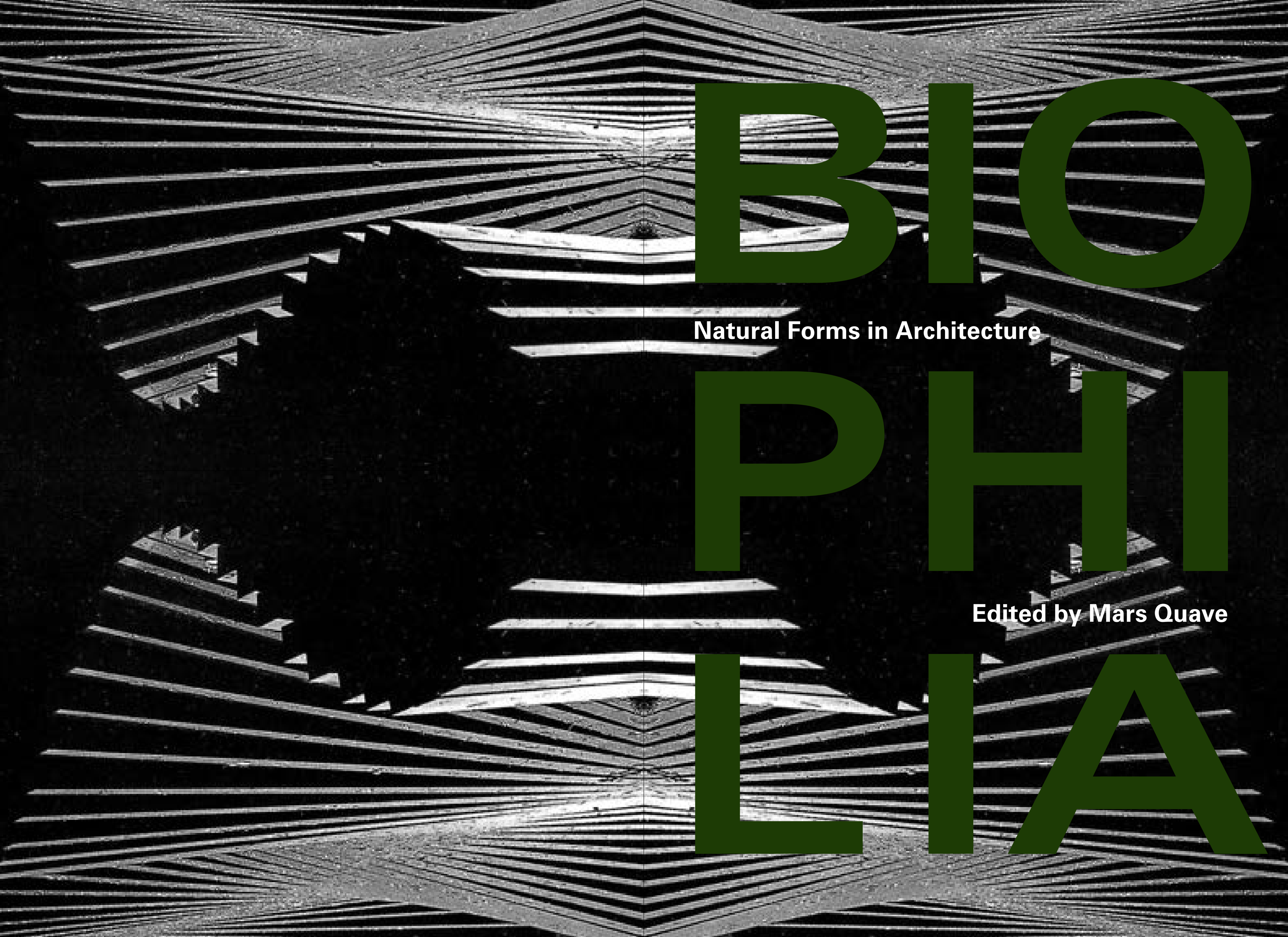

BIOPHILIA

Natural Forms in Architecture

Edited by Mars Quave

Biophilia

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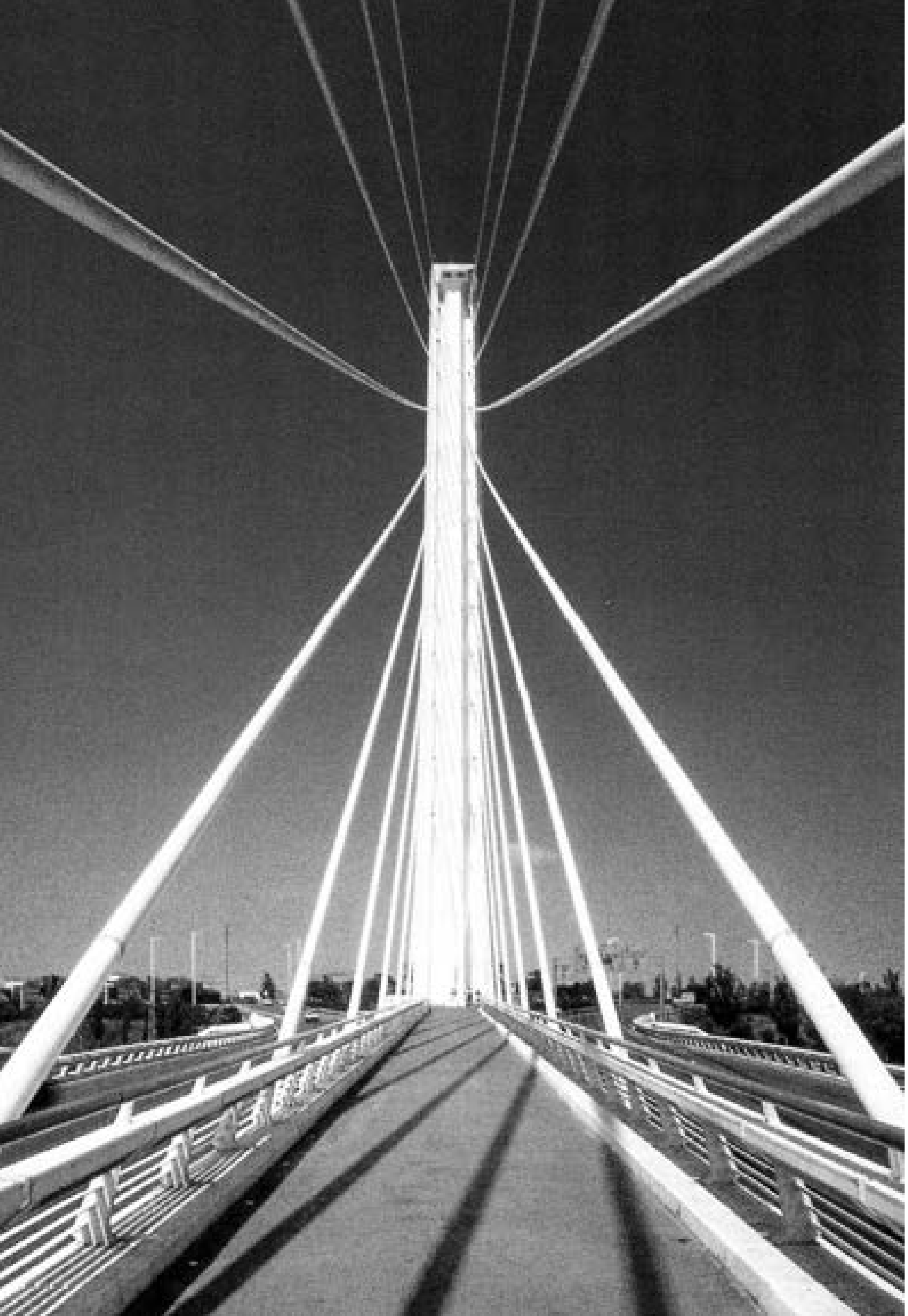
Edited by Mars Quave
York University Press

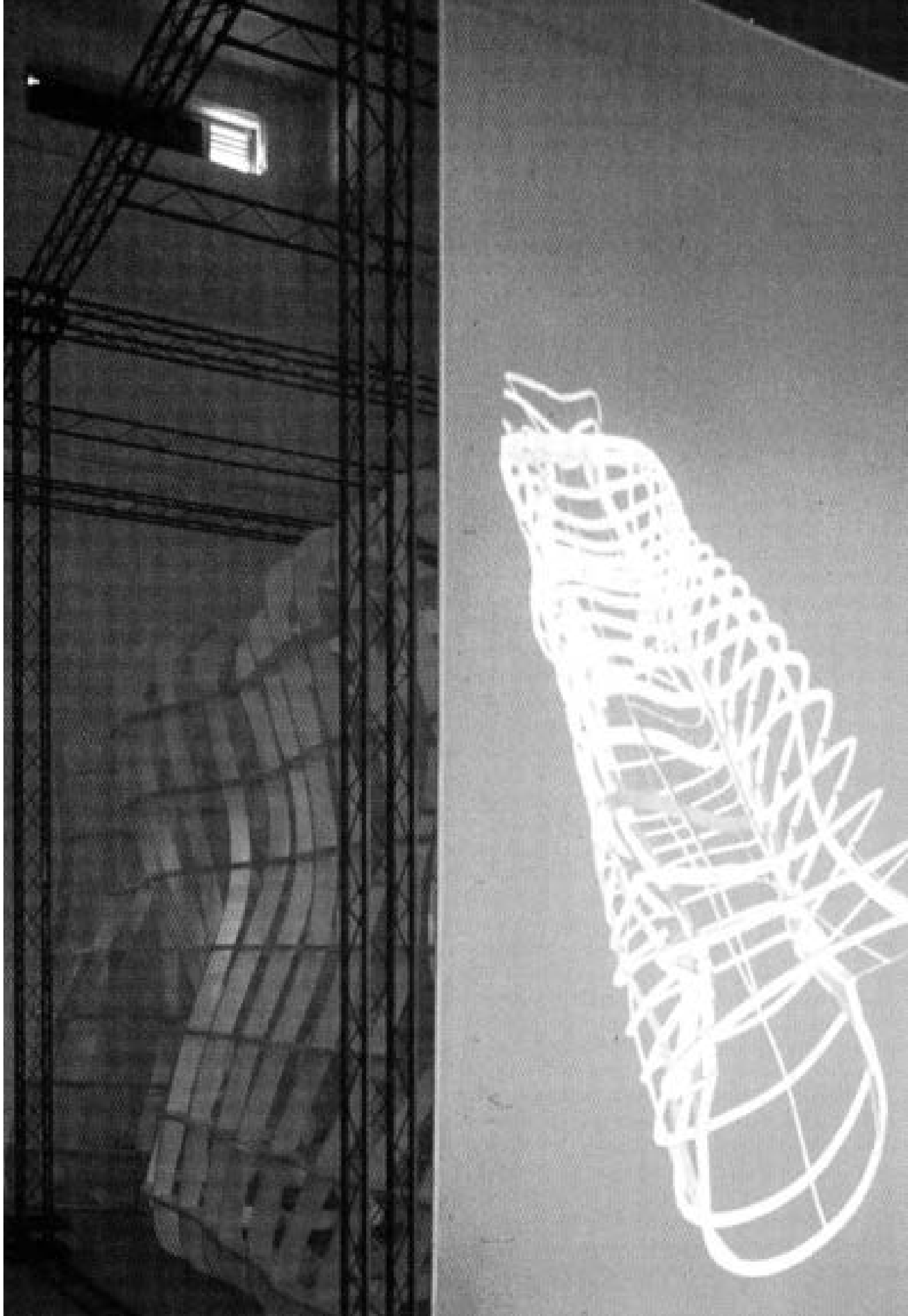


Cognitive and Evolutionary Speculations for Biomorphic Architecture

Yannick Joye

MEMBERS of today's technologically oriented societies have increasingly diminished contact with natural form. This is probably due to a combination of reduced contact with real nature and exposure to architectural settings devoid of references to natural form (e.g. minimalist architecture). Humans, however, evolved in natural environments, and there is reason to believe that the human brain is adapted to processing natural settings and objects. The central aim of this article is to make some suggestions pertaining to the field of architecture that may help in overcoming the discrepancy between the workings of the brain and modern living environments.

In the first part of this article, I present evidence that humans are endowed with a cognitive system specially dedicated to natural information. The existence of so-called biophilic responses

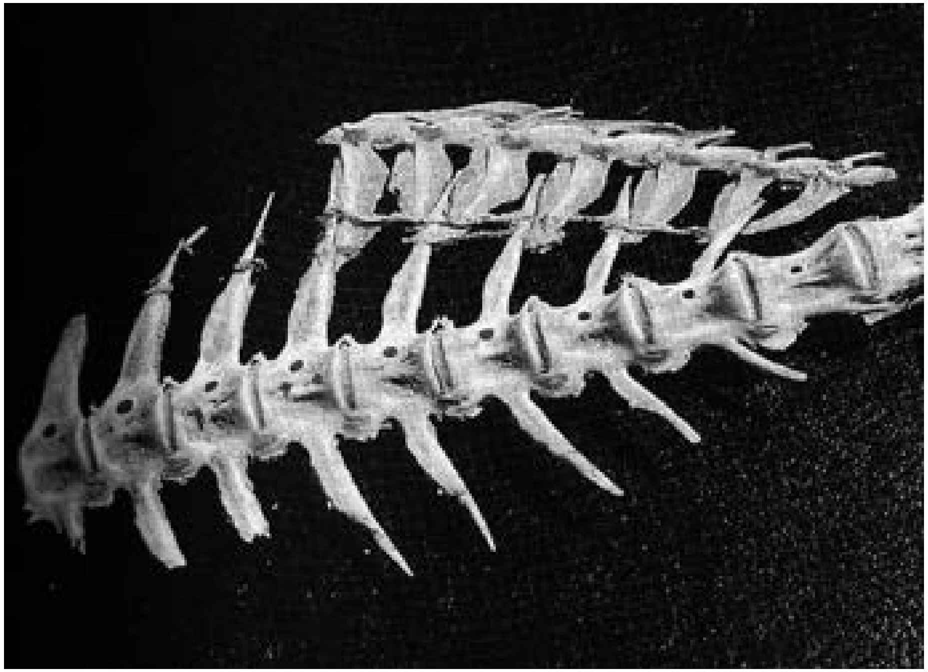


suggests that this system is linked to neural areas dedicated to causing emotional reactions. The subsequent parts consider how these neural assemblies can be stimulated by biomorphic architecture, which shares essential geometric features with natural objects. After a presentation of examples, the final sections discuss how such architecture can enrich the human relationship to the built environment.

Biophilic Responses

Research indicates that humans are innately predisposed to have an emotional affinity with nature. This affinity, sometimes called biophilia, can be explained by the fact that the brain evolved in a biocentric world.[1] In such an environment, an individual had clear survival advantages if it were genetically predisposed to react emotionally toward living things. This entailed that living things with a high survival value (e.g. fruits) would be associated with positive emotional states, as opposed to living entities that were harmful (e.g. snakes). Such emotional states motivated the organism to respond adaptively to the original stimulus (e.g. consuming the fruits, avoiding the snake).

A primary expression of biophilia is the universal human preference for certain natural elements. For instance, various preference studies indicate that people find vegetation-rich landscapes more aesthetically appealing than urban settings without vegetation. When different urban environments are compared, people most prefer those contain ing some vegetation.[2] The preference for these elements is due to their survival value for our human ancestors. For example, because it is difficult to differentiate between plants when they are not in bloom, flowers helped in identifying different sorts of vegetation. Further more, flowers were conspicuous signs of the presence of food resources



Rock Codfish spine

and were cues for future foraging sites. The value of trees can be related to the fact that they provided our ancestors retreats from certain dangers and views of the surrounding landscape.[3]

Living things are also found to influence other aspects of human functioning. According to Roger Ulrich, early humans were often confronted with threatening and demanding factors (e.g. predators) leading to physiological and psychological stress.[4] Those individuals who could recuperate easily from these situations by reducing stress had better chances for survival. Ulrich argues that such restorative responses typically occurred in unthreatening natural settings. The stress reducing effect of nature is still effective today because the individuals who were able to respond restoratively to stressful situations survived and reproduced better. This conclusion is supported by empirical investigation. For example, Ulrich notes a study finding that hospital patients with views of out side trees felt and recovered better, and required less pain medication, than patients with views of a brick wall.[5]

There is evidence that unthreatening animals also positively influence human functioning and psychological development.[6] For example, Frumkin's review indicates that contact with animals reduces stress, is associated with fewer general health problems and lowers systolic blood pressure and cholesterol.[7] An experiment by Friedmann and Thomas reveals that survival chances of persons having suffered a myocardial infarction were higher after one year for patients owning pets (especially dogs).[8] Similarly, watching fish in an aquarium decreases blood pressure in normal subjects and hypertension patients.[9] Another experiment revealed that contemplation of an aquarium was as effective as hypnosis in inducing relaxation and comfort in subjects having to undergo dental surgery.[10]

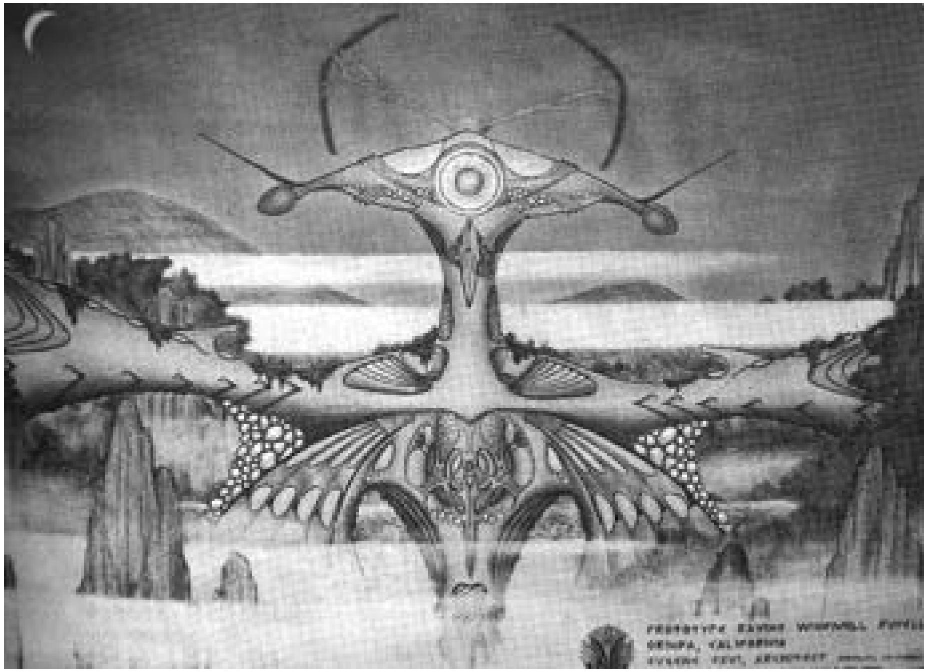
Santiago Calatrava
Science Museum
Valencia, Spain (1991–2009)

Biophilia and Cognitive Neuropsychology

Roger Ulrich concluded his essay "Biophilia, Biophobia, and Natural Landscapes" with the observation that studies of brain activity in subjects view ing different classes of stimuli (e.g. nature vs. buildings) could shed light on the genetic aspect of biophilia.[11] In view of this supposition, interesting insights could be drawn from inquiries into the organization of semantic memory. Within this field, crucial information about the organization of object knowledge in the brain is drawn from subjects with so called category-specific deficits caused by brain damage. Patients with such deficits have impaired knowledge of certain classes of objects (e.g. they are unable to name a certain object when presented a picture of it). Interestingly, in the majority of cases, knowledge about the class of living things is impaired, but subjects with a deficit regarding non-living things have also been reported.

A widely adopted theory about the organization of object knowledge is the Sensory Functional Theory (SFT).[12] According to this theory, knowledge in the semantic system is organized into subsystems that each process some "type" or "modality" of knowledge. The central claim of SFT is that recognition of the category of living things is dependent on the "perceptual" semantic subsystem. This means, for example, that the concept "zebra" will activate perceptual concepts (e.g. black and white stripes). On the other hand, the "functional" semantic subsystem is most crucial for recognizing non-living things. According to this view, the concept "key" will activate functional concepts (e.g. "locking"). When one of these subsystems is damaged, this can result in deficits for the categories of objects that are associated with the subsystem.

Recently some convincing arguments against the Sensory Functional Theory have been proposed.[13] It is therefore interesting

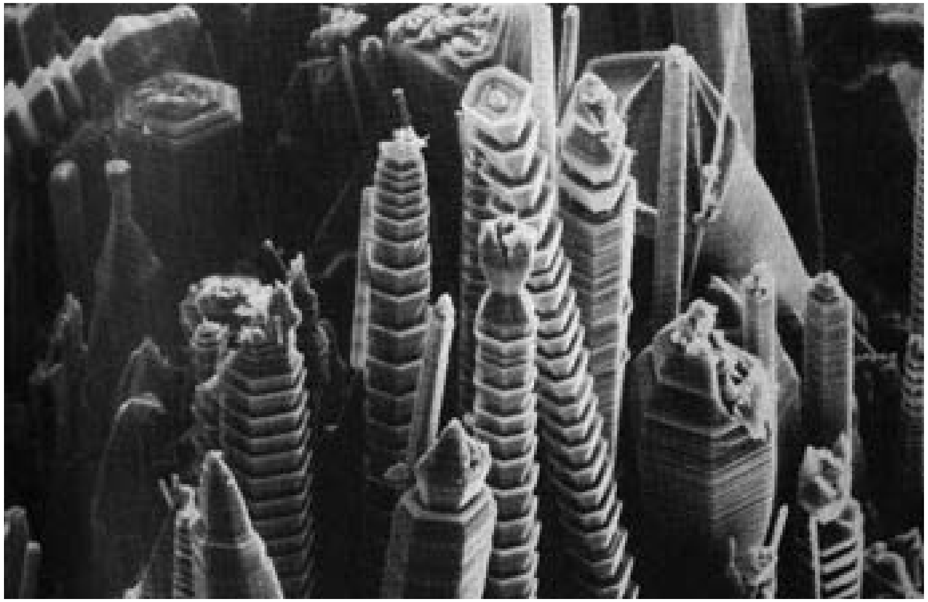


Eugene Tsui
Prototype ravine dwelling
Orinda, California USA (1987)

to consider an alternative theory of the organization of object knowledge in the brain. One approach, of particular importance to the discussion below, is referred to as the Domain Specific Account.[14] According to this view, knowledge about living things is organized categorically in the brain. This means that specific neural circuits are dedicated to knowledge about specific object categories and that category-specific deficits can occur when this circuitry is damaged. The driving force of this regional specialization was evolution. It is speculated that neural mechanisms only developed for those things that had evolutionary significance for humans: animals, vegetable life, conspecifics and possibly tools. Support for the genetic aspect of this system comes from the case of the patient "Adam," who has been brain damaged since birth.[15] This damage is associated with a persistently impaired knowledge of living things. That Adam could not repair this deficit through experience or by learning suggests a genetic basis for knowledge about living things.

It is crucial to note that some proponents of the Domain Specific Account hypothesize that the category-specific specialization of certain neural circuits is not only restricted to the level of object knowledge but also is true of the lower level of object perception. This is concluded from studies of subjects whose recognition of living things is impaired by brain damage. For example, these subjects are unable to differentiate real from chimerical animals. These findings suggest that some neural pathways in the human brain are specialized not only in conceptual knowledge about living things, but also in processing perceptual information about this class of objects. Crucially, the existence of biophilic responses suggests that this neural aggregate includes neural projections to areas involving affect or emotion.

Electron microscope enlargement of metal rust



Biomorphic Architecture as Input for the Natural Module

This system, specialized in natural information, will be referred to as the natural module in the following sections. The idea of a module is borrowed from evolutionary psychology, where it is used to indicate specific neural assemblies evolved to perform a specific evolutionarily relevant task. What, however, is the relevance of such modules for architectural design? This question can be answered by look ing at the types of input that a cognitive module can analyze. Clearly, modules can be stimulated by the objects to which they are dedicated. For example, a face detection module will be activated by its "proper" input: actual human faces. Yet it seems that cognitive modules do not take into account whether the objects they analyze are in any sense real. More specifically, a module will also be activated by elements that share geometric features with the proper input of the module.16 This is one of the reasons why a smiley, and even the fronts of cars, are perceived as having face-like features.

This observation can be extrapolated to the natural module. It is highly probable that the module specialized in processing natural elements will also be activated by stimuli that share essential geometric features with natural elements. More specifically, a central conjecture of this article is that architectural design can play a role in stimulating this system. Because lower-level subsystems of the natural module are specialized in perceptual information about living things, this role can be fulfilled through the integration of biomorphic architecture into the human living environment. Such architecture shares important visual and structural properties with natural features and settings and can therefore stimulate the natural module.

Antoni Gaudí
Casa Milà, "La Pedrera"
Barcelona, Spain (1906–1910)

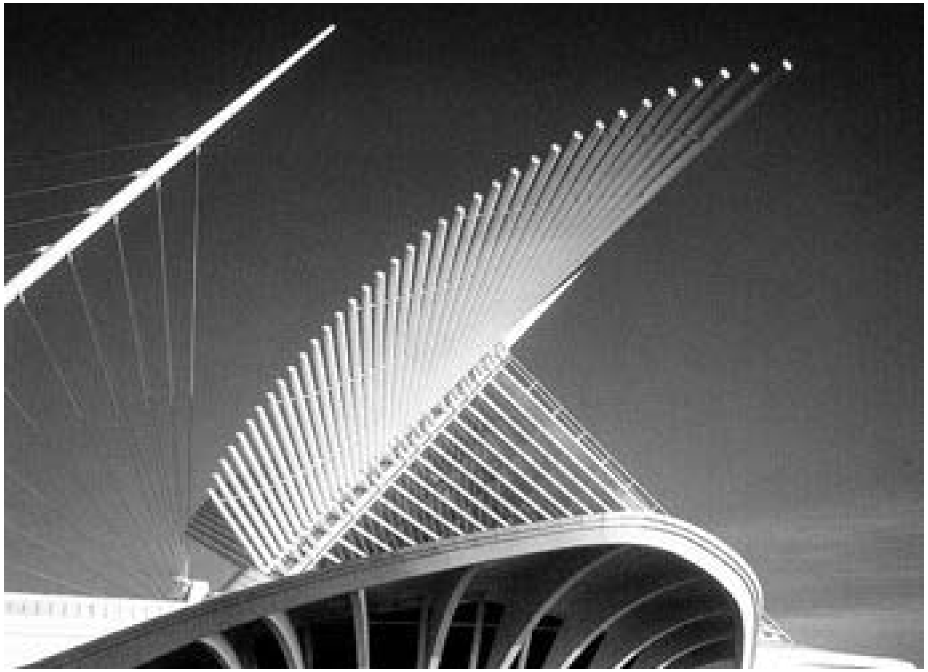
Concrete Natural Elements

The integration of natural forms in architecture can include multiple levels of abstraction. For instance, owing to the important formal overlap with real natural objects, the natural module will analyze architectural designs or elements when these are almost literal imitations of natural elements. Evident examples of such imitations can be found in traditional ornament, which often contains representations of leaves, flowers, fruits, animals, monsters, etc.

An alternative to such literal imitations would be the implementation of more stylized imitations of natural elements. A stylized design retains some global or schematic visual similarities to the original natural object: Consider a smiley, which is a stylized representation of a face. Further examples can be found in the biomorphic architecture of Eugene Tsui.[17] His interest in natural form can be traced to two important components. First, Tsui argues that the image emerging from the "complexity sciences" is one of a nonlinear, dynamic universe, characterized by chaos, fluctuations and evolution. The architect tries to adapt to these views, leading to "[c]hange, physical movement of building components, continuity of structure and surface, open and variable space, a non-uniform grid plan or no grid plan at all, fluctuation of floor..."[18] A second motivation for Tsui's biomorphism is the observation that current building is wasteful and in efficient in its use of materials and energy and poorly adapted to the landscape. Tsui holds that this tendency can be countered by drawing inspiration from the makeup of natural organisms, which, as a result of evolutionary forces, have be come very efficient and economical in their functioning, material form and energy use.

Eugene Tsui
Ojo del Sol
Berkeley, California USA (1993–1995)

Antoni Gaudi designed perhaps the most widely known examples of biomorphic architecture. Consider, for instance, how the columns and vaults in the Temple Expiatori de la Sagrada Familia resemble trees and branches. To a certain extent, the biomorphic character of these works can be traced to Gaudi's aim to re solve a problem in Gothic cathedrals: that the thrust of the vaulting had to be counteracted by buttresses. His solution consisted of constructing tilted columns. These were developed using wire models whose form followed the logical lines of loads and stresses of the building represented in the model. Thus, the building imitates not natural forms but the natural forces acting beneath its surface. Today, a similar interest in structural concerns is present in the biomorphic works of Santiago Calatrava. For instance, the tilted columns in the Stadelhofen rail way station are not the result of an aesthetic decision but are required to hold up the structure. Despite the importance of structural concerns, however, neither Gaudi's nor Calatrava's biomorphism can be reduced to structural issues alone. Gaudi aimed also at giving his work "life" or "expressiveness" and did so by integrating different types of biomorphic pat terns, textures and sculptures. Similarly, Calatrava's interest in structural concerns goes hand in hand with the fact that natural forms are also a direct source of inspiration. For example, his structure near the Milwaukee Art Museum can be seen as a stylized interpretation of a bird, while structures in the BCE Place (Toronto) and in the Orient Station (Lisbon) resemble trees.



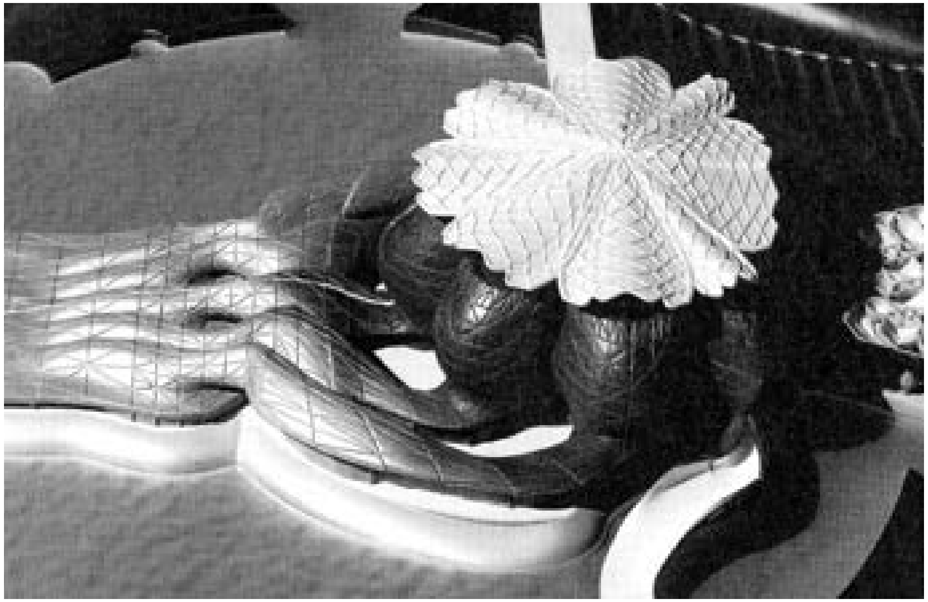
Santiago Calatrava
Milwaukee Art Museum
Milwaukee, Wisconsin USA (1994–2001)

Abstract Structural Features

The emergence of computer technology and digital design software has substantially facilitated the creation of biomorphic architecture and design. An interesting example is Greg Lynn's design for the Ark of the World Museum. This proposed building, designed to be situated in the mountains of Costa Rica, consists of a natural history museum and an eco-tourism center. The flowering construction is based on indigenous fauna and flora. Yet, besides such imitations, naturalness can also be evoked by incorporating the more abstract geometric features of natural objects. Although such designs will not be recognized as being similar to specific natural objects (e.g. birds, flowers), they still can activate primary visual subsystems of the natural module that are dedicated to nature-like geometric features. Because of these activations, such creations could still evoke naturalness.

A primary abstract geometric feature of animal form is curvature: Measurements indicate that animal contours are characterized by a high degree of curvature.[19] Interestingly, curved shapes have been notably appropriated within the field of generative architecture. The essence of generative architecture is that the computer is no longer only a tool for drawing but has also become a creative and form-shaping instrument. A typical generative strategy consists of translating some type of information into vector fields that act upon a predetermined geometric structure and de form it. The research group dECOi has adopted such a method to create the structure Foster/Form.[20] The shape, a carapace spanning three theaters at Gateshead, UK, is the result of a form finding process. More specifically, forces were attributed to the three theaters, corresponding to the number of people they could contain. The final shape was obtained by letting these forces act on the elastic surface.

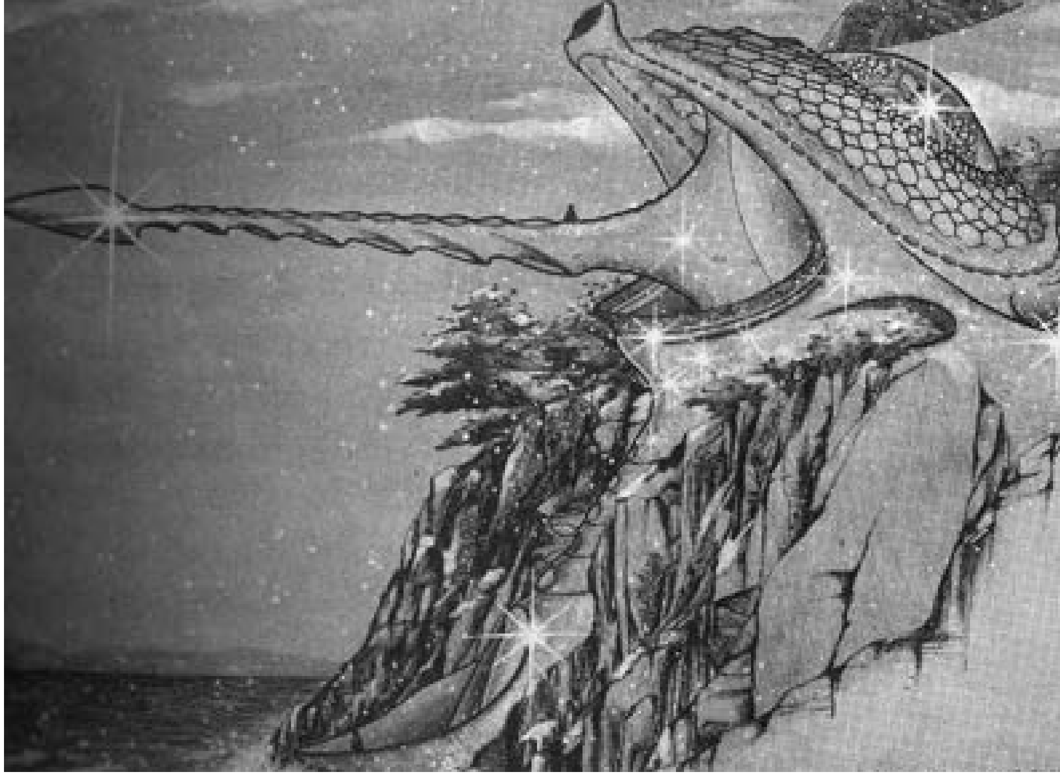
Greg Lynn
Ark of the World
San Juan, Costa Rica (2002)



One of today's leading generative design practices is Nox, headed by Dutch architect and designer Lars Spuybroek. The interaction between subject and architectural setting plays a crucial role in Nox's design philosophy.[21] More specifically, Spuybroek, inspired by Merleau-Ponty's phenomenology, views world and subject as entities that constitute and structure each other. When applied to architecture, this assumption entails that the subject can no longer be the passive receptor of the architectural program. Instead, a subject's temporal activities within the architectural setting be come constitutive of the architectural shape. In turn, temporal changes in the architectural environment influence the specific nature of subjects' behavior.

This conception of interaction is applied in the architectural installation Son-O-House, near Eindhoven, the Netherlands. This voluptuous design is the result of digital modeling of the different types of movements people per form in houses. An interactive sound installation, developed by composer Ed win van der Heide, is integrated into the project. Twenty-three sensors capture the movements of the visitors, and these influence the generative process that produces the sounds. In this way, a feedback loop is generated in which elements of the architectural settings and subjects are mutually constitutive. In particular the process leads to a cycle in which the sound condition of the installation challenges the visitors to move to other locations, and these movements in turn lead to the generation of new sounds.

The curvaceous architecture of generative design is most often static and timeless. Some design proposals, however, are also capable of continuously updating their shape, which makes the link with living nature even more profound. Recently, proposals for such adaptive architecture have been developed by Kas Oosterhuis.[22] In fact, Oosterhuis believes that architecture is an



Eugene Tsui
House for Hugh and Ida Fraser
Oslo, Norway (1986)

attractor of information (e.g. people come in and out). Moreover, the architect holds that there is a universal tendency to increase the information content of the universe. Architecture participates in this process: It attracts increasingly more information because it is imbedded in large networks and influenced by interactive and participative processes. An important precept of Oosterhuis is that buildings should no longer be passive receptors of this information stream by remaining static. Instead, buildings can amplify their information content by responding to the information flow through a trans formation of their overall shape. The building becomes more and more like an organism that adapts its behavior and form to new kinds of information. An example of such real-time architecture is the proposed project trans_PORTS 2001. This project consists of a series of flexible pavilions situated in different ports and connected with each other virtually. These structures can change their shape according to the local conditions in the associated ports and in response to in coming information from the Real-Time Evolution Game, played on the Internet. The formal adaptations are realized by a space-frame that consists of pneumatic bars.

Fractal Architecture and Design

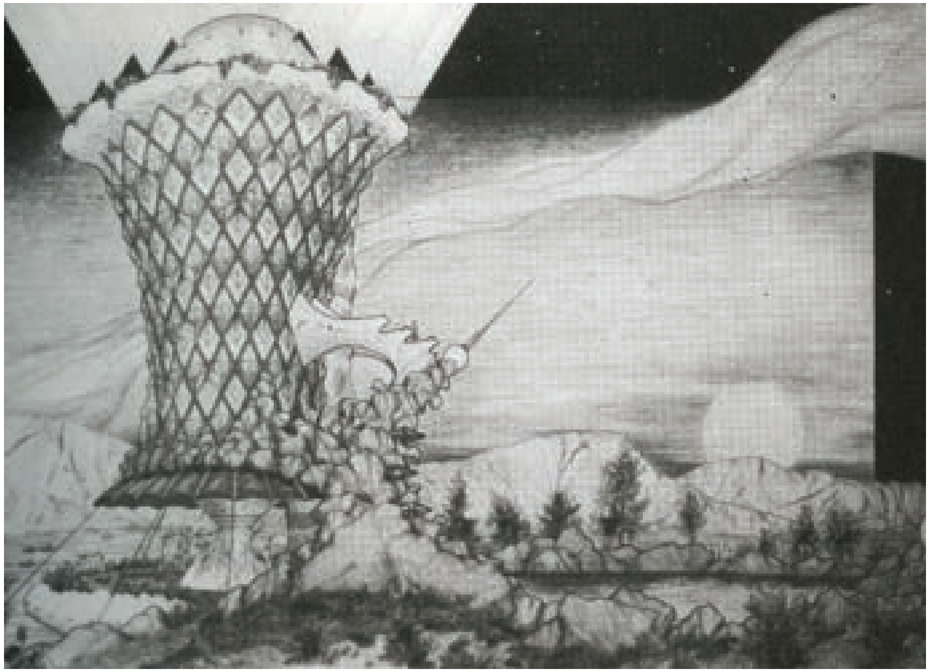
Architecture can also find inspiration in a second type of abstract geometric property characteristic of natural objects. An inspection of the formal appearance of evolutionary relevant natural objects (e.g. trees, plants) shows that their shape is governed by fractal geometry. An essential characteristic of fractal structures is that similar details recur on different scales of magnitude. For example, zooming in on the substructure of a tree reveals details similar to that of the tree as a whole. Applying fractal organization to architecture would mean that similar shape-elements occur at

Santiago Caltrava
East Station
Lisbon, Portugal (1993–1998)

different hierarchical scales of the architectural work.

Today, the issue of fractal architecture is surrounded by lively debate. Despite this, modern examples of fractal architecture are relatively rare. This could be found surprising, given the fact that Charles Jencks discusses the issue of fractal architecture in a chapter of The Neiu Paradigm in Architecture.[23] A critical reading, however, reveals that Jencks's application of concepts from fractal theory is largely mistaken. Almost none of the architectural designs Jencks discusses have any significant self-similarity. For example, while Gehry's Guggenheim Museum could be claimed to appeal to nature because it consists of curved surfaces, it cannot be considered a fractal because it contains no similar structures recurring on different scales of magnitude. Although fractal geometry has only developed since the 1970s, more convincing instances of fractal architecture have been created throughout architectural history, for example, in certain Hindu temples and Gothic architecture.

Together with Philip Van Loocke, I am currently involved in designing objects based on fractal principles.[24] The design process of the examples in begins from a linear, 3D fractal tree. The endpoints of the tree are given a certain load, which is derived from the proper ties of high-dimensional datasets. These can include datasets derived from DNA, musical code, textual code, etc. These loads can be intuitively understood as forces that deform the linear branches of the original tree. When the bending pro cess ends, a nonlinear tree is obtained, whose form is a function of the datasets. If desired, the nonlinear tree can be enveloped by a complex surface, resulting in flower-like constructions. While these examples are not architectural, they show the possibility of creating 3D shapes based on fractal principles.



Eugene Tsui
Torrevista
Tejiras, New Mexico USA (1986)

The Emotional Significance of Biomorphic Architecture

There is a growing discrepancy today be tween certain aspects of human nature and the type of environments in which we live. In particular, modern cities and industrialized areas are increasingly dominated by concrete and steel constructions stripped of all ornamentation, detail and color. Such minimalist environments are very remote from the formal richness of the natural elements with which humans have been confronted over their evolutionary history and to which their cognitive system has become adapted. One could even argue that they seem to have been designed by people with a category-specific deficit for living things.

There are few reasons to believe that the gap between who we are and how we live is closing. In a recent speech for World Environment Day, United Nations Secretary-General Kofi Annan declared that by 2030, 60 percent of the world's population will inhabit urban environments. While this evolution undoubtedly puts enormous pressures on natural ecologies, increasing urbanization also has negative implications for psychological well-being, because exposure to natural form is often drastically reduced in such environments. As a consequence, the innate human talent for recognizing natural information could become largely unused or even underdeveloped. Furthermore, in such modern settings, occasions to experience biophilic responses will decline, denying humans access to a broad range of positive attitudes and re actions that emerge from contact with living form.

I speculate that biomorphic architecture can provide a counterweight to this impoverishment. Because biomorphic architecture shares important visual features with living things, it is analyzed by the perceptual subsystem of the natural module. Because the natural module includes projections to areas involving emotion or affect, this analysis could trigger affective responses

Santiago Calatrava
Campo Volantin Bridge
Bilbao, Spain (1990–1997)

associated with certain classes of living things. For example, architectural elements that resemble vegetation are likely to induce aesthetic responses, which in turn can promote emotional well-being and positive behavior. One can even hypothesize that such architecture can help in reducing psychological and physiological stress and promote apprehension and attentiveness. Because its forms evoke natural objects, biomorphic architecture can enrich human emotional relation to the built environment.

Biomorphic Architecture and Mindset

Another possible effect of the widespread integration of biomorphic architecture is that of subtle shifts in human thinking. To explain this point, it is essential to keep the central claim of the Domain Specific Account in mind: that specific neural regions are dedicated to information about living things and possibly some nonliving things, such as tools. Yet some theorists believe that it is quite possible that these neural areas are each embedded in neural systems that are specialized in a certain type or modality of knowledge.[25] In particular, it could well be that neural areas dedicated to living things are embedded within the perceptual modality, while the areas dedicated to nonliving things are embedded within the functional modality. Note how this would entail a recuperation of the central claims of the Sensory Functional Theory.

This view could have subtle but important consequences. I have noted above that the presence of nonliving things, and especially purely functional architecture, is ever increasing in the human living environment. This entails that semantic networks that perform functional analyses are ever more dominant when processing the elements that constitute our surroundings. Such a dominance of functional concepts could promote a tendency

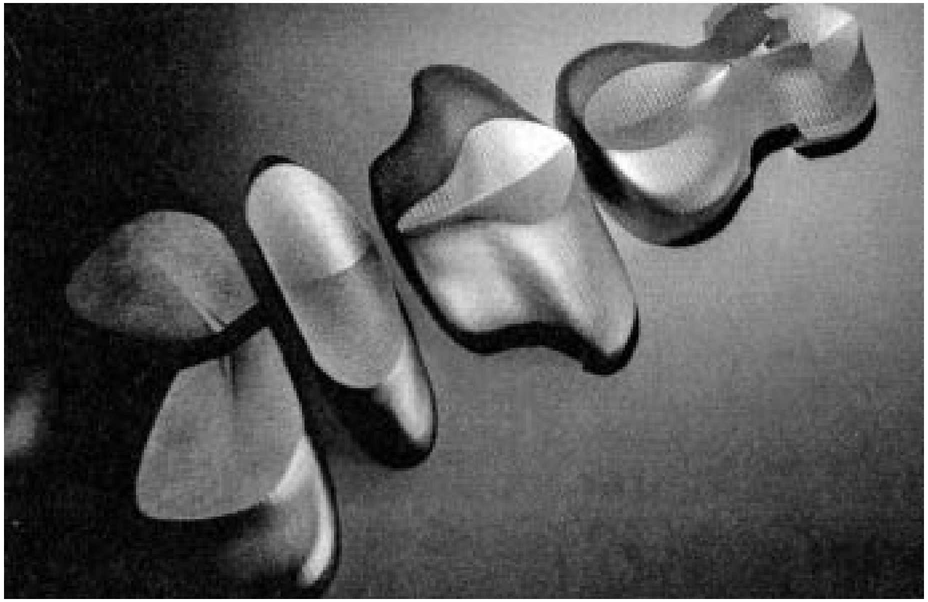
Antoni Gaudí
Casa Milà, "La Pedrera"
Barcelona, Spain (1906–1910)

toward functional thinking and behavior, further strengthening beliefs in the utility and value of functional objects and architectural de sign. Although it is clear that a functional attitude has its merits in certain contexts, its overt dominance can be harmful for our relations toward others and toward the natural world.

Biomorphic architecture could provide a counterweight to the increasing dominance of these functional semantic networks and the associated epistemological attitude. Because of its similarities with natural things, such architecture also activates semantic networks that are not predominantly related to functionality. In fact, given the correlation of living things with perceptual knowledge, biomorphic designs could stimulate neural areas that establish the perceptual uniqueness of objects. Such an emphasis would be especially relevant to our relationship to nature. While in modernity nature is increasingly valued from a purely utilitarian perspective, designs that integrate natural form could help us learn to be also attentive to nature's perceptual qualities. Such an epistemological shift would make it more probable that nature would be enjoyed for its own perceptual presence and not only for the functions it can fulfill. This new emphasis could therefore be understood as a robust form of environmental education.

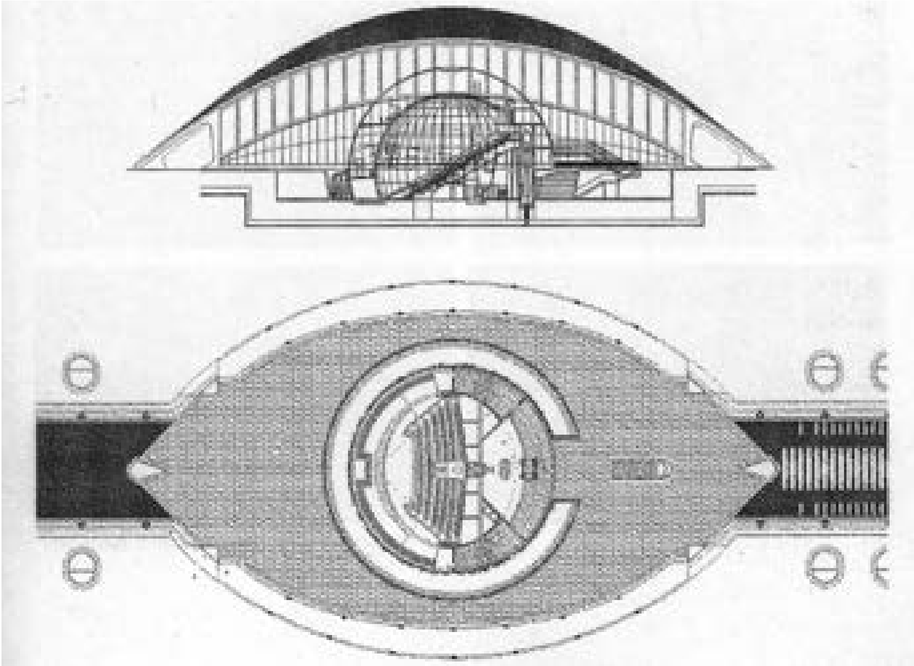
Finally, nature's forms can be considered a generative grammar for creating artwork and architecture. A relative shift toward attention to perceptual qualities can have important artistic consequences. It could draw the attention of artists and students to nature's rich formal grammars, which makes it more probable that these forms find a genuine artistic translation. More specifically, they could come to study the different processes, shapes and structures in nature, and consider them as a generative grammar that forms the basis of an endless variety of formal permutations.

Greg Lynn
BMW Factory Leipzig
Leipzig, Germany (2002)



Discussion

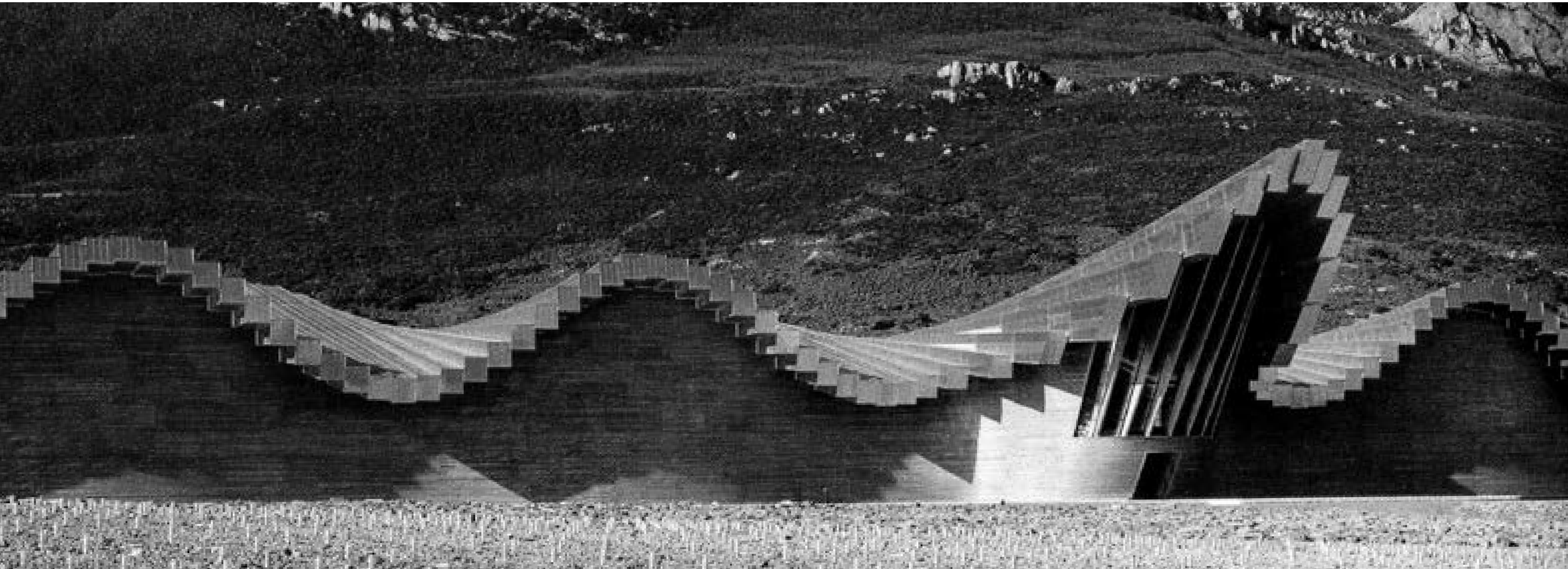
Adolf Loos considered ornament a sign of cultural and intellectual degeneracy, with negative effects on human well being.[26] Against it, he defended an aesthetic purism that banned the use of ornamentation. The above argument advances a completely opposite view. Because biomorphic architecture is to a large extent ornamental, I speculate that it can lead to subtle improvements in well-being and shifts in epistemological attitude. Such a view cannot be considered intellectually backward. On the contrary, that characterization would seem to apply more to Loos' own rhetoric, which rests upon an outdated under standing of human psychology, often referred to as a belief in the "blank slate," which holds that human thinking and behavior are determined only by experiences. Yet evolutionary psychology has revealed that human behavior and psychology, and their cultural outcomes, are not only the result of experience but are also guided by a number of innate adaptations.[27] In order to design interesting and stimulating objects and environments, architects and designers could learn from these adaptations. This plea for biomorphism therefore cannot be understood as an unengaged aesthetic "gesture." Instead, its crucial motivation is the aim of being responsive to certain basic levels of human functioning.



Santiago Calatrava
L'Hemisferic
Valencia, Spain (1991–2009)

Antoni Gaudí
Casa Milà, “La Pedrera”
Barcelona, Spain (1906–1910)

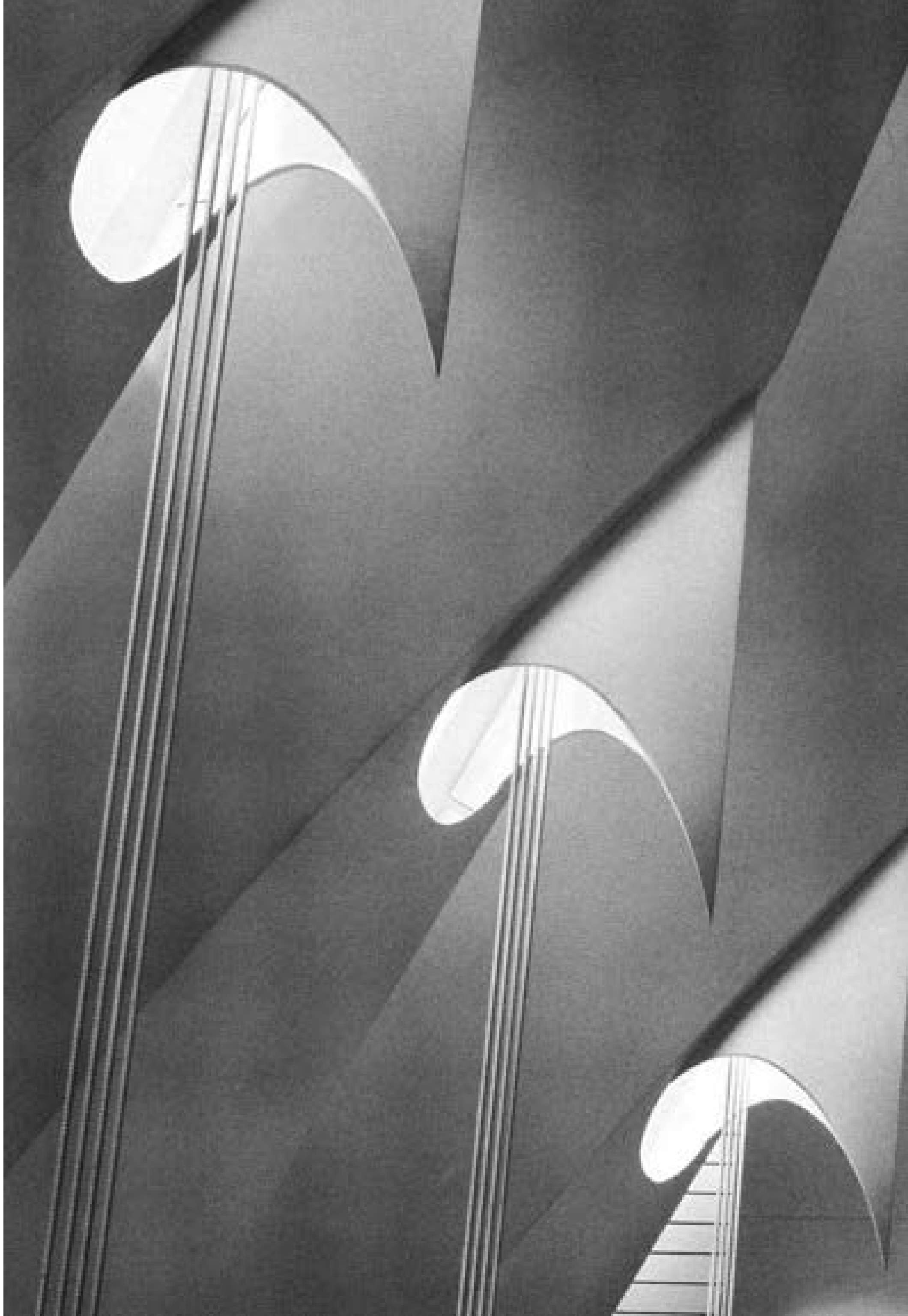
Santiago Calatrava
Ysios Winery
Laguardia, Spain (1998–2001)



Monsters, Mutations and Morphology

Michael Weinstock

THE MYTHICAL monsters of the classical world were imaginary creatures, composed of parts of known animal forms and the human body. The Sphinx, for example, had the head of a woman, the body of a lion and the wings of a bird. The Minotaur had the body of a man and the head of a bull, and the Centaur had the body of a horse and the head and torso of a man. These monsters were mutations of the human body, deviations from the ideal of harmonious proportion and beauty, beings that united mankind and animals. Other monsters, like the Chimera, a fire- breathing monster that had the head of a lion, the body of a goat and the tail of a serpent, were entirely composed of animal forms. Cerberus had three dogs' heads, a serpent tail, and many serpents' heads on his back.



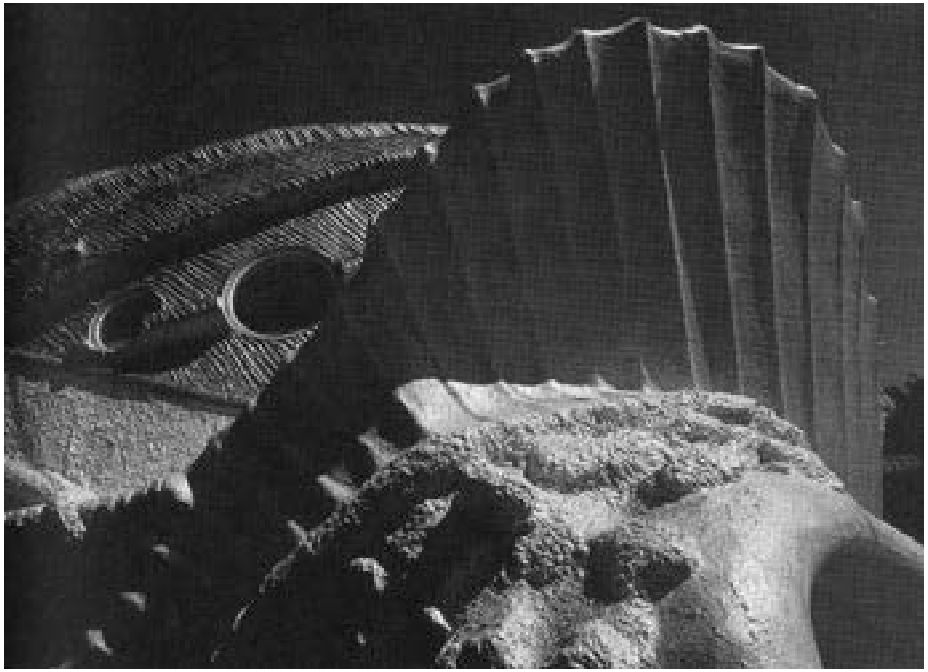
There are common characteristics they share, of which the most striking is the fact that they were composed of different parts in order to do more than mortal humans could do. Stronger and more powerful than normal humans, they also were untamed and closer to the more "natural" animal, and terrible in their appetites and anger. The Sphinx devoured humans who could not answer its riddle;[1] Cerberus, the hound of Hell,[2] tortured souls; the Minotaur was confined in the labyrinth built by Daedalus to hide its monstrosity and fed on the flesh of virgin youth.[3] The Centaurs killed men and ravished women and boys,[4] but they were also knowledgeable of human culture- Chiron, the most righteous Centaur,[5] taught Achilles medicine and music, hunting and war. Classical monsters were not new or truly alien forms but rather deviations from known human or animal forms, parts of existing forms aggregated into systems of differences, and it was the union of differences that produced their excessively natural, superior yet deviant functionality.

Mutations to the forms of animal and human bodies occur naturally. Cyclops mutations, for example, are a frequent occurrence in many species. Fish may become cyclopic if their embryos are thermally or chemically traumatized, pregnant ewes grazing on corn lilies can produce cyclopic lambs, and in humans diabetes or the consumption of excessive amounts of alcohol during pregnancy dramatically increases the chances of the embryo mutating to the cyclopic form.[6] It is a very common mutation, a deviation at the very beginning of the normal development of the embryo.[7] The morphological characteristics of Cyclopia are similar in all species, including humans. The mutation produces an undivided brain, lacking the normal two hemispheres, and a single eye, usually with the nostrils located above the eye.

Antoni Gaudí
Güell Pavillions
Barcelona, Spain (1884–1887)

The construction of a systematic study of all "the monsters and prodigious products of nature, of every novelty, rarity or abnormality" is one of the earliest projects of science.[8] The study of the different, of the "Errors of Nature," of the monstrous and mutated, is an essential part of Bacon's proposition that Natural History should be split into three inter- related domains: the study 1) of ordinary or usual nature, 2) of deviant nature and 3) of nature manipulated by man. In the first instance, Nature produces the "history of generations," or species that develop in the ordinary course. In the second, Nature is forced from the ordinary course by the perversity of matter and produces monsters. In Bacon's third domain, Nature is constrained and molded by mankind to produce the artificial. Furthermore, the three regimes were not to be treated separately, but could be subjected to the same inductive methodology of enquiry. "For why should not the history of the monsters in the several species be joined with the history of the species themselves? And things artificial again may sometimes be rightly joined with the species, though sometimes they will be better kept separate."[9]

Biological monsters reveal the space of morphological variation or differentiation of any given species. In evolutionary terms, they are subject to strong negative selection, but are produced in every generation by the internal processes of the system of embryonic development. Morphological differentiation of the full adult form is produced by small variations that occur very early in development, and may be initiated by genetic errors, environmental changes or may be induced by experimental manipulation. The process of embryonic development determines the morphological variation or differentiation in the population of any species, the set of available forms. It might be thought that genetics and embryology take quite different approaches to



Eugene Tsui
Ojo del Sol
Berkeley, California USA (1993–1995)

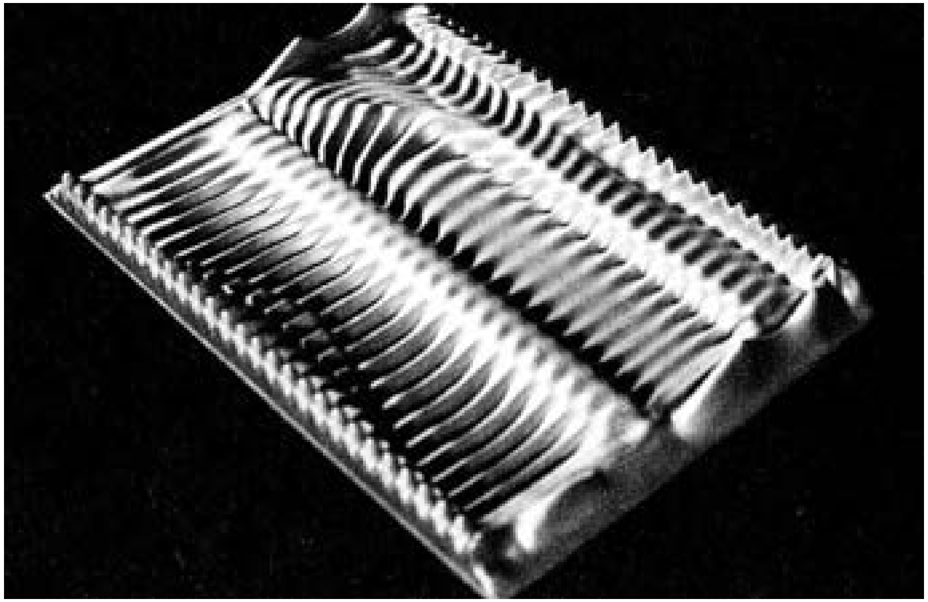
differentiation, as they appear to have fundamentally different arguments. However, what is common to both systems of thought is differentiation.

Differentiation and the Body Plan

Genetics argues that all living things are the products of natural selection, operating on inherited small mutations or changes in the genome over many generations. It is these small changes (to the genome) that produce differentiation within populations, and drive evolution. Every reproductive cycle requires the organism to replicate its genetic material, and this process is susceptible to small copying errors, so that offspring are produced that are a little bit different from the parents. In the most extreme account, organisms are described as a kind of temporary host for the genes, a mechanism for their perpetuation.[10]

Differentiation during the development of an individual is controlled by the Homeobox genes (originally discovered in the fruit fly Drosophila) that turn other genes on or off during development, controlling the order of morphogenesis and the position of different parts in relation to the body plan. The Homeobox genes control differentiation in all species.[11] In the case of the fruit fly, the mutation of a single gene, called Antennapedia, produces changes to the morphology and function of the fly's antenna, so that it develops as a leg rather than an antenna. This is possible because all cells in the fly have all of the information necessary to become leg cells or antennae. Every cell in an organism carries a complete genome, all of the information necessary for the development of the complete organism. Antennapedia and its homologues control limb development in all vertebrates, so that the forelimbs of birds develop as wings, or the extremities of the forelimbs develop as hands in humans or flippers in seals. Homeobox DNA sequences

Greg Lynn
Visionaire #34 Case
New York, New York USA (2001)



have been conserved throughout evolution and are controlling factors in the development of even distantly related organisms.

Changes to the Homeobox genes have substantial effects on the morphology of individuals, and when these changed individuals survive the rigors of natural selection, new descendant species are formed. If individual mutations offer the advantage of superior functionality in some capacity, then the mutant organism will have an enhanced reproductive fitness. If its progeny inherit the changed genome, then evolutionary change will occur. Differentiation by speciation, new species arising from a common ancestor, is normally described in phylograms, or tree-like charts. The underlying logic is to plot the sequence of morphological differentiations that lead from the "form" of a common ancestor to the multiple differentiated forms of the whole group or taxa.[12] For example, the common ancestor of all arthropoda, including crustaceans, centipedes, spiders, scorpions, and insects, was a simple tube-like worm. The arthropoda group has over one million species alive today, with a fossil record that starts in the early Cambrian era, and it accounts for over 80% of all known organisms. The sequence of morphological differentiation produced segmented bodies, exoskeletons, and jointed legs.

As opposed to genetics, embryology treats organisms as whole beings that evolve not only by the small incremental changes of genetic mutation and natural selection, but through transformations. D'Arcy Thompson argued that natural selection is efficient at removing the "unfit," but that the significant differentiations of new structures are a product of the mathematical and physical properties of living matter, just like trie shape of nonliving things in the natural world.[13] Transformations between major groups do not happen in the completed adult, but may occur in embryos. The embryos of highly differentiated adults

Santiago Calatrava
City of Arts and Sciences
Valencia, Spain (1991–2009)

are strikingly similar. Genetic information does not need to fully specify the adult form, as the action of the natural forces in the environment and consequent mathematical principles determine the scales, bounding limits and informing geometries of the development of adult forms.

In more contemporary expressions, organisms are described as members of a class of complex dynamic system with distinctive properties of order and form, and it is these characteristics of organisms that are drivers of evolution.[14] The differentiated morphology of living organisms is determined not only by the genome, but also by the combination of the internal forces such as chemical activities and pressure in their cells, and of external environmental forces such as gravity. The effect of these natural forces is expressed in different ways, depending on the size of the organism.

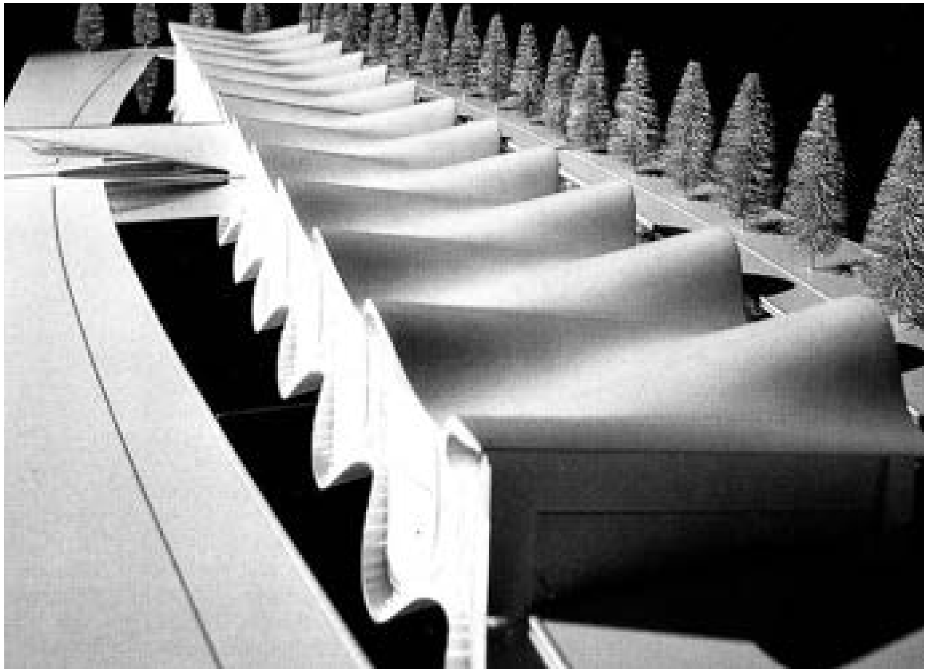
Embryological development of an individual organism is a process of differentiation. In all animals and insects the sequence of differentiation commences when the fertilized egg divides to produce a cluster of cells, and as numbers increase, organizes itself into a hollow sphere. A thickened flat plate forms and on the surface of the sphere the edges curl up and meet at the dorsal midline to form a hollow tube. The next step in differentiation is when one end of the tube grows and becomes convoluted, and subsequently develops into the brain. The other parts of the tube follow a similar process and subsequently become the spine and lower limbs. A fully recognizable version of the final adult body plan is achieved very early in embryological differentiation. This process is identical in fish, birds, mice and men. The duration of the process of differentiation does depend on the final body size, so that a full body plan is evident in mice by day 14 of gestation, and a similar point is reached in the gestation period of humans by

Asymptote Projects
I.Scapes Installation
New York, New York USA (1999)

day 60; but it is clear that there is a commonality, a fundamental unity to the processes of morphogenetic differentiation across species and phyla.

Hopeful Monsters

"Hopeful monsters" was a controversial term used by evolutionary biologists to describe an event of mutation that produces a new species, an idea that predates the sequencing of the "genome."[15] In 1942 the biologist Richard Goldschmidt proposed that mutations in genes that have a significant role in the development process of the embryo could produce large effects on the physical organism or "phenotype." In The Material Basis of Evolution, he argued that mutations that affected the whole organisms were "hopeful monsters" because they had the potential to succeed as a new species. The idea of developmentally significant mutations producing large effects is now widely accepted, but to extend from this to a theoretical proposition of speciation through systemic mutation has very little support, as it neglects the role of the dynamics of evolving populations. A single hopeful monster cannot constitute a new species, or found one. However, at least part of Goldschmidt's theory, universally rejected by the prevailing orthodoxy of the time, might get a more sympathetic hearing today—in particular, his finding of what he called "rate genes," genes that control the timing of local growth and differentiation processes. The earlier a mutation occurs in the process of embryonic development, the more extensively it will alter the organism, but such early mutations produce such profound changes that the fully developed organism is rarely viable. A small mutation at a very early stage of development, such as the mutation of the gene Antennapedia that changes the antenna to a leg, can bypass millions of years of the small incremental changes



Santiago Calatrava
Ysios Bodegas
Vitoria, Spain (1998)

of Darwinian evolution. The more complex an organism is, the more extensive the changes will be, and more likely they are to be lethal to the organism.

Steven Jay Gould, writing some 60 years later in The Structure of Evolutionary Theory, gives an analysis of what might make a monster hopeful- for example a mutation that produces two eyes on one side of the head of a fish of the most common morphology (such as tuna) is a monster; a mutation to a flatfish that produces two eyes on the upper surface of the head, with better scanning of the surroundings as a lucky result, is a "hopeful monster."[16] To be hopeful, the monster must be well suited to a previously unexploited environment, it must be fully functional, and it must have the means and opportunity of reproducing and propagating itself.

Plant Bodies

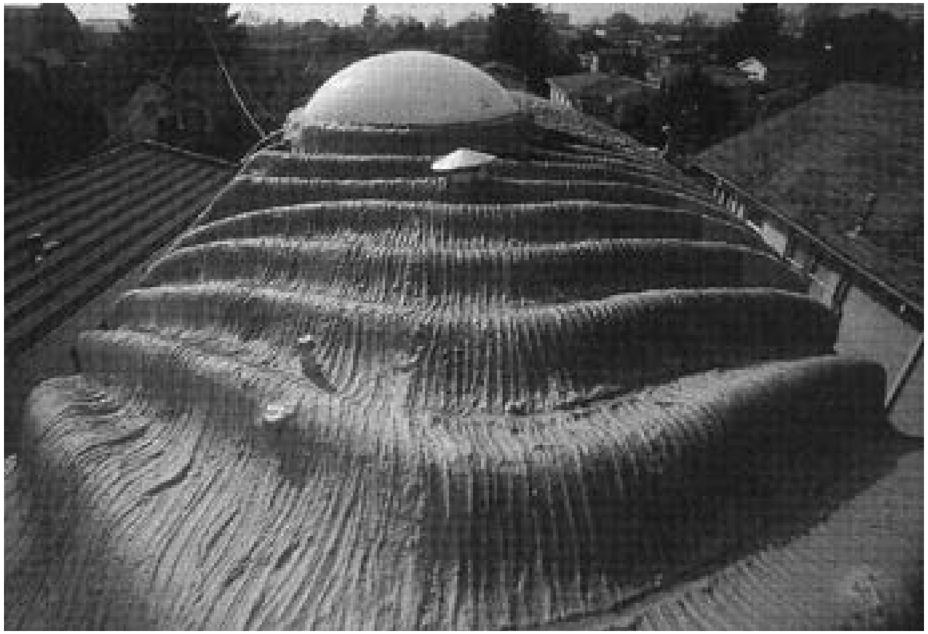
Homeobox genes control the body plan of the adult plant, as in animals, but the body plan is not evident in the "embryo" or young shoot when the first growth begins from the seed. Plants differ from animals too in that the stem is capable of developing branches, leaves, and the cones or flowers of its reproductive system throughout the life of the plant. The body plan is adaptable to environmental conditions, developing morphologically and functionally according to sunlight, temperature and nutrients. There are only four basic body plans for plants; the unicellular, the colonial, the syphonous and the multicellular; and each have their own method of growth. Unicellular plants such as the green algae Chlamydomonas are the most ancient, and the significant differentiation between unicellular and colonial plants is that unicellulars remain independent and do not aggregate. Unicellular organisms are typically very small, which has the advantage of a

Greg Lynn
Predator
Columbus, Ohio USA (2000)

large surface area relative to the contained volume, making the metabolic process very efficient. Because of this ratio of surface area to volume, smaller organisms rapidly absorb nutrients through passive diffusion, process them efficiently, and grow and reproduce speedily.[17] This makes them able to respond to favorable environmental conditions which may be brief or seasonal to complete their life cycle, remaining dormant in unfavorable conditions.

Most of those advantages are maintained when single cells are aggregated together. Siphonous plants typically have a cylindrical geometry as the module to be iterated in the construction of the body. A cylinder of any size always has the same ratio of surface area to volume. In aggregation each cell retains its individual capacity for rapid growth and reproduction, and in appropriate geometrical arrangements, metabolic activities can be coordinated. Syphonous and Colonial plant systems achieve greater overall size by aggregating are not strongly differentiated or specialized in themselves. An interesting colonial plant is the alga Water Net (Hydrodictyon), which has an ordered morphology like a hollow sack, made up of a "mesh" of cylindrical cells lying against each other. Each cell has to be morphologically similar, and to contribute to the global colonial morphology.

Large land-based multicellular plants require differentiated tissues that are specialized for the vertical movement of nutrients, as leaves and branches became increasingly elevated from supplies of nutrients and water at ground level. Vascular tissues are typically located in the central axis, where they experience the lowest tensile, compression and torsional shear stresses—but in this position they are less effective structurally. Other tissues surround the vascular bundles that are differentiated with higher structural capacity to respond and adapt to environmental



Eugene Tsui
Ojo del Sol
Berkeley, California USA (1993–1995)

stresses and dynamic loadings of gravity and wind pressure.[18] The differentiated distribution of cells, fibres and bundles, according to height and slenderness, produces variable stiffness and elasticity within multicellular plants. Variations in the section produce anisotropic properties, and a gradation of values between stiffness and elasticity along the length of the stem that is particularly useful for resisting dynamic and unpredictable loadings.[19] It is clear that body plans across very widely different plant lineages have converged on remarkably similar anatomies and morphologies (and similar structural solutions), even though they organize growth quite differently.

Adaptive Radiation

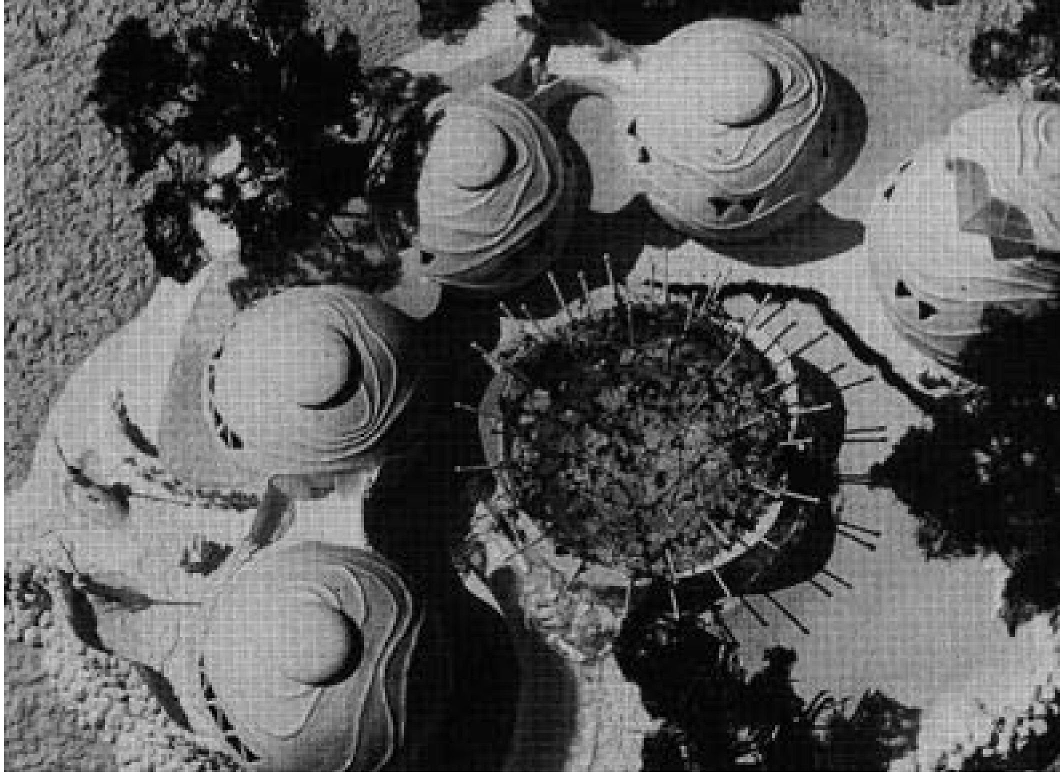
In periods of severe climate change extinction events occur. There have been five major mass extinction events, each of them featuring extensive glaciations and a retreat of living organisms to a narrow zone around the equator. The biota and the environment recovered after each event, but it took evolution tens of millions of years in each case for the full recovery of biologically diverse ecosystems.[20] Innumerable lesser events have occurred, either at local or global levels, and it is clear that climate and environment play a significant role in speciation. New species arise from a common ancestor species, acquiring new adaptations to a changed environment, expanding their geographical range and further differentiating into multiple descendant species. These in turn will fall from dominance when a new and different climatic change occurs, making way in time for the rise of a new, better adapted species. This process of differentiation, known as adaptive radiation, has been replayed in endless iterations, and some species may be stable for millions of years before disappearing rapidly when the ecosystem is disrupted. The new ecological

Santiago Calatrava
East Station
Lisbon, Portugal (1993–1998)

niches will be rapidly filled by many new species.

Adaptive radiation also occurs within stable climatic periods. The clearest examples of the dynamics of adaptive radiation are in isolated habitats, such as islands and archipelagos. Isolation tends to make the movement of organisms into the habitat rare, but when such a migration event does occur, it is followed by rapid evolutionary divergence. In the original mainland habitat other species may have filled all the available ecological niches, so providing no opportunities for variant forms to diversify. On the island there may be vacant niches. The availability of unoccupied ecological niches, combined with the absence of competition and predators, presents maximum opportunities for colonization. The ancestor of the finches on the Galapagos Islands was a ground-dwelling, seed-eating bird, and must have migrated millions of years ago the 800 miles from Ecuador. One original migrant species evolved into the 13 distinct species of finch that Darwin observed, some species living on cactuses or trees and eating seeds and other species living in trees and eating insects. Darwin noted the gradation of size and morphology in the differentiation of the beaks, some with slender beaks that they use to catch insects or drink nectar, some with shorter, stronger beaks that are used to crack open seeds.

As a lineage rapidly diversifies, the newly formed species evolve different morphologies and behavioral adaptations. The Galapagos is the site of extensive adaptive radiations of many kinds of plants and animals.[21] As on many other remote island sites, members of the plant family Compositae (including weeds, lettuce and herbaceous flowering plants) have successfully colonized the majority of the available ecological niches. Most trees of the tropical and temperate climates do not disperse seed very far from the parent, and these seeds do not survive immersion



Eugene Tsui
Watsu Center at Harbin Hot Springs
Middletown, California USA (1991–1999)

in salt water. Weeds, by contrast, have many wind-driven dispersal mechanisms for their hardy seeds. Once established on the oceanic islands which were devoid of trees and shrubs, Compositae rapidly speciated, and evolved from herbs to shrubs, and from shrubs to trees. Adaptive radiations always involve a response to an ecological opportunity, including the evolution of a new functional adaptation that allows the organism to exploit previously unexploited resources. The geographical dimensions of the habitat are a constraint on adaptive radiation- an island will suffice for insects, birds and plants, but it takes a continent- sized habitat for mammalian speciation. All contemporary mammals are the product of three great radiations.[22] Amongst all species, it is the dominant (most numerous in comparison to other related groups) that are prone to experience adaptive radiation.

Coda

As mutations to the known forms of organisms occur naturally, so too have the small innovations, theoretical "errors" and design mutations of ancient architectures produced the "populations" or cities of buildings, and driven the historical evolution of architecture, with its limited morphologies and convergent set of available forms. The significant recent changes to culture, climate, and energy economies have destabilized the equilibrium of the cultural and physical ecology in which architecture lives.

Architecture is within the horizon of a systemic change, driven by the changes in culture, science, industry and commerce that are rapidly eroding the former boundaries between the natural and the artificial. The material practices of contemporary architecture cannot be separate from this paradigm shift, as the context in which architecture is conceived and made has changed. In the natural world change is normal, but its intricate choreography is

Antoni Gaudí
Casa Vicens
Barcelona, Spain (1883–1885)

now further accelerated and perturbed by human activities. Global climate change is upon us, and its effects will be local and regional—more energy trapped in weather systems produces emergent behavior and consequences that are not entirely predictable. So, too, the emergent behavior of local economies and cultures, now connected and interlinked globally, are substantially reconfigured.

The cultural and physical parameters of the ecology from within which a new architecture is emerging are clear. The ecological opportunity that has arisen is part of the growing cultural fascination with fluidity and dynamics, with networks and new topologies, and with soft boundaries between private and public domains, and between interior and exterior space. The experience of being in spaces that flow one into another, where differentiation between spaces is achieved less by rigid walls than by extended thresholds of graduated topographical and phenomenological character, and in which connectivity and integration are enhanced, is central to contemporary existence. Other parameters determining the evolutionary course of the new architecture are the changed parameters of climate and economy, of technologies and means of production.

The study of natural systems offers many models for architecture, and suggests the means of conceiving and producing an architecture that is more strongly correlated to material organizations and systems in the natural world. Architecture must make a positive contribution to the environment, construct a more symbiotic relationship with nature, and can do so by developing morphologies, material systems and metabolisms for buildings and cities that extend far beyond the minimizing environmental strategies of "sustainability." We learn from the systematic study of the "errors of nature" that singular macromutations, even when fully functional and well suited to a previously unexploited

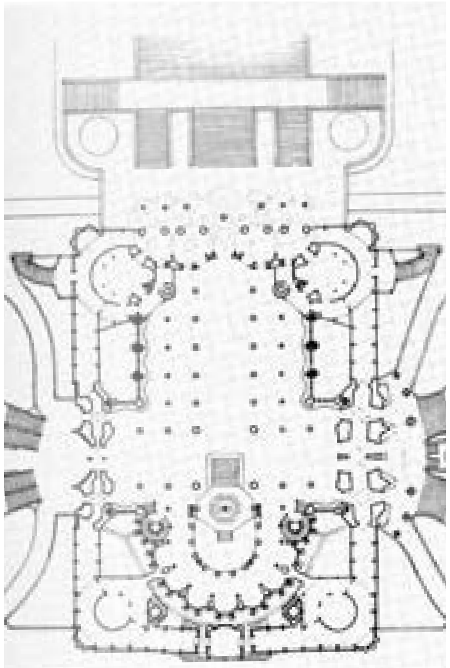
Eugene Tsui
Catanaria
Brentwood, California USA (1984)

environment, do not have the potential to become new species. The "hopeful monster" will recur in every generation but is an evolutionary dead end. Sustainability is the "hopeful monster" of this generation, the Cyclops of the new ecology. The concept of sustainability, insofar as it can be said to have a concept, contains little more than a set of mitigating strategies to reduce the impact of human activities on the biosphere. It offers, at best, the continuity of things continuing as they are, albeit in a slightly cleaner physical environment; and it is by no means clear that reducing the impact of human activities will have such an effect. There is a fundamental, potentially fatal, misreading of the coupled processes of the natural complex systems of climate and ecologies.

The new emerging architecture that relates pattern and process, form and behavior, with spatial and cultural parameters, has a symbiotic relationship with the natural world. The design and construction of a symbiotic architecture must be the product of the mathematical and physical properties of living matter. This is part of the contemporary reconfiguration of the concept of "nature," a change from metaphor to model, from "nature" as a source of shapes to be copied to "nature" as a series of interrelated dynamic processes. As energy plays a critical role in differentiation at all biological scales, from the cell to the ecosystem, so energy flows and morphological differentiation, co-evolution, and speciation in ecological systems offer a metabolic strategy for buildings and cities that recognizes the dynamics of natural systems, and incorporates them. The conditions for the successful proliferation of a new symbiotic architecture into new ecological niches, the colonization of cities and towns by new morphologies and behavioral adaptations, are suggested by the study of Adaptive Radiation.

Santiago Calatrava
Campo Volantin Bridge
Bilbao, Spain (1990–1997)

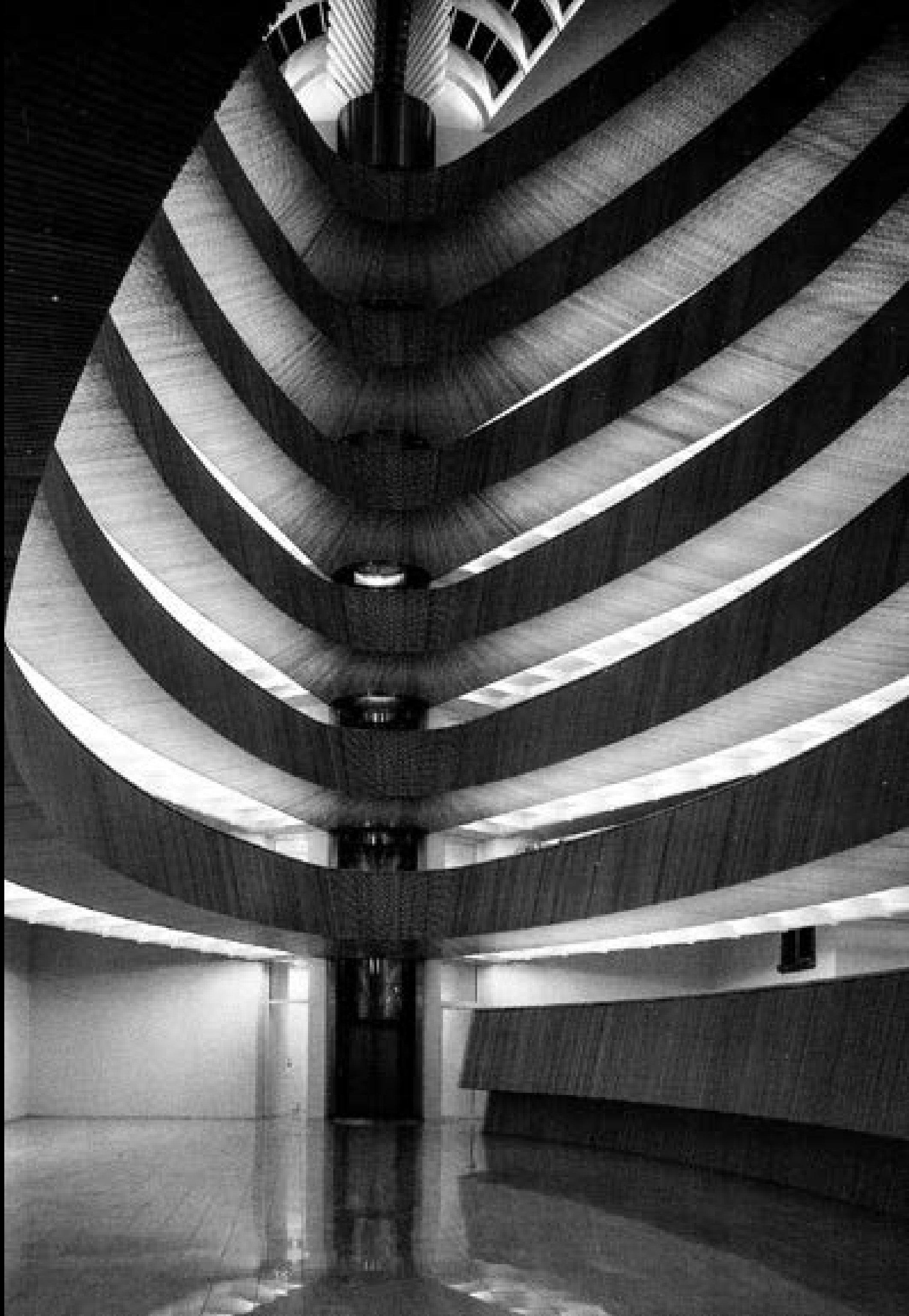
Santiago Calatrava
Olympic Site
Athens, Greece (2001–2004)



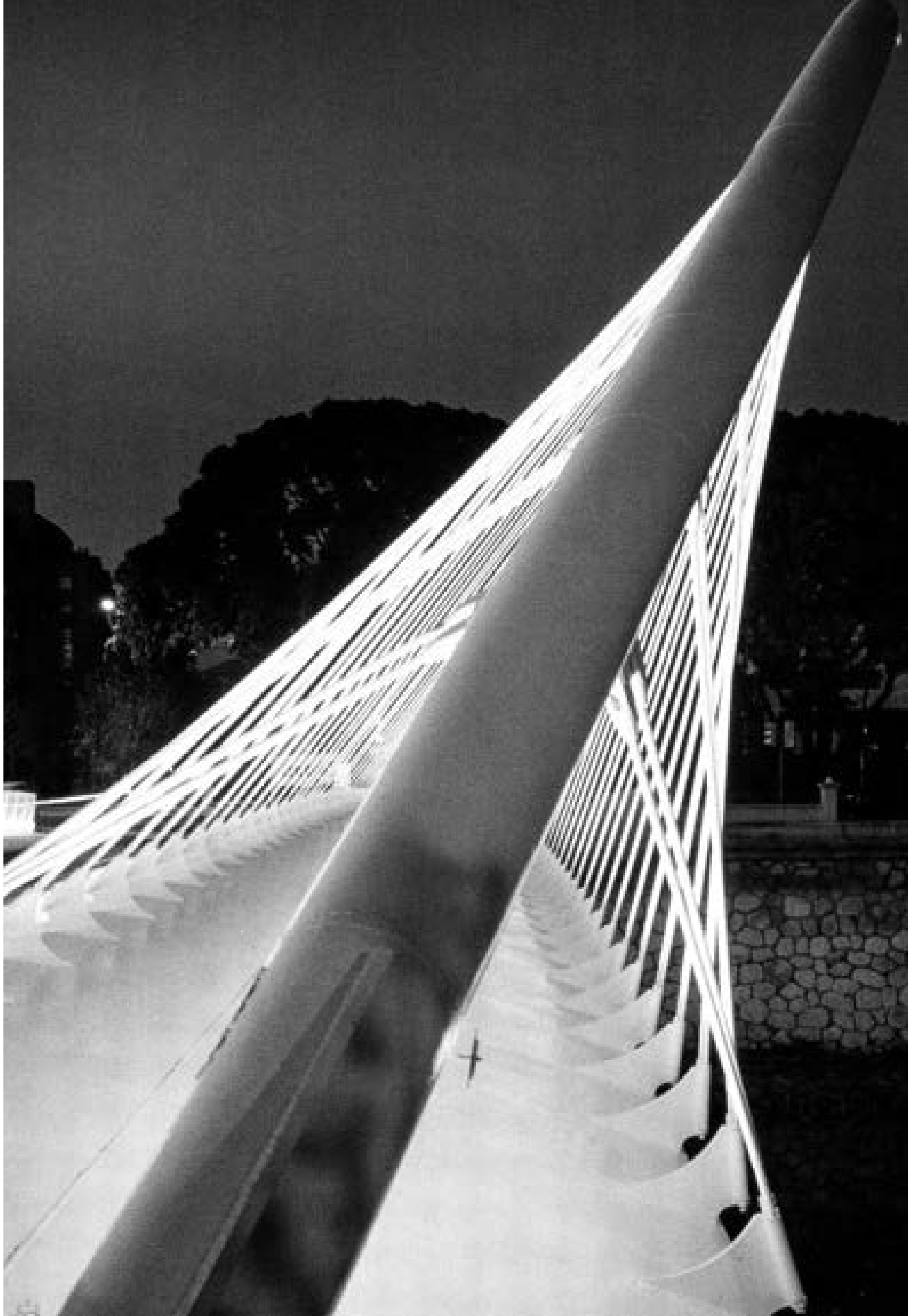
Antoni Gaudí
Church of the Sagrada Familia
Barcelona, Spain (1882–1926)

Architecture as Nature: A Biodigital Hypothesis

Dennis Dollens



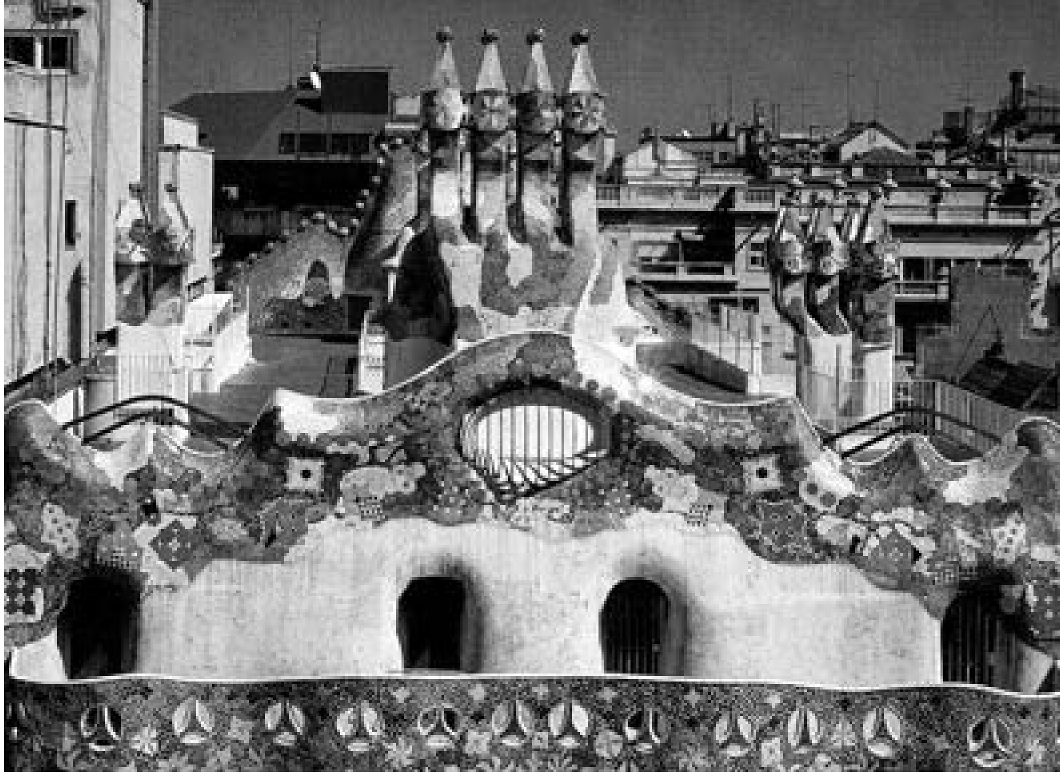
IN WHAT follows, I present an understanding of properties and attributes of nature and how they may be selectively transferred to digital design, while simultaneously speculating on the potential of biodigital architecture. Additionally, I focus on the process of thinking as a generative, biological design operation—a genetically driven process of living cells and subatomic forces meeting perceptual, remembered and imagined reality and thereby streaming spontaneous impressions, interpretations or visualizations as ideas within our biology of consciousness. From this formulation—necessary for conceptually bonding design with nature—I conclude that nature produces design and architecture. This hypothesis, embodied in the syllogism below, seems obvious: All consciousness and thinking are components of life and thus parts of nature All design and architecture are components of



consciousness and thinking Therefore design and architecture are parts of nature. My syllogistic recipe associates the process and product of thinking—generative ideas—as elemental nature, even while I caution that syllogisms are demonstrations, not proofs.

Some generative ideas lead to physical design resolved through object-making using nature's materials—ideas embedded in architectural results. The making of tools, ceramics, knots and fabric (among the earliest known craft products) aided humans' development of agriculture concurrent with shelter building.[1] According to this line of conjecture, the technologies of farming, craft and building cross-pollinated each other. The first buildings were thought/idea/hand extensions of the environment and the builders' needs. These original buildings—shelters—were akin to other living organisms' evolved nests, hives and burrows and may therefore be understood as genetic/cultural expressions—extended phenotypes, as discussed in evolutionary biologist Richard Dawkins's book The Extended Phenotype.[2] Furthermore, it is plausible that crafts such as ceramics, weaving, knotting and adobe building were biomimetically appropriated—that animal and insect shelters were observed and extrapolated from by our designing ancestors.[3]

The merging of design thinking into a collaborative union with Darwinian science via extended phenotypes and generative ideas is related to our conscious participatory roles in nature. Such merging is seemingly fundamental for reconstructing a working, sustaining environment—balancing the rights of nature while also causing bioarchitecture to evolve with it. In the push toward integrated practices of designing with nature, important first chapters have been written and arguments voiced by animal rights and environmental advocates, theorists and philosophers. While I see little evidence that these chapters have been widely



Antoni Gaudí
Casa Batlló
Barcelona, Spain (1904–1906)

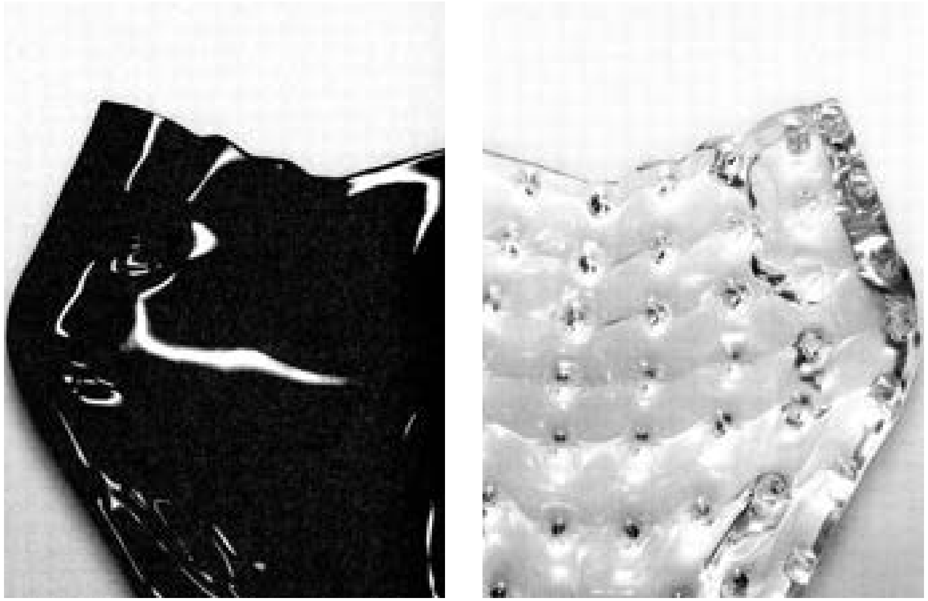
embraced by design professionals, let alone informed university design programs or urban planning agencies, they are nevertheless indispensable for transplanting bioethics from animal protection, wilderness, landscapes and garden theory to physical design.[4]

If architecture, urban planning and design can be reconceived as natural extensions of human genotypes and seen as expressions of nature, then the development of cultural, environmentally synthesized biodesign might face fewer social and political dead ends. Information from plant and animal morphology, algorithms and biochemistry mediated through the designer's vision and mediated again through software and digital fabrication is creating a species of biomimetic ideas that index nature while propelling design and architecture into the living, organic world. In an age of urgently needed bioremediation, an expanded conceptualization of matter, molecular bonds, atomic forces and design—in relation to life, ideas, designing and thinking—could evolve, revealing embedded ideas as a subcategory of molecular life in objects. To amend the poet famously saying "No ideas but in things—Invent!"[5] we might speculate that ideas are things.

Digital-Biomimetic Architecture

If designing a building to digest carbon monoxide, purify air, recycle water, harvest power and cool itself; retrofitting older buildings with biological functions supporting an endangered plant or bird; or utilizing firefly and jellyfish proteins for bioluminescent cladding are not emerging visions in planning, design and architecture, then the model of today's design profession is inadequate. Consider organisms creating shells, silk, bones or wax—for example, sponges such as Euplectella aspergillum fabricating silica skeletons excreted underwater, at low temperatures, using enzymes and water-borne minerals—and then ask why that process cannot

Greg Lynn
Chess Set for Dietch Projects
New York, New York USA (2001)



be mimicked to make bridges, highways and buildings.[6] I think a biomimetic design profession is coalescing, nurturing an emerging architectural paradigm wherein digital computation, generative scripting, advanced fabrication, bio-materials and nature develop new systems, forms, structures, aesthetics and materials.

Upgrading equipment and software for visualization and digital simulations of organic life is critical for biodesign's systemic and aesthetic viability. Studio and classroom doors need to be opened to design research using technical and scientific imaging, biosimulation, programming, microscopy and other visualization processes not traditionally associated with design. Our current emphasis on aesthetics is excellent, a great strength, but one-sided aesthetic production requires appropriate evolving materials and technologies, and questions are quickly arising: Why cannot buildings be organically sensitive; smart as well as aesthetic and technically benign?

Computational generation and analysis of clustered forms or fractal surfaces, instead of single, rectangular building envelopes, using, for example, liquid photovoltaic units sprayed on highly faceted surfaces, are procedures waiting to be tested. So too are material formulas, 3D weaving, soft tensegrity, folding techniques, geometries and spatial relationships (from nature and traditional cultures) waiting to be applied in shelters, buildings and cities.

Ongoing and intensified research is hinting at the anatomical and morphological performance of future architecture. Structures with clustered units, mimicking, perhaps, the distribution of flowers around their stalks, present alternative fluid dynamics as well as aesthetics differing from most current building typologies. Self-reconfiguring building skins may filter both urban noise and airborne toxins; new membranes and monocoque could monitor interior and exterior light and provide self-shading

Antoni Gaudí
Teresian Convent School
Barcelona, Spain (1888–1890)

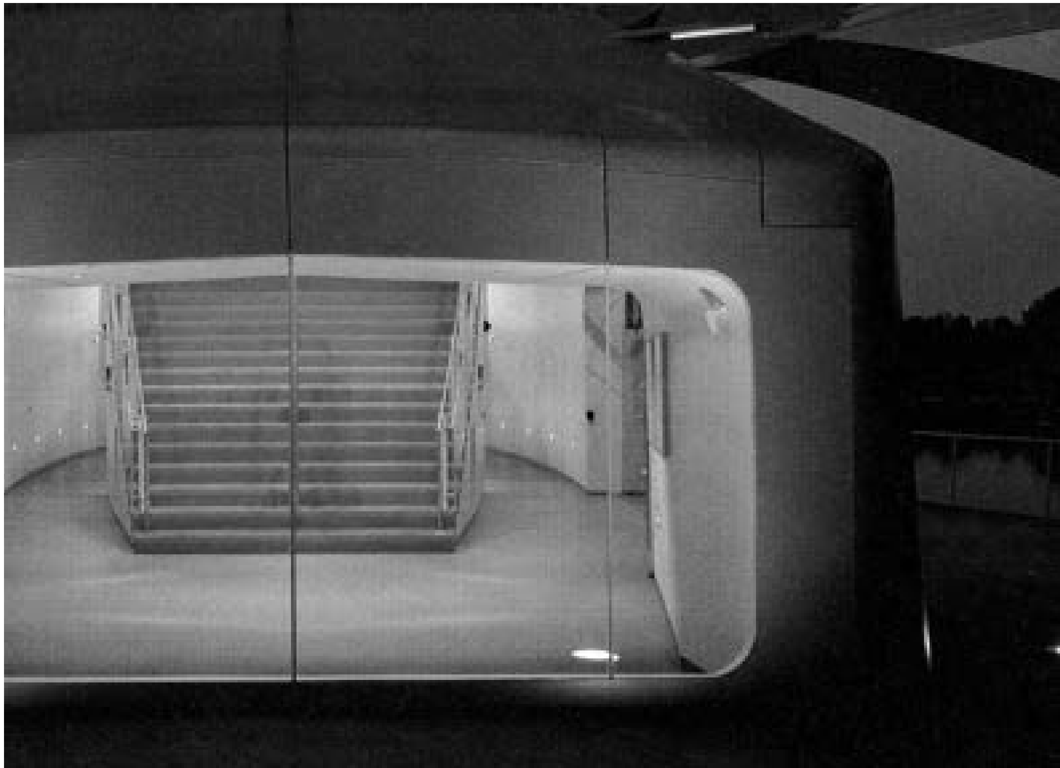
temperature control. Non-rigid cladding could be reconfigured as pleated surfaces harvesting rain runoff follow- ing cues from unfurling leaves. Flowers, plants, skeletons, fish scales and shells provide some immediate visual and biological attributes for experimentation, as well as inspiration for architecturally unexplored forms, geometries, living and mechanical systems, stacking and twisting protocols and generative mathematics. (To be clear: I am not advocating architecture or design that looks like flowers, shells or animals.)

Synthetic Life as an Architectural Component

If we design new forms, botanic relationships and genetic procedures for hybridizing cities and buildings, we will be able to better comprehend, extend and design for the more difficult proposition that cities and buildings could evolve with environmental intelligences. For example, molecular breakthroughs by teams working with genome-sequencing scientist J. Craig Venter have, as The New York Times reports, "successfully transplanted the genome of one species of bacteria into another," demonstrating that synthetic life may be an answer (one of many needed) to environmental problems.

The development of a synthetic bacterium is intended, for example, to "make cells that might take carbon dioxide out of the atmosphere and produce methane," reducing dependency on fossil fuels.[7] Related discoveries may address water recovery in drought-stressed areas and eventually feed toxic waste to single-celled microorganisms for onsite, in-building water treatment, sewage processing, passive water cooling and advanced greenwall and garden cultivation.

Asymptote Projects
Hydra-Pier
Haarlemmermeer, Netherlands (2001)



Immanent in Venter's experiments, as well as in those taking place in other labs, is the transformation of existing modes of science, culture and styles of living. Shifting our perspective of the natural world to accommodate biological forces is notoriously difficult. Extrapolating from science, Venter's for example, into design practice and theory is equally difficult. Yet doing so beneficially may yield architectures imbued with living or life- like systems hosting bioremediating bacteria, algae, lichens or plants in parallel with software monitors, mechanical activators, bio/ digital sensors, computational robotics and AI.

If we more generously credit mineral elements and molecular forces as constituents of life and consider employing bacteria and synthetic biology in architectural processes and materials, we may graft into building components not only information from science and technology but also from organisms—transforming architecture into living systems. Hybridization may guide design and architecture toward the realities of embedded biological intelligence and/or biomechanics, for example genetic fluorescence or subcutaneous bioluminescence. Biomaterials, biological intelligence and/or self-sustaining life may eventually provide architecture with materials and infrastructures, perhaps energy, for environmental sensing, actuator and robotic controllers, and biocomputation.

By hybridizing cities and their subsets of neighborhoods (and neighborhood subsets of buildings) as passive bioremediators, we could begin to categorize them as proto-natural. Seeing them as structures and organisms with biological potential, possessing vast vertical surfaces and valuable wall membranes, we might cultivate them as urban lungs, pollution sensors, air filters, information nodes and vertical parkland. Fostering existing urban assets, we may eventually bring biodesign into closer proximity with day-to-

Antoni Gaudí
Casa Batlló
Barcelona, Spain (1904–1906)

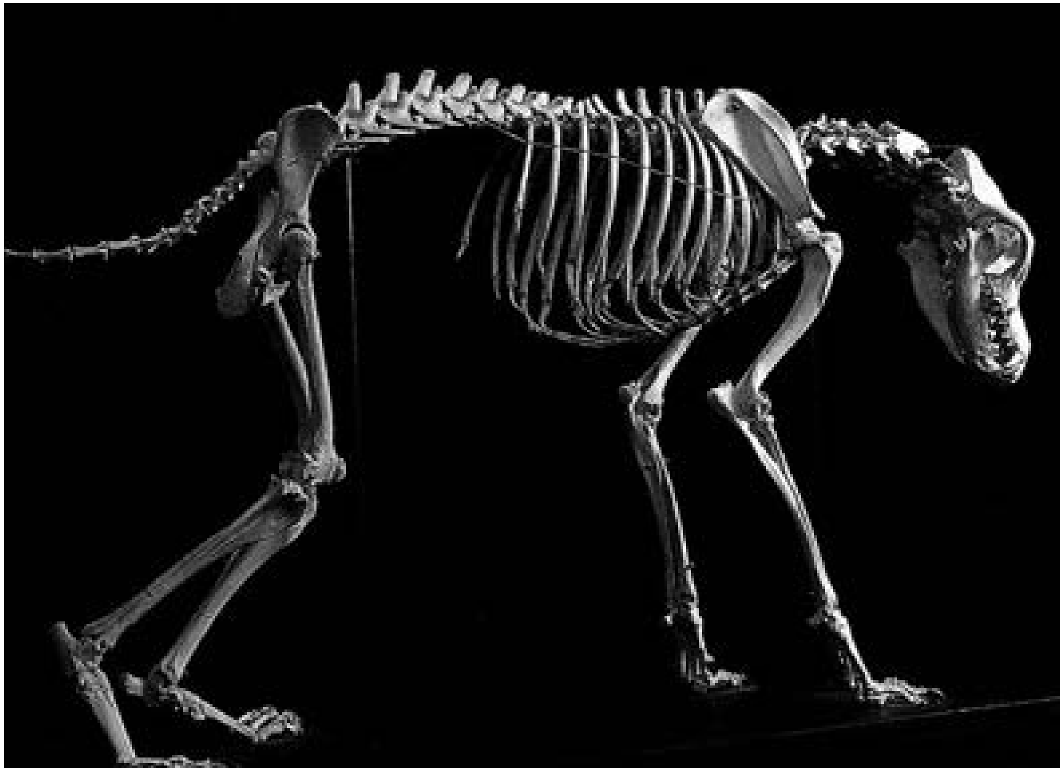
day living, slowly upgrading old buildings and streets into living systems. Casting a positive atmosphere for biodesign and digital biomimetics is therefore critical for reversing perceptions that architecture and urbanisms must be large, dead objects.

Retrofitting existing structures with materials and organisms for evolving low- and high-rise bio-typologies will help convert environmental liabilities into environmental assets. Enabling buildings, not only with functions found in plants or bacteria but also with electronic sensing and instant communications, gives them biodigital tentacles into regional information systems. Biosensing and bioresponse abilities may further join participating structures into global networks with benefits ranging from disaster warnings, peak energy adaptability, urban temperature control and microclimate oversight. Additionally, chemical, light and proximity sensing are plant attributes viable in digital/biological architecture. Buildings could enlist botanic sensory and social abilities for recognizing and responding to allergens or differing light wavelengths, thereby creating responsive environmental/architectural interfaces.

Nature Dead/Nature Alive

Contemplating the ethical and theoretical landscape for the emerging fields of genetic architectures, bioarchitecture and biomimetic design is a project needing widespread and concentrated effort on the parts of many teams and individuals. Toward this goal, I found in John Rajchman's introduction to Pure Immanence by Giles Deleuze a constructive observation outlining what Deleuze learned from Hume. Rajchman, Deleuze, and Hume teach ways of being in a social, civil and material world. I think Rajchman's view applies beyond his philosophical subject, becoming significant for us in his discussion of design's

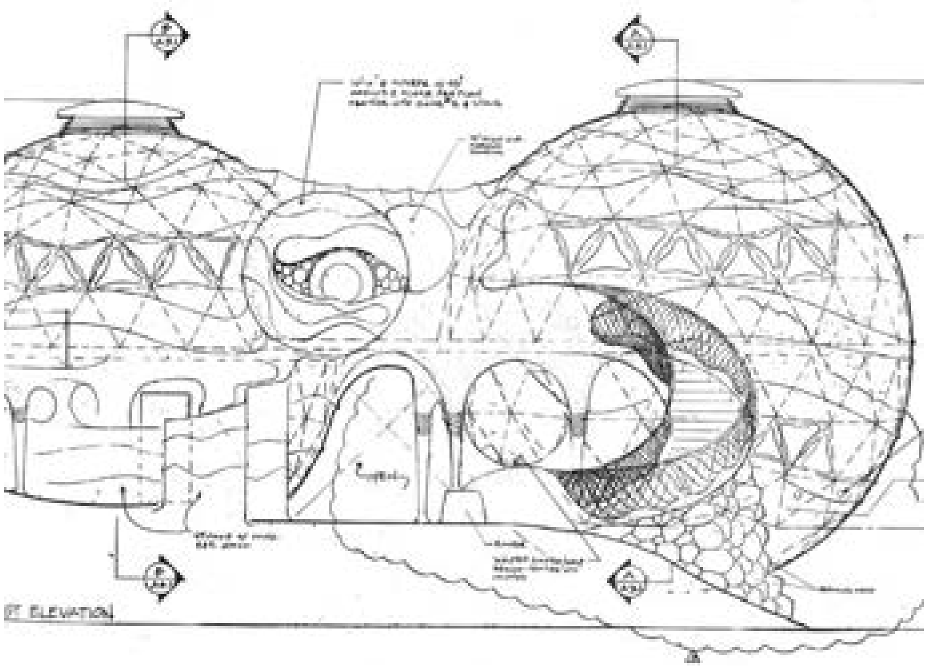
Dog skeleton in Calatrava's office



environmental place in nature. Furthermore, Deleuze's theoretical construct, immanence—a state of becoming—itself emerges as an important procedural thought-tool reinforcing the conviction that architecture and design ideas exist as parts of nature—social, civil, technical and biological. Rajchman tells us: "What the young Deleuze found singular in Hume's empiricism is then the idea that this self, this person, this possession [individual consciousness], is in fact not given. Indeed the self is only a fiction or artifice in which, through habit, we come to believe, a sort of incorrigible illusion of living; and it is as this artifice that the self becomes fully part of nature—our nature."[8]

Rajchman and Deleuze understand consciousness as epiphenomenal and emergent. To backtrack for a moment, this consciousness appropriates (via sense perceptions) environmental data interacting with generative idea structures, embedded culture and intuitive environmental knowledge—a trait often viewed in the natural world of insects as hive- mind but resulting for us in both generated and generative ideas encompassing aspects of how we colonize nature.

Nature colonized—for example, tract housing in a wetland—becomes as environmentally dysfunctional as its colonizers were environmentally ruthless. In our stereotyped view of nature, which excludes places like concrete jungles and reclaimed coastlines, we make the mistake of further alienating ourselves from nature. Likewise, not considering our thinking and designing process as well as their resulting building as part of nature, we unnecessarily and irresponsibly simplify our natural presence. In the process of idea making, perceptions modify biochemical and cultural factors, linking physical and virtual information with biological process. By expanding our understanding of wild and environmental nature to include all human nature and habitat, we move from a self-



Eugene Tsui
Ojo del Sol
Berkeley, California USA (1993–1995)

serving tunnel view to one in which actions and consequences must be weighed with criteria that take into consideration other species and terrain attributes. Within such an environmental scope, human- extended phenotypes (i.e. architecture and design) may conceptually stand equal to naturally occurring habitats such as nests, webs and hives.

Our built environment is extrapolated from nature, cultural traditions and inspiration, while simultaneously conscious- ness is merging the world of matter and molecular forces. Animate life, inanimate matter and natural forces may thereby be understood as factors perceptually employed to define our working/living environment. Ideas are one consequence of human life within nature—thought's union of forces, perceived information and chemicals—the mechanism through which Rajchman/Deleuze's "incorrigible illusion" comes to sustain our seemingly unique mental being and the process from which organic ideas grow.

The Plyword

In the first layer of a three-part word lamination, I am grappling with the above conceptual framework in order to ply Deleuze's immanence with monad, a root- bound word usually associated with Gottfried Wilhelm Leibniz's philosophy.[9] (Monad, as evolved for this text, should be understood to include ideas as atomic-scale, thought-particles and/or molecular forces, resulting from our cellular, electromagnetic and chemical brain processes.)[10] This definition, fused with immanence, unfolds as a pliable conceptual apparatus able to explain monad as a virtual mechanism that includes delayed development and emergence: properties found in immanence. The third layer, extended phenotypes, imbues the first two with ideas extended into physical materials (Dawkins's

Antoni Gaudí
Church of Colònia Güell
Barcelona, Spain (1890–1915)

theory introduces the mechanism of genetic extension into the context of physical constructions).

This etymological laminate thus aids an old-growth metaphysical idea embodied in monad, helping it evolve and counter the widespread, bipolar conception that the environment is simultaneously animate and inanimate and that human actions, including building, are outside of nature. It does so by filtering our understanding of nature through Leibniz, Rajchman/Deleuze and Dawkins, accounting for, and redefining, ideas as quasi-living and therefore capable of extending ideas into things as extended phenotypes.

If we reconceptualize our generally limited notion of alive/dead as synonyms for organic/inorganic and inclusively redefine the inorganic as life giving, recognizing elements, molecules and forces as proto-life, we may consequently revivify our views of organic/inorganic nature. It is useful to pause to remember that the components of our bodies are inert gases and minerals: oxygen (65%), carbon (18%), hydrogen (10%), nitrogen (3%), calcium (1.5%), phosphorus (1.0%), potassium (0.35%), sulfur (0.25%), sodium (0.15%) and magnesium (0.05%). These are only the first 10 elements—but they testify to the union of animate processes and inanimate materials in biology and thought. Forces and molecular clusters fit as components of generative ideas linking life, consciousness and thinking—through nature—to human-made objects, design and architecture. Therefore, formulating nature to include all works and workings inherently redefines what is environmentally permissible in a moral society. Seeding an environmentally integrated design hypothesis, we are only 60-some years behind Alfred North Whitehead's advice: "We should conceive mental operations as among the factors which make up the constitution of nature."[11] With the role of minerals, chemical

Santiago Calatrava
Alamillo Bridge
Seville, Spain (1987–1992)

interactions and elemental forces (gravity, electromagnetism, the weak and strong forces) shadowing a constitution of molecular ideas, we may fall in step with Whitehead, further recognizing idea-generating systems in ways related to technology, philosophy, science and design.

Designing through this or a related hypothetical filter, we may renegotiate architecture and urban infrastructures as pliable and elastic, like trees, and thus seismically adaptive. Through this filter, building materials can be made to biologically mimic nature's leaves, shells or crusts, becoming semi-native and eventually environmentally non-invasive. Thereafter, architecture and cities may function more like biological organisms, biological circuits. More immediately, we come to understand idea-extension as design grown within nature resulting in craft, electronics, horticulture, industrial design, urbanisms and architecture.

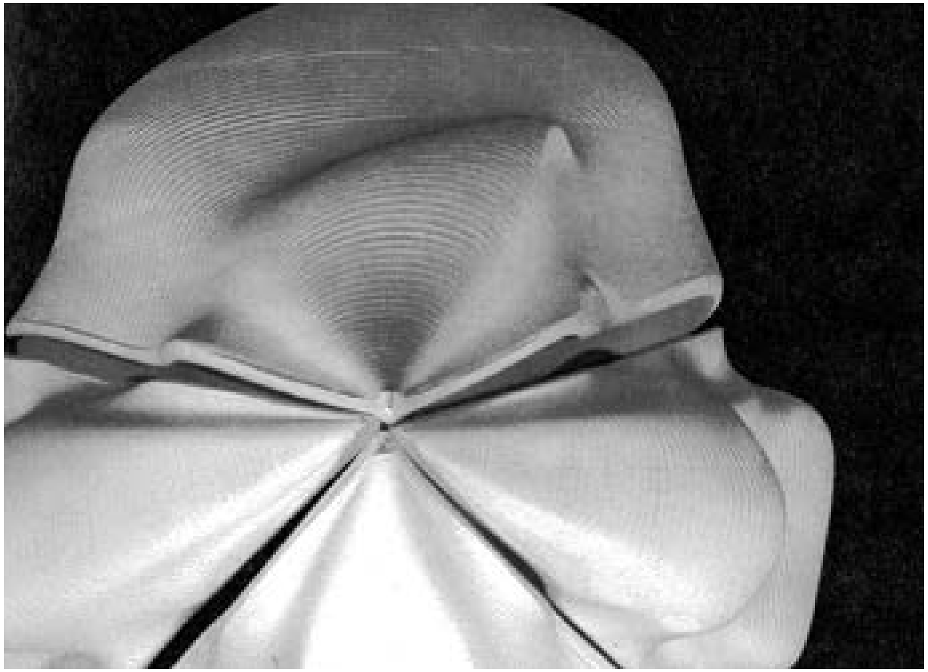
BioArchitecture

Historically the frontiers of cyborg design have been staples of theory and science fiction; robotics, technology, organic bodies and medicine are symbiotic and/ or synthesized. Yet medical frontiers visualized in cyborg body-space rarely appear in larger technologies such as buildings or cities. The lack of porosity between medicine/biochemistry and design is limiting advanced architectural visualization and experimentation. Architecture and design must learn, appropriate, transform and envision prosthetics or pharmaceuticals able to enhance buildings in ways medicine serves for people, plants and animals. Thus, while medicine may be approaching an era of post-cyborg genetic interventions, architecture has yet to enter an equivalent era of bioprosthetics or biomechanics (assuming one does not count greenwalls and greenroofs as cyborgian).

Santiago Calatrava
Lyon Airport Train Station
Satolas-Lyon, France (1989–1994)

Medical, agricultural, bacterial and arboreal technologies could advance biodesign beyond current building and urban sciences. Interventions and medical prosthetics such as artificial hearts, joints, skin—as well as new experimental technologies focusing computational power and sensors to, for example, stimulate biological sight in individuals who have never seen, or computational and laser techniques exemplified by Lasik—are model interventions. Donna Haraway's "Cyborg Manifesto," in which Haraway contemplates hybrid technical-biological implants in organic systems, is meaningful in this discussion as a precursor.[12] Of the first steps toward bio- architecture, some will be prosthetic-like attachments or building amendments. Nevertheless, the premise of a seamless biological architecture is not science fiction, but will involve sci-fi-like radical extrapolation if we are to learn from stem cells, cellular signaling and protein folds and direct those designs toward an architectural biology, for example, of photosynthesizing walls or membranes. Relatedly and retrospectively, we may view and appreciate SymbioticA's art-biology experiments (pigskin cells grown over sculptural armatures) as pioneering bioarchitecture—as I have discussed in earlier texts.[13]

A biodesign hypothesis enables an appropriation and colonization of nature different from anything that has come before, placing emphasis on hybridized buildings with biomechanical and biological systems. It reorients our material and energy claims on resources, helping us to plot patterns for remapping/reorganizing urban settlements while ushering in self-regenerating systems for reducing toxic environmental stress. New settlement configurations will emerge, bringing opportunities for open space, urban forestry, gardening and wildlife habitat. Overall, rethinking our relationship with nature impels us to redesign existing, resource-



Greg Lynn
Alessi Tea and Coffee Piazza 2000
Verbania, Italy (2002)

draining structures and establish new design perspectives even as we grapple with extended phenotypes as part of nature. What Deleuze calls "our nature" underscores this process—nature not reduced to the binary of alive and dead, thought not understood as a cosmic or theistic phenomenon. Rather, our recognition is that thinking is part of nature, that designing is part of thinking and that consciousness and thought are environmentally dependent.

Bioarchitecture relies on the cultivation of thinking and critical observation for harvesting ideas and growing them as design ecotones (transition zones between habitats) overlapping with economics and supporting regional cultures. Speculating on a genetic link, we may understand human impulses to build, resulting in architecture, as allied with counterpart constructions in the wild, specifically witnessed in nests, hives, galls and mudworks. Designers pondering this evolutionary lineage recognize nature and cultural history as underexplored design territory. Our disposition to build cities, structures and objects is probably genetic—and not substantially different from termites' will to build solar-oriented, naturally ventilating adobe megastructures. Genetic derivation binds our urbanism, architecture and design together as biologically driven events implicating our cities in nature. Internalizing this hypothesis might alarm us into practicing environmentally safe building, underpinned by the need to prevent design from annihilating the works and environments of other species.

The trajectory of industrialization, manufacturing and materials leaves only sporadic traces of nature's nature in today's cities and buildings. Design's evolutionary path, which began with organic objects employed as implements—stone tools, sticks, hides, mud, blood and dung—continues, even if mostly repressed and unrecognized. We can look at the contemporary building

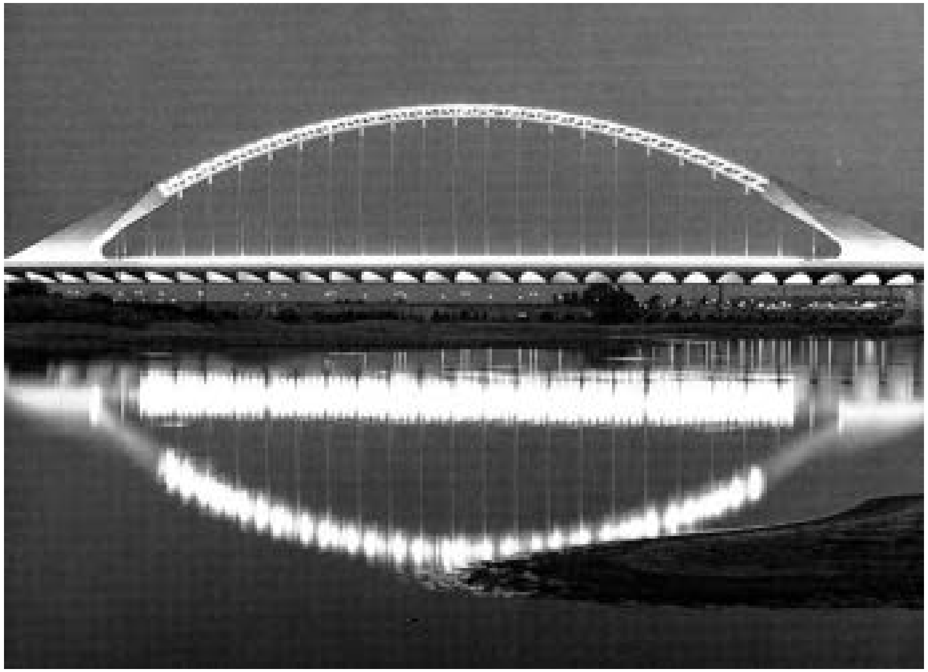
Santiago Calatrava
Museum of Sciences
Valencia, Spain (1991–2009)

undertaken by homeless people worldwide or we can study spontaneous urban organisms in, for example, colonias and favelas, to witness genetic building impulses manifested in constructed form. Architectural shelters built with found, appropriated and recycled urban materials—cardboard, plastic, fabric, rope, adobe, metal and wood-scraps, sometimes pirated electricity, water and WiFi—testify to an enduring, universal genetic disposition to build. Homeless-built and adaptive shelters demonstrate material and structural inventiveness evolving—and self-organizing on the basis of minimal resources and tools—for the builder's environmental and psychological comfort and protection.

The Mix

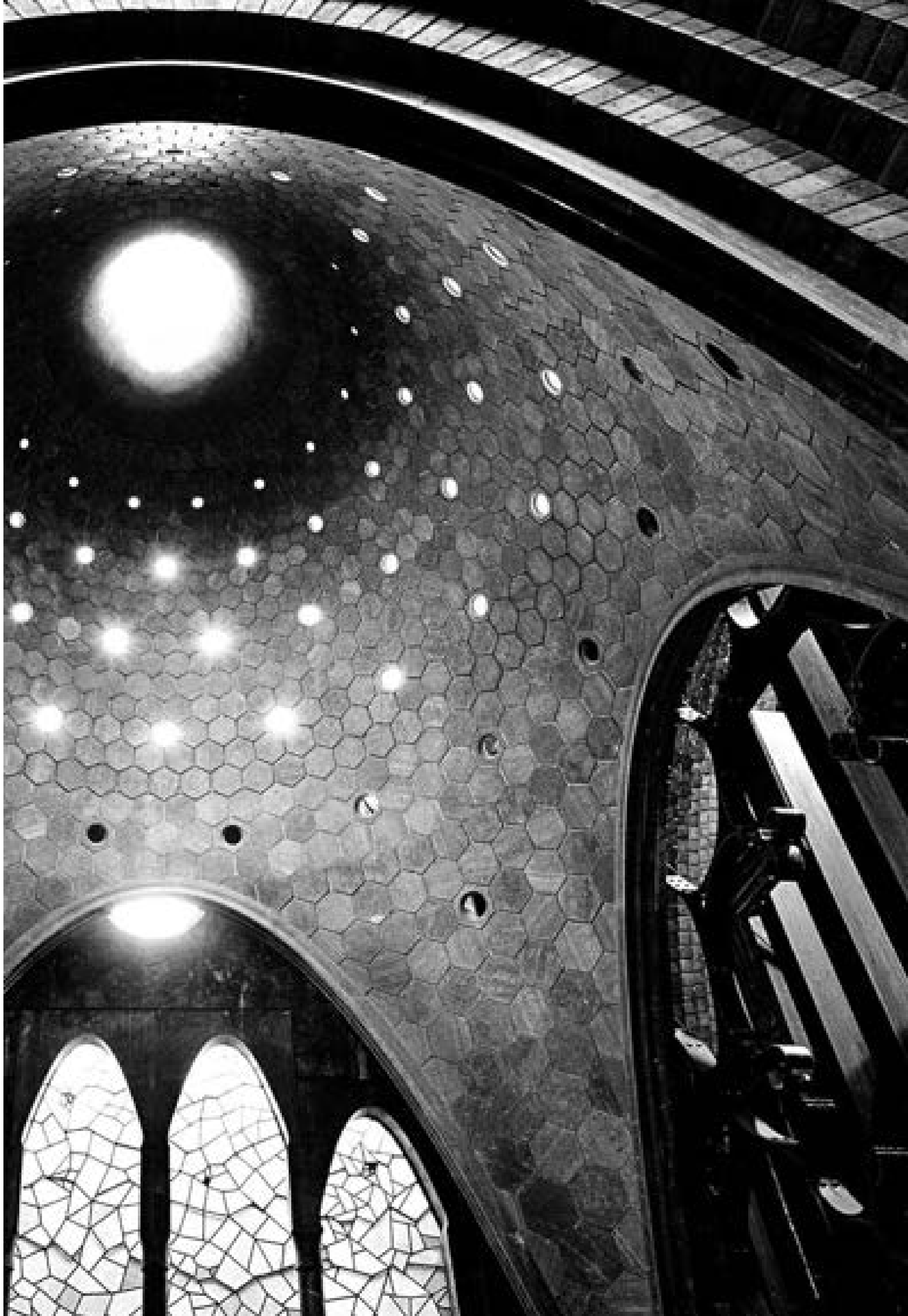
By appropriation, inference and extrapolation I am taking Leibniz's Monadology, Rajchman and Deleuze's Pure Immanence, and Dawkins's Extended Phenotype as pathways to a conceptual lattice for discussing ideas as genetic forces of nature and design as natural, extended phenotypes. The experimental projects illustrated earlier were designed—digitally grown—in an atmosphere of related thinking.[14] My intention is to bond idea generation (thinking), tool-making and handcraft (extended phenotypes), and space-making and materials (architecture/design) into a comprehensible hypothesis situating design and construction as natural. Hybridizing and invigorating Leibniz's monad theory with immanence's emergence and extended phenotypes' extension instills in this plyword a seed- like quality of idea germination.

Reflectively, the pleated etymologies imply first that ideas are contingently alive or a type of unexplained element-force and, secondly, that thought extensions are genetic. Posing the concept of idea-life as animating the word monad and folding it



Santiago Calatrava
Campo Volantin Bridge
Bilbao, Spain (1990–1997)

into the discussion of design-evolving-through-consciousness raises questions of cellular growth, neuronal processes, chemical reactions, trace elements and atomic forces as they pertain to consciousness, thinking and design. Accordingly, ideas as evolutionary forces and buildings as extended phenotypes unfold as genetic design process and product, with wide-ranging implications for bioarchitecture, urban gardening, city planning, wildlife and plant habitats and bioremediation, as well as future bio-industrialization. The upshot: If design conceptualization evolves, design will evolve. To quote part of a poem from William Carlos Williams: “So much depends upon a red wheel barrow.”[15]



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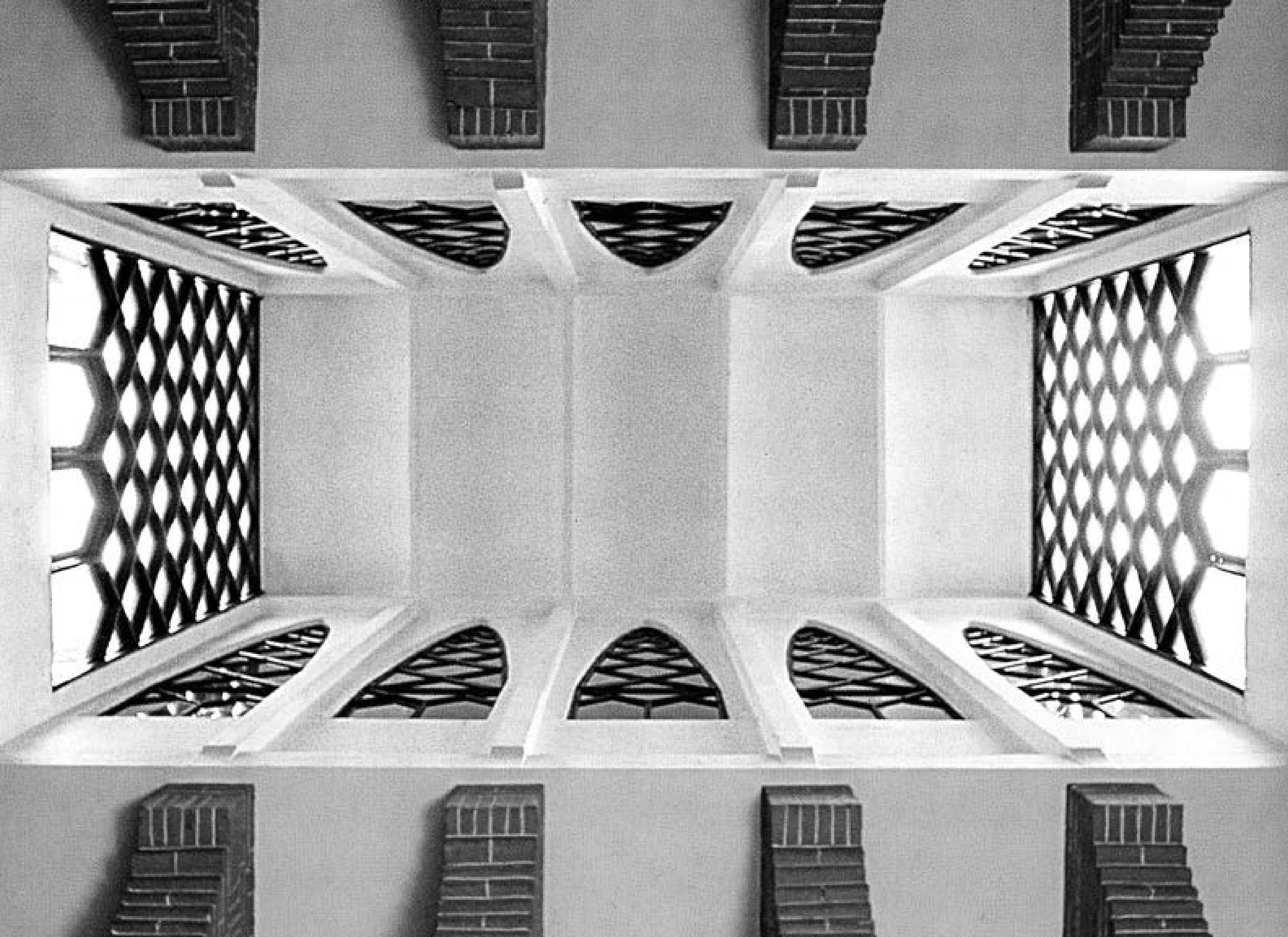

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