecular level on up. He quotes the molecular biologist David Goodsell as comparing cells to “inventive architects” with examples at the molecular level of such structures as fences, reservoirs, valves, waterproofing, and adhesives (p. 17). While any comparison can be pushed too far, Hersey has a lot of fun with the comparisons he makes between the biological and the human-built worlds. He doesn’t confine himself to animal structures, devoting a chapter to molecules, cells, and viruses with their very ordered structure. In another chapter on leaves and flowers, he includes a photograph of the very leaf-like roof of a hockey rink designed by Eero Saarinen. Toward the end of the book, Hersey becomes more daring with a chapter entitled “Penis Paradigms” in which he looks not only at such obviously phallic structures as obelisks and skyscrapers but at a “House of Pleasure” designed for Paris in 1790 that has what can only be called a phallic floor plan. Hersey also gives equal time to female structures in a chapter that compares domes to breasts and shell-shaped fountains to vaginas. Obviously, he sometimes goes too far in his comparisons, but the book is nonetheless well worth reading for biologists because it forces us to look at the human-built world in a very different way and to realize that there is a much more intimate relationship between nature and the human-built than we might suspect.
This is also a major theme in a very different book, Eugene Tsui's (1999) *Evolutionary Architecture: Nature as a Basis for Design*. Tsui is a practicing architect in the tradition of Gaudi and Frei. His book is filled with examples from his own work where he has consciously drawn inspiration from the living world. His designs are radical and many of them remain unbuilt, but they are interesting examples of how an architect can translate the natural into the human-made. Tsui is interested in nature not only as a source of structural ideas, but of functional ideas as well. He wants his buildings to fit into the natural settings where they are to be located, but he also wants the buildings to be environmentally responsible. He discusses ways to make buildings energetically self-sufficient and capable of recycling all the waste materials generated within them. Tsui also touches on the use of recycled materials in construction and on making sure that building materials are nontoxic and nonpolluting in themselves. So his book is very different from Hersey's which focuses primarily on structure and doesn't deal with functional or environmental considerations. Tsui sees a building as a living organism that can respond to changing needs. Many of his designs look more like organisms, with curves, wings, and even tentacles, rather than like the more conventional boxes that most of us live and work in today. They are indications of one direction that architecture is taking and of how fruitful the study of biology can be for architects.

**Architectural Pleasure**

Another area where biology and architecture interact is the extent to which biology influences our architecture. It is obvious that animal architects are genetically programmed to create certain types of structures, but is this true of humans as well? The short answer is no. For humans, there is no distinctive building style, and the wide range of styles found around the world suggests more about the environments in which we build rather than that we are wired to weave, or to dig, or to pile up sticks. But there is some research indicating that, at a more fundamental level, there may indeed be some genetic influence on what humans build. In his book *Origins of Architectural Pleasure*, Grant Hildebrand (1999) argues that there is a relationship between certain aspects of our surroundings and "our innate survival-support behaviors" (p. xvii). He focuses on the ideas of refuge and prospect, terms that the British geographer Jay Appleton (1996) used in his study, *The Experience of Landscape*. Refuge is a place of safety that obviously has survival value, but survival also involves being prepared to deal with intruders, so a prospect, a look-out point, is essential. Hildebrand uses these ideas to analyze why so many homes are situated to have a view; this isn't just for aesthetics, it satisfies an instinct for safety. Rooms with low ceilings, on the other hand, satisfy the need for refuge. Also, Hildebrand has done a number of studies with consistent results indicating that men tend to prefer prospect and women refuge. Do with this data what you will.

Hildebrand sees an adaptive advantage to architectural details that evoke mystery. He cites the work of Stephen Kaplan (1987) showing there is a preference for natural scenes that convey a feeling of mystery either with a trail that disappears around a bend or a brightly lit clearing partly concealed by foliage in the foreground. Kaplan argues that mystery involves not the presence of information, but its promise: follow the path around the bend or peak behind the foliage and you will see more. As Edward O. Wilson (1984) contends in *Biophilia*, an attraction to mystery, a sense of curiosity, has survival value because it encourages exploration, which has its dangers, but these are outweighed by the new information that exploration provides. Hildebrand shows how a sense of mystery can be created in buildings by having narrow corridors curve to hide their end or closing off part of a room with a screen or divider.

A number of other writers have also explored the issue of how our innate sense of space may influence the types of environments in which we choose to live. Tony Hiss's (1990) *Experience of Place* is a great book, in which he explores urban landscapes and how we respond to them. The most memorable part of this book for me is his description of the experience of being in the central space of Grand Central Terminal in New York. This was written in the days before this train station was completely refurbished and a lot of the advertising debris of recent decades removed. Still, the experience would be essentially the same today, because what Hiss writes about is the sense of place created by such a huge open space with a curved ceiling depicting the constellations. But there is much more to his book than this; he deals with work spaces and landscapes as well. Though not all his analysis is based on biology, he definitely makes you think much more deeply about your surroundings and how they influence your work, attitudes, and even your disposition. The writings of Yi-Fu Tuan are also very thought-provoking, though he takes a more philosophical and culturally diverse approach to human responses to their environment. Just as Wilson coined the word biophilia, to describe an innate human urge to associate with other species, Tuan (1974) has coined toposophilia to describe an innate attraction to certain environmental features. He has also written about the role of aesthetics in the choices made by different cultures about created environments (Tuan 1993).
Museums & Labs

Among the environments humans create are those in which to investigate and to examine nature: museums and laboratories. Both these types of architecture have been receiving a good deal of attention recently. It's as if those who study science and those who study architecture have just discovered that the interface between the two might be worth exploring. One of the first books in the genre was written by the architectural historian Michael Girouard (1981) who looked at the work of Alfred Waterhouse in designing the Natural History Museum in London in the 19th century. The influences on Waterhouse's design say a lot about the relationship between British science and society just at the time Darwinism is coming on the scene. Carla Yanni (1999) takes up a similar theme but on a broader scale in a more recent work, Nature's Museums. She deals with the Natural History Museum but also with its precursors and with similar institutions on the continent and in the United States. Like Girouard, Yanni is interested in how architecture plays a role in reflecting society's values and also in shaping attitudes toward science.

A work that looks not only at museums but at laboratories is The Architecture of Science, edited by Peter Galison and Emily Thompson (1999). This book covers everything from natural history collections in the early Renaissance to late-20th century laboratory buildings. The architect Robert Venturi writes as a non-scientist about the organization of spaces for scientific inquiry. Then the molecular biologist Arnold Levine describes working in the Lewis Thomas Laboratory at Princeton University, a facility designed by Venturi's architectural firm. In all, Levine's comments are positive, but they do bring up an issue that isn't often investigated: Just how much does the architectural configuration of a laboratory influence what goes on there? In an article on this theme in Science, Jon Cohen...
Appleton, Girouard, down(2000) compares two laboratories designed by the same architect, Louis Kahn. His Richards Medical Research Laboratories at the University of Pennsylvania was hardly a success. Dust dropped down from exposed pipes onto lab benches causing a severe contamination problem, and the huge windows meant that some labs baked in sunlight, making temperature control almost impossible. Yet Kahn later designed the Salk Institute in La Jolla which, like the Richards, received accolades from architects, but unlike the Richards was also praised by its scientists-occupants. Cohen also surveys some more recent laboratories designed by famous architects, including Frank Gehry, the dean of curved walls, who created the Vontz Center at the University of Cincinnati. Though it looks rather vertigo-producing from the outside, it apparently is a pleasant place to work.

It is probably in natural history museums rather than in laboratory facilities that all the themes I’ve covered are most likely to come together, where the issues of animal architecture are most likely to be studied and where the architecture of the building can influence the kind of work that is done there. Mary Winsor (1991) has written of the building of the Museum of Comparative Anatomy at Harvard University which was originally conceived by Louis Agassiz in the mid-19th century and then completed by his son Alexander. Today, visiting the Museum is like revisiting the biology of the past. It is a building filled with mystery, with corners to turn that provide new wonders, with beautiful iron columns and grill work. Yes, it is an anachronism, but its architecture is also a reminder of the biology as mystery, it reveals something of the anatomy of the science as it does the anatomy of the organisms in its displays.

References


