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 containing 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. Furthermore, flowers were conspicuous signs of the presence of food resources 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 [4], early humans were often confronted with threatening and demanding factors (e.g. predators) leading to physiological and psychological stress. 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 [5] notes a study finding that hospital patients with views of outside trees felt and recovered better, and required less pain medication, than patients with views of a brick wall.

There is evidence that unthreatening animals also positively influence human functioning and psychological development [6]. For example, Frumkin’s review [7] indicates that contact with animals reduces stress, is associated with fewer general health problems and lowers systolic blood pressure and cholesterol. An experiment by Friedmann and Thomas [8] reveals that survival chances of persons having suffered a myocardial infarction were higher after one year for patients owning pets (especially dogs). 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].

**ABSTRACT**

Evolution in natural environments has endowed humans with a cognitive system that is specialized in processing information about living things. Yet the presence of living things in the human living environment is ever decreasing, which leads to the underdevelopment of this system. The author speculates that biomorphic architecture or design can counteract this trend, which would have positive implications for various aspects of human functioning and could provoke subtle shifts in certain areas of human thinking.
BIOPHILIA AND COGNITIVE NEUROPSYCHOLOGY

Roger Ulrich concluded his essay “Bio-
philia, Biophobia, and Natural Land-
scapes” [11] with the observation that
studies of brain activity in subjects view-
ing different classes of stimuli (e.g. na-
ture vs. buildings) could shed light on the
genetic aspect of biophilia. In view of this
supposition, interesting insights could be
drawn from inquiries into the organiza-
tion of semantic memory. Within this
field, crucial information about the or-
ganization 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 major-
ity 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 or-
ganization of object knowledge is the
Sensory Functional Theory (SFT) [12].
According to this theory, knowledge in
the semantic system is organized into sub-
systems that each process some “type” or
“modality” of knowledge. The central
claim of SFT is that recognition of the cat-
egory of living things is dependent on the
“perceptual” semantic subsystem. This
means, for example, that the concept “ze-
bra” 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 re-
sult 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 to consider an alternative the-
ory of the organization of object knowl-
edge in the brain. One approach, of
particular importance to the discussion
below, is referred to as the Domain Spe-
cific Account [14]. According to this view,
knowledge about living things is orga-
nized categorically in the brain. This means
that specific neural circuits are dedi-
cated to knowledge about specific object-
categories and that category-specific
deficits can occur when this circuitry is
damaged. The driving force of this re-
gional specialization was evolution. It
is speculated that neural mechanisms
only developed for those things that had
evolutionary significance for humans: an-
imals, vegetable life, conspecifics and pos-
sibly 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 ex-
perience or by learning suggests a ge-
etic basis for knowledge about living
things.

It is crucial to note that some propo-
nents 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 con-
cluded from studies of subjects whose

Fig. 1. Ornamental biomorphic
design elements. (Photos © Yannick Joye)

BIOMORPHIC ARCHITECTURE

AS INPUT FOR THE NATURAL MODULE

This system, specialized in natural infor-
mation, will be referred to as the natural

Fig. 2. Stylistic interpretations of animal form: (a, top) Arctic Gas Pipeline Research
Centre (Alaska) and (b, bottom) Apple
Computer Headquarters (California).
(Photos © Tsui Design & Research)
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 looking 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.

**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. (Fig. 1).

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
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 inefficient 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 become very efficient and economical in their functioning, material form and energy use (Fig. 2).

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 resolve 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 (Fig. 3a). Today, a similar interest in structural concerns is present in the biomorphic works of Santiago Calatrava. For instance, the tilted columns in the Stadelhofen railway 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 patterns, textures and sculptures (Fig. 3b). 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.

**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 (Fig. 4). 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 deform it. The research group dECOi has adopted such a method to create the structure Foster/Form [29]. The shape, a carapace spanning three theaters at Gateshead, U.K., 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.

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 become 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 (Fig. 5). This voluptuous design is the result of digital modeling of the different types of movements people perform in houses. An interactive sound installation, developed by composer Edwin 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 time-less. 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 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 transformation 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 incoming information from the Real-Time

Fig. 5. Son-O-House, Eindhoven, the Netherlands. (Photos © Edwin van der Heide)
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 evolutionarily 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 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 New 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 (Fig. 6).

Together with Philip Van Loocke, I am currently involved in designing objects based on fractal principles [24]. The design process of the examples in Fig. 7 begins from a linear, 3D fractal tree. The endpoints of the tree are given a certain load, which is derived from the properties 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 process 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.

**The Emotional Significance of Biomorphic Architecture**

There is a growing discrepancy today between 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
To explain this point, it is essential to
that of subtle shifts in human thinking.
integration of biomorphic architecture is
Another possible effect of the widespread
BIOMORPHIC ARCHITECTURE
built environment.
ural objects, biomorphic architecture can
tentiveness. Because its forms evoke nat-
ducing psychological and physiological
that such architecture can help in re-
stitute emotional well-being and posi-
tive behavior. One can even hypothesize
that such architecture can help in redu-
ducing psychological and physiological
stress and promote apprehension and at-
tentiveness. Because its forms evoke nat-
ural 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 infor-
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 spe-
cialized 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 ded-
icated 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 some subtle but
important consequences. I have noted
above that the presence of nonliving
things, and especially purely functional
architecture, is ever increasing in the hu-
mans living environment. This entails
that semantic networks that perform
functional analyses are ever more domi-
nant when processing the elements that
constitute our surroundings. Such a
dominance of functional concepts could
promote a tendency toward functional
thinking and behavior, further strength-
ening 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 pro-
vide a counterweight to the increasing
dominance of these functional semantic
networks and the associated epistemo-
logical attitude. Because of its similarities
with natural things, such architecture
also activates semantic networks that are
not predominantly related to func-
tional objects and architectural de-
sign. Although it is clear that a functional
attitude has its merits in certain contexts,
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our relations toward others and toward
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Biomorphic architecture could pro-
vide a counterweight to the increasing
dominance of these functional semantic
networks and the associated epistemo-
logical attitude. Because of its similarities
with natural things, such architecture
also activates semantic networks that are
not predominantly related to func-
tionality. In fact, given the correlation of liv-
ing things with perceptual knowledge,
biomorphic designs could stimulate neu-ural areas that establish the perceptual
uniqueness of objects. Such an empha-
sis would be especially relevant to our
relationship to nature. While in moder-
nity, 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 per-
ceptual qualities. Such an epistemologi-
cal 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 empha-
sis could therefore be understood as a ro-
bust form of environmental education.

Finally, nature’s forms can be consid-
ered a generative grammar for creat-
ing artwork and architecture. A rela-
tive shift toward attention to percep-
tual qualities can have important artistic
consequences. It could draw the atten-
tion of artists and students to nature’s
rich formal grammars, which makes it
more probable that these forms find a
genuine artistic translation. More specif-
cally, they could come to study the dif-
ferent processes, shapes and structures in
nature, and consider them as a genera-
tive grammar that forms the basis of an
endless variety of formal permutations.

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 ad-
vances a completely opposite view. Be-
cause 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 consid-
ered intellectually backward. On the con-
trary, that characterization would seem
to apply more to Loos’s own rhetoric,
which rests upon an outdated under-
standing of human psychology, often re-
ferred to as a belief in the “blank slate,”
which holds that human thinking and be-

Fig. 7. Examples of
fractal bifurcating trees.
(© Yannick Joye)
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.

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11. Ulrich [2].

Yannick Joye studies philosophy at the University of Ghent, Belgium, where he has been a doctoral researcher since 2002, attempting to deduce specific architectural constraints from the human affinity with the natural world.