Review of General Psychology
2007, Vol. 11, No. 4, 305–328

1089-2680/07/$12.00 DOI: 10.1037/1089-2680.11.4.305

Architectural Lessons From Environmental Psychology: The Case of Biophilic Architecture

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A review of findings from the field of environmental psychology shows that humans are aesthetically attracted to natural contents and to particular landscape configurations. These features are also found to have positive effects on human functioning and can reduce stress. However, opportunities for contact with these elements are reduced in modern urban life. It is argued how this evolution can have subtle but nontrivial adverse effects on psychological and physiological well-being. These can be countered by integrating key features of natural contents and structural landscape features in the built environment. Several practical proposals are discussed, ranging from literal imitations of natural objects (such as plants) to the use of nature's fractal geometry in an architectural context.

Keywords: biophilia, environmental psychology, fractal architecture, biophilic architecture

Natural objects, shapes, and processes have often acted as a source of inspiration throughout the history of architecture. Perhaps the most obvious example of this inspiration is ornament, which often contains representations that are closely similar to, or reminiscent of, the animal and plant world. Besides such literal imitations, some architects, notably Antoní Gaudí, drew lessons from the structural forces governing natural structures, resulting in efficient and economically built architecture (e.g., Sweeney & Sert, 1960). Today, there seems to be a renewed interest in the relation between nature and architecture, especially in zoomorphic or biomorphic architecture (e.g., Feuerstein, 2002). More specifically, such architecture makes use of digital design software, which allows one to easily recreate the curvy shapes and geometry that are characteristic of natural entities (Lynn, 1999).

This article affirms the importance of natural form as a perennial source of inspiration for architecture. In fact, the main conclusion of this study is that nature-based forms and organizations in architecture are valuable for human emotional and cognitive functioning. However, the exact way in which this conclusion is reached differs in an important respect from the narratives and arguments proposed in theories of organic and biomorphic architecture, which are often more philosophical (Lynn, 1998) or even pseudophilosophical (e.g., Steiner, 1999) in nature. In contrast, the argument for nature-based forms in architecture in the current study is mainly based on empirical findings from diverse psychological subdisciplines. In particular, the article starts with a concise review of empirical findings from the field of environmental psychology and aesthetics. This survey reveals that humans have an emotional relation with natural elements and shows that contact with natural form is in a sense good for human psychological and physiological functioning. It is argued that, by architecturally mimicking natural forms and structural organizations of natural settings, these beneficial effects can be tapped in a built context.

The Psychoevolutionary Framework

Different psychological subfields study the human relation with nature. For example, evolutionary psychologists argue for the existence of cognitive modules that are specialized in conceptual and perceptual knowledge about

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natural entities. Such cognitive devices are claimed to have evolved to handle the survival-related challenges and opportunities that were present in the natural settings in which human ancestors lived (e.g., finding food; Mithen, 1996; Pinker, 1994). Scott Atran (1995) argues how cross-cultural similarities in human folkbiologies support the existence of such a system. In particular, Western and non-Western individuals seem to classify nature in similar ways and consistently ascribe essences to the taxonomic types of folkbiologies. Atran's view is consistent with the literature on category-specific deficits, in which people are reported to have deficient perceptual and conceptual knowledge about the category of living things. One of the interpretations of the causes of such deficits is that, under evolutionary pressures, specific neural areas have become specialized in information about living entities (e.g., Caramazza & Shelton, 1998).

Perhaps the psychological field that has most profoundly studied the human (affective) psychological relation with natural entities is environmental psychology. This research area draws on numerous empirical studies and is, therefore, less speculative than the just-mentioned modularity thesis. One of the central issues of environmental psychology is how different types of settings can trigger different affective states in individuals (e.g., liking or preference reactions). Two important proposals have been advanced with regard to the specific process underlying these emotional states. In the preference matrix, developed by Stephen and Rachel Kaplan, the occurrence of such states is to a large extent the result of cognitively assessing whether certain informational features are present in a setting (R. Kaplan & Kaplan, 1989). This contrasts with a central tenet of Roger Ulrich's (1983) psychoevolutionary framework. In this model, which will form the backbone of the current study, affective responses toward environmental settings are not mediated by cognition but stem from a rapid, automatic, and unconscious process by which environments are immediately liked or disliked. These fast affective reactions are claimed to be rooted in human evolutionary history and are essentially adaptive: They motivated the organism to quickly undertake actions that contributed to its well-being and survival. For example, if early humans came across a setting containing an important risk (e.g., turbulent water, a predator), this triggered negatively toned affective reactions (e.g., dislike), ultimately leading to avoidance behavior. On the other hand, if a setting offered good opportunities for survival and reproduction, this would have caused liking reactions, leading to explorative behavior.

In agreement with Ulrich's (1983) model, empirical evidence shows that environments (e.g., urban vs. natural) are processed according to their affective valence. Moreover, this process seems to occur very rapidly, which supports the immediate and automatic character of these affective responses (Hietanen & Korpela, 2004; Korpela Klemettilä, & Hietanen, 2002). According to the psychoevolutionary framework, survival chances further increased if these emotional reactions had an inherited component: No precious time and energy had to be spent learning what kinds of environments were either beneficial or harmful (S. Kaplan, 1987, 1988; Ulrich, 1983). With regard to the neural origin of these affective states, some researchers attribute an important role to subcortical areas, especially the amygdala. Because these structures are also involved in modulating stress-related hormones, it provides an explanation of why certain types of settings have a different influence on autonomic stress responses (Parsons, 1991; see also Joye, 2007, for an in-depth discussion of this issue).

Aesthetic Preference and Structural Landscape Features

What is the character of the settings or elements that can trigger such immediate affective states? The literature states that, on the one hand, these reactions can be provoked by some typical structural landscape features. Although coming from a different research field, geographer Jay Appleton was one of the first to propose a model addressing this issue (Appleton, 1975). According to Appleton's prospect–refuge theory, human beings' preference for landscapes correlates with two environmental qualities: prospect and refuge. The notion of prospect refers to settings or landscape elements that facilitate obtaining information about the environment. A typical example is a hill, which aids to visually access and inspect the surrounding area. On the other hand, refuge points to settings that can provide shelter and protection.

An evident example is a cave, which can protect against predators and weather conditions.

Ulrich's psychoevolutionary framework lists some other visual cues that are associated with immediate positive affective reactions: complexity, gross structural properties (e.g., patterns), depth properties, ground surface and texture, absence of threats, and deflected vista (Ulrich, 1983). The predictors in Rachel and Stephen Kaplan's preference matrix overlap to a certain extent with the variables listed by Ulrich. The Kaplans' model (R. Kaplan & Kaplan, 1989; S. Kaplan, 1987, 1988) describes two types of postures toward the environment. An individual can be actively involved in an environment: One can, for example, explore the setting. Alternatively, an individual can try to understand the environment. The Kaplans argue that these two attitudes are associated with four structural landscape properties, each of which correlates with positive aesthetic evaluations and positively influences landscape selections. The structural properties that facilitate involvement in the environment are complexity and mystery. Stephen Kaplan defines complexity as a measure for "how much is 'going on' in a particular scene, how much there is to look at" (1988, p. 48). Mystery refers to settings whose layout suggests that more information can be acquired if the scene is penetrated more deeply. An example of a mysterious landscape quality is a deflected vista, such as a winding trail. Structural properties that facilitate understanding the environment are coherence and legibility. Coherence refers to features that contribute to the organization, understanding, and structuring of the landscape image, such as symmetries, repeating elements, and unifying textures. Finally, legibility refers to landscape qualities that help to predict and maintain orientation in the landscape as one further explores it. Think, for example, of a prominent rock functioning as an orientation point.

The Aesthetic Appeal of Natural Contents

In addition to the previous structural landscape features, the field of environmental psychology also studies the natural contents that contribute to the aesthetic qualities of settings: namely (calm) water features and vegetative elements. The explanatory framework, again, is essentially evolutionary. These elements are liked because they contributed to the survival and reproduction of early humans. Flowers, for example, signaled the presence of food sources and were cues for future foraging sites. They also helped in differentiating between different vegetation types, because plants that are not blooming often look quite similar (Orians & Heerwagen, 1992). Trees protected against sun and rain and offered early humans prospects on the surrounding landscape and retreats from predators (Appleton, 1975; Orians & Heerwagen, 1992; Summit & Sommer, 1999).

These benefits can explain why vegetative elements and settings containing vegetation still cause aesthetic or liking reactions. Different empirical studies show that individuals consistently prefer natural, vegetated landscapes over urban settings without vegetation. When urban environments are mutually compared, highest preference is associated with urban settings containing some vegetation, especially trees, or a water feature (Smardon, 1988; Thayer & Atwood, 1978; Ulrich, 1986). Such phytophilia is also clear from the observation that nonnatural environments (e.g., home and working interiors) often contain actual vegetative elements or (decorative) references to natural content (Eibl-Eibesfeldt, 1989; Heerwagen & Orians, 1986). Although empirical research on preferential reactions toward flowers is scarce, some studies show that these elements are indeed associated with positive aesthetic reactions (e.g., Haviland-Jones, Rosario, Wilson, & McGuire, 2005; Todorova, Asakawa, & Aikoh, 2004).

Still, a possible critique of preferential research into greenery is that when vegetated landscapes and nonvegetated (urban) architectural settings are mutually compared, the latter most often involve representations of quite modern buildings or at least buildings that are not very rich in form. However, it can be pointed out that nature is often characterized by a typical sort of geometry, or *fractal geometry* (see later discussion). This type of geometry often does not apply to modern buildings or modern urban settings. A possibility that needs to be entertained is that the preference for vegetated scenes is not due to the fact that it is a natural setting but, instead, that it must (to a certain extent) be drawn back to the underlying geometric features of the scene. It would, therefore, be interesting to compare natural settings with buildings or urban scenery that emulate a more natural geometry, such as Gothic cathedrals. (Note that this critique does not undermine our plea for nature-based, or biophilic, architecture but instead only strengthens it.)

The Savanna Hypothesis

In habitat theory, savannas are claimed to be the settings in which early humans spent a substantial part of their evolutionary history, and these seem to display an ideal mix of the previously discussed structural landscape features and natural contents (Van den Berg, 2004). This type of biome can be broadly described as low to intermediately complex settings, having a relatively even and grassy ground surface dotted with scattered trees or tree groups. Savannas contain a high degree of biomass and meat, and these are relatively easily accessible for terrestrial beings (as opposed to, e.g., tropical forests). Furthermore, the openness of savannas facilitates detecting predators and game and is conducive of movement and a nomadic lifestyle (Orians, 1980; Orians & Heerwagen, 1992).

The aesthetic preference for savanna-type landscapes has been the subject of a few empirical studies. Balling and Falk (1982) found that young individuals preferred savannas over other biomes without ever being exposed to the former type of landscape. The researchers hypothesize that these findings could well point to an innate (aesthetic) preference for savannas (see also: Synek & Grammer, 1998; but see Coss, 2003, for contrasting findings). Consistent with the savanna hypothesis, research indicates that people tend to prefer tree shapes characteristic of high-quality savannas: These typically have a low trunk, a broad canopy, and a moderate canopy layering (Orians & Heerwagen, 1992; Sommer & Summit, 1995). Inquiries into the evolution of artists' work (e.g., John Constable) show an increase of conspicuous savanna features over time (e.g., opening up views; Heerwagen & Orians, 1993). Furthermore, studies indicate that when artificial changes are made to plants and trees, these increasingly come to resemble savanna-type vegetation (Heerwagen & Orians, 1993). Finally, areas that are created for recreational or aesthetic purposes (e.g., parks or golf terrains) often resemble savannas (Orians, 1980).

Within the field of landscape aesthetics, the savanna hypothesis is often taken for granted and has remained mostly undisputed. Nevertheless, we find it troubling that almost no attention is paid to discussions in the field of paleoanthropology. For instance, Wilson (1993) argues how our preferences for nature, savannas in particular, are remnants of paleohominid and early *Homo* evolution in this type of biome, a view shared by many in the field of habitat theory and landscape aesthetics. Yet there is no consensus on the claim that the savanna is the unique environment of evolutionary adaptedness. In his review, Potts (1998) sketches a more complex view that is supported by scientific environmental analyses. It evidences that, during the evolution of early hominids, there was quite some variation in the environments that were inhabited, ranging from forests to savannas to open-canopy woodlands. Still, it could be countered that the truth value of the savanna hypothesis does not have any bearing on the finding that humans adapt to and display positive affective affiliations with natural environments. As Kahn (1999, p. 39) points out, "The evolutionary account can hold, but the savanna hypothesis needs to give way to a broader account of genetic predispositions to inhabited landscapes."

Naturalness and Stress Reduction

Besides causing liking responses, natural elements (e.g., vegetation and water features) are also found to contribute to the restoration of human individuals. Two major interpretations of restorative responses have been proposed. The first, attention restoration theory (ART), was developed by the Kaplans (e.g., R. Kaplan & Kaplan, 1989). Essentially, ART interprets restoration as the recovery of directed attention or the ability to focus. This capacity is deployed during tasks that require profound concentration, such as proofreading or studying. Natural settings have been found to be ideally suited to restore or rest directed attention (e.g., Hartig, Evans, Jamner, Davis, & Gärling, 2003; Hartig Mang, & Evans, 1991).

The second major interpretation of restoration is a part of Ulrich's psychoevolutionary framework. In this view, restoration applies to a much broader context than attentional capacities (e.g., Parsons, 1991; Ulrich, 1993; Ulrich et al., 1991). More specifically, Ulrich understands restoration as stress reduction, and stress can occur even when directed attention is not fatigued. Within Ulrich's model, restorative responses are explained by the fact that early humans were often confronted with threatening and demanding situations (e.g., a predator). As discussed, such confrontations lead to the quick onset of negatively toned affective reactions and corresponding adaptive behavior. Ulrich (1993) notes that the immediate effects of such responses are beneficial for the individual. Yet such reactions also have a certain cost in that they lead to physiological and psychological stress (e.g., high blood pressure, feeling depressed). When the threat has vanished, the individual is in need of restoration from the stress that has been caused. The benefits of such restorative responses are "a shift toward a more positively toned emotional state, mitigation of deleterious effects of physiological mobilization (reduced blood pressure, lower levels of circulating stress hormones), and the recharging of energy expended in the physiological arousal and behavior" (Ulrich, 1993, p. 99). These restorative responses typically occurred in natural unthreatening (savanna-like) settings. Such open, low-risk environments often contained a (calm) water feature and sometimes had a small fire. Restoration was also facilitated by the availability of resources, which reduced stress related to the uncertainty of finding food (Ulrich, 1993).

The stress-reducing effect of nature is still effective today because those individuals who could respond restoratively to stressful situations survived better. In an often-cited article in *Science*, Ulrich (1984) discusses a study of hospital patients who had undergone gall bladder surgery and had rooms with views of either a small tree group or of a brown brick wall. As opposed to patients with the brick wall view, patients with the tree view had shorter hospital stays, received fewer negative comments from the nurses, required less moderate and strong analgesics, and had slightly fewer postoperative complications. (For further research into the relation between stress reduction and nature, see, e.g., Custers, 2006; Hartig et al., 2003; Parsons, Tassinary, Ulrich, Hebl, & Grossman-Alexander, 1998; Ulrich, 1981; Ulrich et al., 1991).

The Value of Nature-Based, or Biophilic, Architecture

Although there is solid empirical evidence that humans hold positive affiliations with a specific set of landscapes and natural elements, this does not preclude that some natural features or occurrences also cause more negative and even aversive reactions in humans (e.g., Mineka & Öhman, 2002; Van den Berg & ter Heijne, 2005). Another issue is that the experimental outcomes are sometimes difficult to integrate into a coherent, overarching conceptual framework. For example, what is the relation between abstract structural landscape features and the preference for water elements? Other issues are that differences in nature appreciation are often left in the dark in these discussions (but see Van den Berg, 2004), and it is still a matter of debate in which sense the genetic component of these (positive) affiliations should be understood (Cummins & Cummins, 1999). Still, whatever the outcome of these matters, the general picture emerging from the previous concise review is that humans have a (partly) hardwired emotional affiliation with certain classes of natural objects. Some researchers have argued about the affective relation with natural elements and landscapes in terms of biophilia (e.g., Kellert & Wilson, 1993; Wilson, 1984). Although the theoretical merits of this term have been questioned (Joye, 2007), in the remainder of this report the notions *biophilic* and *biophilia* will nevertheless be used as synthetic concepts.

The occurrence of biophilic responding stands in sharp contrast with the observation that there is increasingly less contact with nature in Western technologically oriented societies. Wolff, Medin, and Pankratz (1999) found that such an evolution has nontrivial effects on cultural expressions of nature. In particular, they made a historical study of word use in dictionaries and found that, from the 20th century onward, the use of (folk)biological terms devolved, and their application lost precision. In contrast, several nonbiological terms evolved during this period (e.g., books, clothes, furniture). Apart from being associated with an impoverishing conceptual framework for natural objects, it is also plausible that reduced contact with nature can be accompanied by a reduced knowledge of the rich variety of forms characteristic of natural entities. A probable artistic or creative consequence is that the formal curriculum of artists and architects becomes narrower. The reason is that natural form can be considered as a creative or compositional grammar, which can be used for creating artwork, or, as Stephen Kellert put it, "The aesthetics of nature can function as a kind of monumental design model" (Kellert, 1997, p. 36). The loss of this monumental design model has its architectural counterpart in modern urban settings, which are increasingly governed by euclidean geometry and stripped of ornament, patterning, detailing, and color (Salingaros, 2004). Architectural references to nature can help put an end to this uniformity. By encouraging architects to integrate natural forms and patterns in their work, they are motivated to study nature's shapes and compositional rules, and this can enrich their creative curriculum.

Besides having creative consequences, reduced contact with natural form could also subtly influence the way in which people think about the world. Inquiries into semantic memory indicate that processing conceptual information about living things mainly relies on perceptual information (e.g., the concept "zebra" activates perceptual information, such as "stripes"), whereas processing nonliving things or artifacts depends on functional information (e.g., the concept "knife" activates functional information, such as "cutting"; e.g., Crutch & Warrington, 2003; Farah & McClelland, 1991). These findings could have important implications. The presence of nonnatural things, and especially artifacts (e.g., cell phones, computers, chairs, pots, printers), is ever increasing in the human living environment at the expense of natural structures or entities. A probable consequence is that neural areas related to an object's functionality and hence functional analyses (i.e., how an object should be used or manipulated) are becoming increasingly more dominant in our thinking about the constituents of the modern living environment. As we become more acquainted with such thinking, it is not implausible that it will be deployed in other domains as well (e.g., to generate explanations). This could especially occur when knowledge about phenomena in a certain domain, such as the natural world, becomes increasingly more scarce or more underdeveloped.

Although functional postures are important and necessary in certain fields, transferring them to other domains or contexts can prove problematic and harmful. Today, we can witness how thinking about nature and natural resources in terms of things that can be manipulated has devastating effects. The upshot is that this shifts the balance even further toward functional thinking, because nature is replaced by entities that predominantly require functional analyses. Probably, this process can be countered by extensive contact with the natural world, and developing a rich conceptual framework about it (e.g., by nature education). This could help people realize that functional thinking is not always desirable with regard to nature. While being more speculative, it can be hypothesized that integrating naturalistic elements in architecture can counteract the increasing dominance of functional semantic networks and the associated epistemological attitude. Admittedly, people will not consider biophilic architecture or design as actual nature. However, such architecture shares some essential formal features with living things, and research indicates that perceptual features are important for recognizing living things. Biophilic design could lead to more attentiveness to an object's perceptual qualities, thereby leading attention away from its possible functions and the associated functionalist postures. Furthermore, because of the (hardwired) emotional affiliation with certain natural elements, nature-based architecture can awaken fascination for natural forms. Such an attitude could be ecologically relevant, because it is found that proenvironmental behavior is positively influenced by emotional states toward nature (Kals, Schumacher, & Montada, 1999).

Without a doubt, people can get used to less formal diversity in the built environment. However, such a situation is not desirable because an increasing dominance of uniform (modernist) environments will probably have a number of psychological and physiological costs. Recall how, under evolutionary pressures, natural forms and environments became associated with a broad range of emotions, ranging from fear to excitement. In the human ancestral world, such associations promoted fitness because they motivated the organism to undertake adaptive reactions (e.g., flight). Today, there seems to be a discrepancy between the habitats humans have evolved in and modern urban settings. For example, it was already noted that the former was characterized by, among others, a mix of complexity and order (S. Kaplan, 1987, 1988; Ulrich, 1983). Yet current architectural settings do not appeal to this ordered complexity. Modernist architecture mainly consists of simple volumetric forms and thus deprives the senses in their constant search for meaningful information. On the other hand, postmodern and deconstructive architecture deliberately destroy architectural coherence, either by jumbling together disparate stylistic and formal elements or by placing the destruction of coherence and structure at the heart of the tradition (Salingaros, 2004). Furthermore, modern building is often dictated by efficiency and economic motives, barely leaving room for symbolic and stylistic references to natural contents (e.g., ornament; Pinker, 2002; Salingaros, 2004). In short, much of the modern built environment fundamentally lacks (references to) the contents and structural organization that are characteristic of a good habitat. Exposure to such environments could rapidly and automatically trigger negatively toned feelings and the associated stress-related endocrinal reactions (Ulrich, 1983). Although such responses could go by largely unnoticed because of human habituation to this type of environment, the long-term occurrence of such stress reactions could have important health effects (Parsons, 1991).

Increasing urbanization undoubtedly has a number of positive consequences. For example, in modern cities, people come to live closer together, which could promote social interaction and the pleasure and enjoyment associated with this (Van den Berg, Hartig, & Staats, 2007). Furthermore, there is nothing inherently wrong or undesirable about modern building styles, and there is no reason to doubt the genuineness of positive reactions to such buildings. What, according to the current argument, could become problematic is the (growing) dominance of such nonnatural building styles at the expense of settings with natural form languages (albeit natural or artificial ones). The core argument of the current study is that, by including elements of ancestral habitats in the built environment, one can counter potential deleterious effects, which stem from this dominance, resulting in more positive affects and more relaxed physiological and psychological states. In the remainder of this article, such architectural interventions are denoted as nature-based, or biophilic, architecture.

Integrating Structural Landscape Features in Architecture

How can the structural landscape features, discussed earlier, be meaningfully applied to the built environment? This is a more difficult issue than applying well-defined natural contents to architecture, because the former features are of a more abstract nature. Furthermore, only very few researchers have addressed this issue and proposed clear guidelines on how to successfully integrate these qualities in architectural settings.

First, turn to the type of setting that contains an ideal mix of these structural landscape features, namely the savanna. An evident strategy to imitate savannas is to integrate photographs or projections of savannas in (interior) spaces. Another, more architectural method consists of mimicking key structural features of savannas. Possible strategies include creating wide and open spaces; making variations in the architectural topography; integrating clusters of real or symbolic trees (e.g., columns); and integrating a water feature (e.g., a fountain) or even a small fire. Note how certain retail settings, such as shopping malls, often contain these elements. Because a major goal of the retail sector is attracting people, it should be no surprise that organizational features of preferred settings are (intuitively) deployed in such commercial contexts (Heerwagen, 2003).

Because of their openness, savannas provided good prospects on the surrounding area. Furthermore, trees typical of savannas (acacias) have low trunks and could, therefore, be climbed to see across the landscape and to escape predators. On the other hand, the broad canopies provided good protection against sun and rain. Grant Hildebrand (1999) uses Appleton's (1975) notions of prospect and refuge as explanatory principles for the aesthetic appeal of certain buildings. Although Hildebrand does not provide exact guidelines, his analyses show which spatial organizations influence the prospect and refuge dimensions of buildings. With regard to Frank Lloyd Wright's house in Taliesin, Wisconsin, Hildebrand notes the following: "Deep overhanging eaves, alcoves and recesses, the withdrawal of the house in the dense foliage,

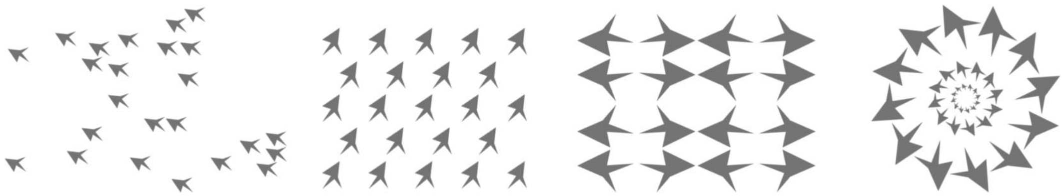

Figure 1. Patterns can be obtained by some simple mathematical transformations (Salingaros, 2003): (A) randomness; (B) translational symmetries; (C) reflectional symmetries; (D) rotational symmetries that are nested. (Copyright © Yannick Joye.)

and the cave-like masses of stone anchoring the house to the hill all convey that this is a haven within which one can withdraw secure. Extensive bands of window and the balcony reaching out over the falling landscape, moreover, indicate that the advantages of generous prospect are likely to be available within" (p. 28). It is clear that feelings of prospect and refuge can be evoked by specific architectural interventions. Strategies for evoking concealment are reducing lighting conditions, lowering ceilings, and making small windowless spaces enclosed by thick walls. The prospect dimension depends on opposite characteristics: larger space dimensions, raised ceilings, thin transparent walls, wide views on surrounding spaces, building on an elevated site, increased lighting conditions, balconies, and so on.

Prospect and refuge can be linked to the predictors complexity and coherence, central to the Kaplans' preference matrix (e.g., R. Kaplan & Kaplan, 1989). Only a setting that contains enough prominent landscape features (e.g., trees, rocks) can provide opportunities for refuge. On the other hand, if a setting contains too many elements, this makes it difficult to have a clear view over the landscape. Although complexity and coherence have primarily been applied to landscapes, there is empirical evidence that a balanced presence of both properties contributes to the aesthetic qualities of built settings (e.g., Herzog, Kaplan, & Kaplan, 1982). However, how can a complex set of architectural elements be ordered? Again, take a look at the architectural tradition associated with Frank Lloyd Wright, namely organic architecture. In essence, organic architecture is not restricted by stylistic conventions but is characterized by an inherent form freedom. Although not necessary, this often translates in buildings that are quite irregular and complex both in plan and elevation. Yet organic architects often use a geometric module (e.g., a triangle) as main compositional element (Mead, 1991). In this way, different parts of the building are given a similar form, which results in an overall coherence (Eaton, 1998).

It could be noted that merely repeating similar elements does not guarantee an ordered complexity. On the contrary: It can even lead to random structures, as in deconstructivism. A possible solution is to organize these (similar) elements through patterns. These are often the result of only a few simple mathematical operations, such as reflectional, rotational, translational, and glide symmetries. More complex patterns are obtained when these symmetries are repeated or when they are nested (Salingaros, 2003; Figure 1A–D). Traditionally, patterns take in a prominent place within the organic tradition. Historically, they can also be found in, for example, tiling, ornaments, mosaics, stained glass windows, and (oriental) carpets.

Another structural feature that positively correlates with landscape selection is mystery. Some claim that this property can be conveyed by specific design elements: "When appearing around corners, attached to walls, and hung from ceilings, interesting objects, architectural details or motifs, graphics, video displays and artifacts can create a little mystery and surprise in the workplace" (Hase & Heerwagen, 2000, p. 30). However, the most straightforward way to apply mystery to an architectural setting is by deflected vista. This can be realized by letting the architectural trail (e.g., corridor) bend away, which can lead to curiosity of what might lie beyond the bend, thereby encouraging explorative behavior. Another mode of mystery is called "enticement." Essentially, this notion refers to the situation in which a person is in the dark, from where it can see a partially visible and enlightened area or setting. Such enlightened regions draw attention and trigger explorative behavior. Although mysterious settings can be aesthetically appealing, too much irregularity or surprise can have the result that the layout of the building becomes confusing and nontransparent, ultimately leading to orientation and way-finding problems. Legibility can be enhanced by integrating signalizations and distinctive markings, by offering views on the outside, and by making the building shape more regular (Evans & McCoy, 1998).

Imitating Natural Contents in Architecture

How could natural contents be integrated into the built environment? Evidently, this can be done by providing views on the outside environment, by integrating vegetation in built settings, by hanging nature pictures on the wall, by nature-oriented screensavers, and so on. These interventions are what Stephen Kellert (2005) called indirect experiences of nature, and they come quite close to the design interventions from the field of evidence-based design (Ulrich & Zimring, 2004; Van den Berg & Van Winsum-Westra, 2006). It is in this sense that the modern built environment sometimes imports some of the icons of habitability that are typical of ancestral habitats. The result is that even architecture that is characterized by nonnatural forms can be consistent with the current argument. For example, some modernist architecture (e.g., Mies's Farnsworth House) is characterized by large expanses of glass, by which the building opens up to the surrounding natural landscape, potentially causing biophilic responses in the inhabitants.

Implanting a building in a natural landscape does not necessarily tell us something about the architectural form and whether it in some sense displays key features of our ancestral habitats. Because we factually inhabit contexts in which buildings are often more dominant than nature, it also becomes relevant to come to biophilic interventions that pertain to the architectural form. But how should such interventions be conceived? A first strategy is to architecturally imitate preferred natural entities, such as vegetative elements. Such imitations can take on different levels of abstraction. A first option is to literally copy these elements in architectural design. As already noted, there is an age-old tradition to copy nature, especially floral and vegetal patterns, in traditional ornament. Admittedly, it could be possible that such imitations will not be very successful, because the associated emotional states could quickly be followed and suppressed by higher order or cultural beliefs. For example, the architectural community could consider such imitations as kitsch. Nevertheless, it should be noted that there is often a discrepancy between what is found appealing by experts and laypersons. The primary goal of this study is not to argue for what is supposedly fashionable or to defend high art but to indicate what could be psychologically appealing for the broad public.

An alternative to literal imitations is to create architectural designs based on schematic imitations of natural elements. These would no longer be exact copies but artistic interpretations that still contain some global visual similarities with regard to the original natural object. One of the central claims of the current study is that such constructions will be accompanied by affective states that are similar to those evoked by real natural contents. Orians and Heerwagen (1992, p. 572) expressed it as follows: "An evolutionary-ecological approach to aesthetics suggests that the incorporation of trees and tree forms, actual or symbolic, into the built environment should have a strong positive impact on people. . .We predict that the presence of these 'symbolic trees' is associated with positive response to built environments."

Although the occurrence of biophilic responses to symbolic representations of nature could be prima facie plausible, it is problematic that it is often taken for granted in the literature on biophilic architecture. Although research that has directly tested this prediction is lacking, some indirect arguments can be presented that support the conclusion. First, it is evident that domain-specific mechanisms in the brain will be activated by the objects in which they are specialized. For example, a face detection mechanism will be activated by its proper input: actual human faces. Yet it seems that such domain-specific mechanisms do not care about whether the objects it analyzes are in any sense real or symbolic. More specifically, these neural areas also tend to become activated by elements that share some central geometric features with the proper input of the domain-specific systems. This is one reason why a symbolic representation of a face, such as, for example, a smiley face (☺) or the front of a car, can be perceived as having facelike features (Pinker, 1997; Sperber & Hirschfeld, 2004) and can lead to the onset of similar emotions as real eyes or faces (e.g., Aiken, 1998a). Similarly, it is probable that the neural mechanisms specialized in processing natural elements will also be activated by stimuli that share essential geometric features with natural elements, such as symbolic or imitative representations of nature in architecture. Because of the importance of quickly displaying adaptive behavior to natural stimuli (e.g., exploration, escape, fighting), it is probable that at the early stages of processing some affective processing or priming will already take place, before any conscious recognition of the imitated natural elements occurs (Ulrich, 1983).

Further reasons why architectural imitations of nature could trigger biophilic responses are more empirical in nature. First, it can be pointed out that research on environmental preferences often uses simulations of nature (e.g., photos, posters, videos, and even paintings). The results that are obtained with these stimuli are close to the responses associated with real nature, which suggests that realness does not play a decisive role. (Yet it should be noted that in such contexts nature is mostly depicted very realistically, and when only realistic representations of nature can be used in architecture, this restricts the range of possible architectural interventions almost exclusively to ornamentation). Second, symbolic representations of nature have been used throughout the history of art for aesthetic enhancements, which suggests that these can trigger biophilic responses. Third, research indicates that preferences for natural settings can be statistically predicted by underlying geometric characteristics, which lends plausibility to the claim that geometric abstractions from nature can cause the associated affective effects (Hägerhäll, Purcell, & Taylor, 2004; see also Fractals and Biophilic Reactions: A Critical Evaluation section).

There is a further important reason why symbolic or schematic interpretations of naturalness can lead to aesthetic reactions. This conclusion is based on the finding that formal abstractions or simplifications of certain conspicuous traits of (survival-relevant) stimuli lead to similar, or even stronger, emotional responses as the original (natural) stimulus. Within the field of ethology, such stimuli are labeled "supernormal stimuli" (Tinbergen & Perdeck, 1950). Ramachandran and Hirstein (1999) argue how this phenomenon is one of the central laws that artists (unconsciously) deploy in art. They clarify this principle by referring to a phenomenon observed in the field of animal discrimination, namely the peak shift effect. A rat that is taught to discriminate between a square and a rectangle and is rewarded for discriminating the rectangle will respond more frequently to the rectangle. However, when the original rectangle is elongated, the rat will respond even stronger to this new rectangle than to the rectangle that it was taught to discriminate. According to Ramachandran and Hirstein (1999), artwork often taps a similar effect: "What the artist tries to do (either consciously or unconsciously) is to not only capture the essence of something but also to amplify it in order to more powerfully activate the same neural mechanisms that would be activated by the original object" (p. 17). According to Ramachandran and Hirstein, such amplifications can occur along different dimensions of the artistic work: for example, form, color, and movement (see also Aiken, 1998b). It is clear that, in the present discussion, main interest goes to amplification of the architectural form, which can cause a peak shift effect with regard to real natural forms.

Maybe the most well-known examples of architecture in which schematic interpretations of natural forms are present have been created by Antoní Gaudí. For example, the interior columns of the Sagrada Familia are quite similar to treelike and flowering structures (Figure 2A–B). Indeed, one can clearly differentiate a stem, which bifurcates into further branches and subbranches. The canopy of these treelike structures consists of flowering forms, which further strengthens the impression of symbolic vegetation. A more modern architect whose work also contains schematic interpretations of natural objects is Santiago Calatrava. Like in Gaudí's work, structural forces are an important determinant of the shape of Calatrava's architecture. Yet he also seems to be directly inspired by the shapes of nature. According to Von Moos, "His architecture relates to the morphologies of plant and animal life—on land, in the depth of the sea, or in imagination" (Tischhauser & Von Moos, 1998, p. 338). Particularly relevant for the present discussion is that several building elements resemble vegetative structures. For in-

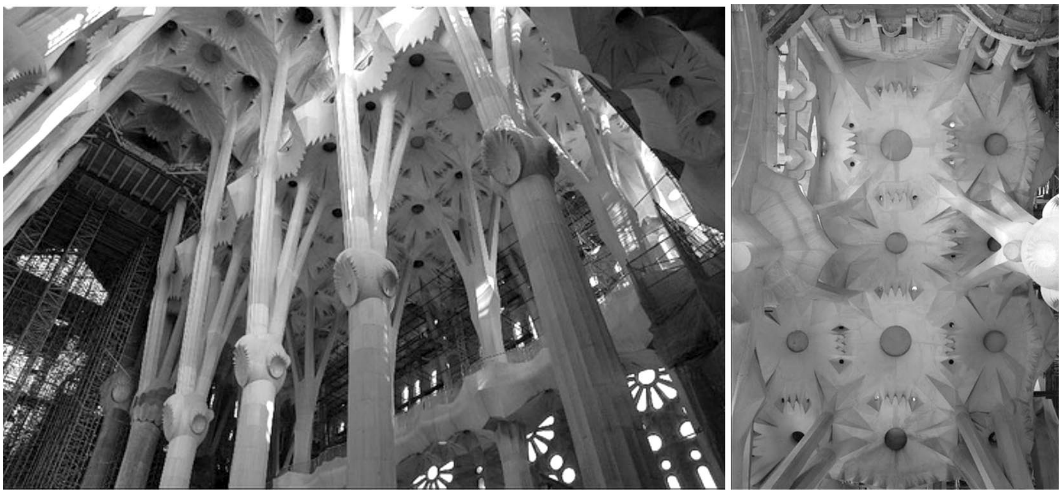

Figure 2. The interior of Gaudí's Sagrada Familia contains schematic interpretations of natural contents. Left: columns as treelike structures. Right: flowerlike canopies. (From Guillaume Paumier. Used with permission).

stance, both Calatrava's Orient Station (Lisbon) and his BCE Place (Toronto) could be interpreted as "'forests' of structural 'trees'" (Tzonis, 1999, p. 82; Figure 3).

Applying Nature's Fractal Geometry to Architecture

What is a fractal? Are there any good reasons to go beyond the imitation of natural contents? Is there something about the outlook of nature that can be abstracted away and applied to architecture while still giving rise to biophilic reactions? We hinted at this already and speculated that the underlying (fractal) geometry of natural scenes is perhaps a contributing factor to aesthetic and stress-reducing responses. Some scholars adhere to similar ideas. Katcher and Wilkins (1993) note that it would be valuable to "search for general characteristics of the patterns in nature that produce relaxation. Exploring the ability of computer-generated fractal structures to entrain subjects' attention and induce calm could be a promising approach, as well, since waves, flames, and clouds can be duplicated by fractals. Fractal structures could also relate the physiological and cognitive effects of both natural phenomena such as waves and cultural artifacts like music" (pp. 177–178). Similarly, Purcell, Peron, and Berto (2001) speculate that the high restorativeness of natural scenes could be due to their fractal characteristics, whereas built environments are low in restorativeness because of their underlying euclidean geometry.

Fractal geometry has been described and explored since the 1970s (Mandelbrot, 1977). The term *fractal* is derived from the Latin word *fractus,* meaning broken or fractured. One of the defining features of a fractal is that this roughness recurs on different scales of magnitude (Figure 4). When zooming in on a fractal, at each magnification a structure appears that is more or less similar to the global form of the fractal, a property labeled "self-similarity." Another feature that plays an important role within the field of fractal geometry is the concept of dimension. In euclidean geometry, lines have a dimension of one, whereas geometric objects, such as squares and triangles, have a dimension of two, and volumes in space are three dimensional. In contrast, the dimension of a fractal, or the fractal dimension, is not an integer value. For fractals in the plane, the fractal dimension lies between the first and the second dimension, which gives a value between 1 and 2 (e.g., 1.46). For fractals in space, the fractal dimension lies between 2 and 3 (Voss, 1988). Essentially, these noninteger values are due to the fact that fractal patterns have a very wrin-

Figure 3. The “forest of trees” in Calatrava’s Orient Station. (From Inge Kanakaris-Wirtl; www.structurae.de. Used with permission.)

kled character and, therefore, occupy more space than a simple line (first dimension) but do not fill the entire plane (second dimension). In essence, the fractal dimension should be interpreted as a measure of the degree in which (similar) detail recurs on different scales of magnitude. Hence, the concept could be understood as a measure of complexity.

Fractals, naturalness, and liking responses. Is there any evidence for the claim that fractal characteristics could as well be associated with biophilic responses to typical natural contents, such as vegetation? In other words, why could fractal geometry be an important beneficial ingredient of natural scenes? First, there is a profound link between the shape of many natural structures and fractals. In essence, the former are fractal-like in that they often display the self-similarity that is so typical of fractals. Evident examples are trees, mountains, lightning, clouds, coastlines, and so on. A second link between fractals and nature is the observation that natural elements can be elegantly mimicked with fractal geometry. For example, plants and trees can be straightforwardly generated by fractal procedures, such as L-systems (Prusinkiewicz & Lindenmayer, 1990). Perhaps the most well-known fractal model of vegetative elements is the Barnsley Fern (Peitgen, Jürgens, & Saupe, 1992), which was discovered by Michael Barnsley. A third way in which fractals and nature can be related is more psychological in nature. Apparently, fractal patterns evoke associations of naturalness in human subjects (Geake, 1992). Closely related is the finding that contact with fractals improves the ability to perceptually differentiate between highly similar natural patterns (Geake, 1992).

Not only are fractals perceptually related to naturalness, but their aesthetic value is also obvious to many. These rich and sometimes colorful images often provoke awe and fascination in viewers. It should, therefore, be no wonder that some artists (e.g., Jackson Pollock) have (unconsciously) deployed fractal principles in their work to reach an aesthetic effect (Mureika, 2005; Taylor, 2002). Still, these connections between aesthetics and fractals are only anecdotal and intuitive. In search for a stronger foundation for fractal aesthetics, reference can be made to preliminary empirical research by Richard Taylor (1998). Taylor mentions that

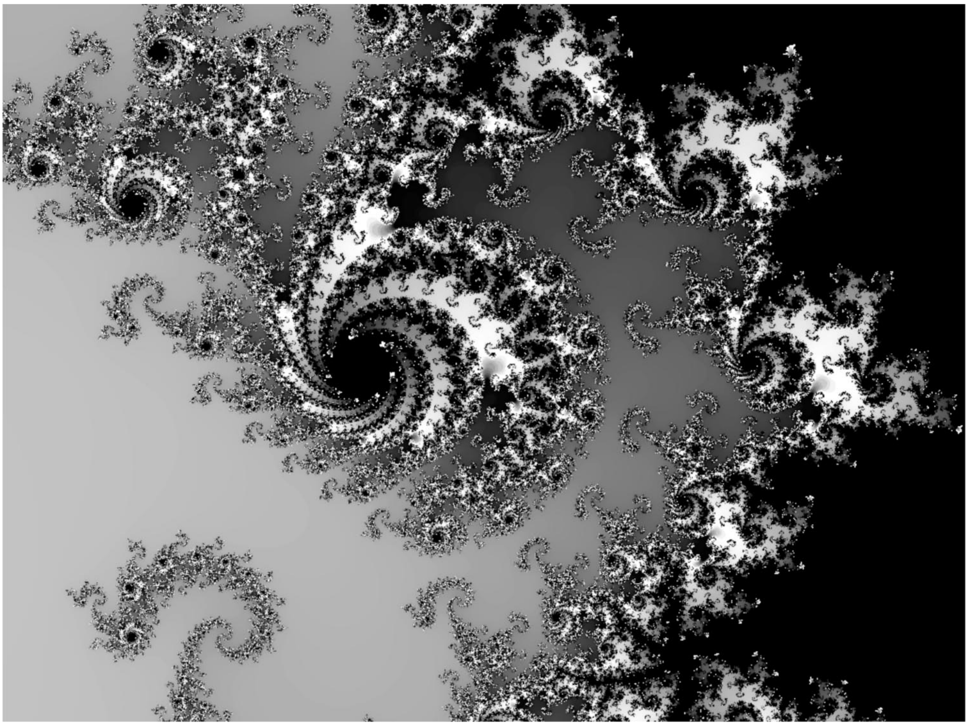

Figure 4. A typical fractal pattern. This is a detail of the Mandelbrot set.

more than 90% of a group of 120 students preferred fractal patterns over nonfractals. Yet it should also be noted that Arthur Stamps (2002) has tested this conclusion more rigorously and did not find that fractal patterns were aesthetically preferred over nonfractals. Nevertheless, it should be pointed out that Stamps used fractal contours, and the self-similarity was not readily perceivable in the representations.

Other research into fractal aesthetics has mainly focused on the relation between fractal dimension and aesthetic preference. One of the first empirical studies of this relation has been carried out by Aks and Sprott (1996). The experiment revealed that 24 study participants preferred fractal patterns with a fractal dimension of between 1.17 and 1.38. The average fractal dimension of the most preferred attractors was 1.26 ± 0.06. Spehar, Clifford, Newell, and Taylor (2003) used three different categories of fractal patterns (mathematical fractals, natural fractals, and fragments of Pollock paintings) and found that patterns with a fractal dimension of between 1.3 and 1.5 were preferred most, as opposed to patterns with dimension values between 1.1 and 1.2 and between 1.6 and 1.9. Abraham et al.'s (2003) study revealed a nonmonotonous relation between aesthetic preference and fractal dimension. Patterns with the highest and lowest fractal dimension were least preferred, whereas those with a midrange fractal dimension were liked most. More specifically, attractors with a fractal dimension ranging from 1.4 to 1.6 (mean fractal dimension of 1.54) received the highest preference ratings.

Although these results need further replication and are to be treated with caution, there is a tendency to prefer patterns with an intermediate fractal dimension, ranging from about 1.3 to 1.5. Note that there are some further hints for the special status of this range of values. For, example Rogowitz and Voss (1990) found that recognizing and finding new shapes in fractal patterns is best for those patterns with a fractal dimension ranging from 1.2 to 1.4. Geake and Landini (1997) found that the variance in study participants' judgments of the complexity of fractal patterns exploded when pictures had dimension values greater than 1.3.

Fractals and stress reduction. If fractals can be meaningfully related to aesthetic reactions, then is there any way in which these patterns can be linked to the capacity of natural contents to reduce stress (e.g., Ulrich et al., 1991)? To answer this, it must first be noted that there are reasons to assume that restorativeness is the underlying factor for aesthetic reactions toward natural settings. Van den Berg, Koole, and van der Wulp (2003) have experimentally confirmed this hypothesis by performing [m]ediational analyses. . .[which reveal] that affective restoration accounted for a substantial proportion of, the preference for the natural over the built environments (p. 135).. How can this finding be related to the field of fractal aesthetics? A plausible answer is that if fractal characteristics underlie aesthetic responses to natural settings to a certain extent, and if these responses are maximal for an intermediate fractal dimension, then it could well be that this range of values will also have the highest restorative potential.

Wise and Taylor (2002; see also Taylor et al., 2005) have carried out a preliminary study to test the relation between fractal geometry and stress reduction. They reexamined a study performed by Wise and Rosenberg (1986) involving 24 individuals who were continuously exposed to four different patterns: a photograph of a forest setting, a simplified representation (i.e., painting) of a savanna landscape, a picture with squares, and a white plane, which functioned as a control picture. While being exposed to the images, participants had to undergo three stressful mental tasks: an arithmetic task, solving logical problems, and creative thinking. Between every task there was a 1-min recovery period. Physiological stress was determined by skin conductance, because research indicates that increased conductance correlates with higher levels of stress.

It was found that the degree of physiological stress was dependent on the type of pattern that was presented to the participants. Because naturalness is found to be a predictor of aesthetic and restorative responses, one would expect that the picture of the forest setting was most effective in reducing stress (indeed, it looked the most like real nature). Contrary to this expectation, this effect was most effectively produced by the unrealistic painting of the savanna landscape. The change in conductance between work and rest periods was 3% lower for the forest photograph and 44% lower for the savanna representation than for the control picture. This means that these pictures dampened (physiological) stress associated with the tasks.

Because the researchers did not expect this outcome, they decided to determine the fractal dimension of each of the pictures. Only the forest and savanna pictures had fractal characteristics. It was found that the pattern that was most effective in stress reduction, the savanna picture, had a fractal dimension that fell within the range of dimension values that was earlier found to correlate with highest aesthetic preference (Spehar et al., 2003). Because this picture is only a rough and simplified representation of a savanna, the authors speculate that the depiction of natural contents alone cannot be a sufficient condition for a restorative effect. If this were the case, then highest restorativeness should be expected to come from the more realistic and naturally looking forest setting. Instead, it seems that, besides depicting natural elements, the scene should also have a specific fractal dimension in order to maximize stress reduction. Specifically, from this experiment, it can be tentatively concluded that its dimension value should fall within the range of 1.3 to 1.5.

Despite these remarkable results, some questions still remain. First, of course, is the preliminary character of these experimental outcomes, which necessitates replication. Second, the literature on habitat theory (e.g., Orians, 1980) claims that humans are innately predisposed to prefer savannas because it is the biome in which they thrived for a substantial part of evolutionary history. Consequently, it could be argued that it is quite natural that the savanna picture leads to the highest restorative responses. Thus, it remains unclear whether it is the fractal dimension that underlies these responses or the specific contents depicted in this image. Perhaps the same experiment should be replicated with fractal patterns, devoid of meaningful representative contents. Again, however, note that Hägerhäll et al. (2004) found that preferences for settings could be predicted by the fractal dimension. This adds support to Taylor's claim that it is the fractal component that underlies the restorative responses, not only the depicted contents. Yet it could also be pointed out that features such as bodies of water are highly preferred contents (Ulrich, 1983) that cannot be straightforwardly analyzed in terms of fractal geometry. Perhaps something similar applies to the savanna painting. For example, the typical shape of savanna trees (low trunk, broad canopy) could be a highly preferred icon in landscapes. Perhaps it is a basic "preferendum" (Ulrich, 1983), which is irreducible to fractal characteristics. It can also be argued that the stress-reducing character of fractals is already established. The reason is that certain fractals are sometimes very difficult to distinguish from real natural elements (e.g., the Barnsley Fern). It is, therefore, very probable that such naturalistic fractals will lead to biophilic responses. A lot of natural entities are fractal, and the main difference with mathematical fractals is that their self-similarity does not extend to infinity.

The affective value of fractals. The affective value of fractal patterns can be explained by the finding that naturalness is a predictor of biophilic responses and by the fact that fractal geometry eminently captures this quality. Sometimes it is even claimed that the aesthetic effect of fractals is due to the fact that such patterns lead to a peak shift effect (Ramachandran & Hirstein, 1999), because they imply an exaggeration of the dimension of recursiveness, which is a characteristic quality of natural form (Joye, 2007; Mureika, 2005). However, what could be the explanation for the preference for fractal patterns with low to intermediate dimension values and for their restorative potential? Because Cutting and Garvin (1987) have discovered a correlation between the fractal dimension and complexity of fractal patterns, a possible answer is that the fractal dimension offers a quick cue of the complexity of a scene. Complexity is a predictor of habitat quality (S. Kaplan, 1987, 1988), and the preference for a low to intermediate fractal dimension could be rooted in the fact that habitats of a low to intermediate complexity (e.g., savannas) offered the best chances for survival (Wise & Taylor, 2002). Indeed, in such settings, information can be quite easily grasped and processed, as opposed to more complex environments (e.g., tropical forests). This reduces the possibility that crucial information (e.g., predators) will be missed or ignored. On the other hand, the complexity is high enough to keep one interested, to awake further explorative behavior, and to provide opportunities for refuge. It is quite probable that the presence of these properties facilitated restoration, hence the restorative responses associated with patterns of an intermediate fractal dimension (Taylor et al., 2005). For example, resting from stressful or demanding events seems more likely to occur in settings that offer retreats but that also contain enough openness, which reduces the probability that one will be attacked by a predator by surprise (Ulrich, 1993). If specialized neural mechanisms exist that assess the quality of a habitat, then it is not too difficult to suppose that these compute the fractal dimension in order to have a rapid cue of habitability.

It should be noted that sometimes the aesthetic appeal of fractal-like patterns is also explained by the fact that the nervous system is governed by fractal-like processes. In particular, Anderson and Mandell (1996, p. 114) argue that human evolution in a fractal world has required "the incorporation of fractal structures as well as fractal processes, and these in turn would be integrated into sensory systems, recognition, memory, and adaptive behaviors." More specifically, the authors describe how human functioning is characterized by a fractal noise signal—1/f noise—from the microscopic level of neural functioning to the macroscopic level of human behavior. For the present discussion, the presence of this type of noise in the human mind and brain seems especially relevant: "In neurobiology in general, and neurophysiology in particular, 1/f patterns in time are profound in their recurrent appearance across many levels of organization in the nervous system, from the underlying cellular dynamics of ion channels and intermittent firing patterns of neurons to developmental phenomena occurring during the organization of breathing to global dynamics in the nervous system such as subcortical, transcortical and scalp EEG defining behavioral states of consciousness" (Anderson & Mandell, 1996, p. 77). Some authors propose that, because of its fractal nature, the brain is optimized to process the statistical characteristics of natural scenes, which are also found to be governed by 1/f spectra (e.g., Knill, Field, & Kersten, 1990). For instance, Gilden, Schmuckler, and Clayton (1993) found that discriminating fractal contours was best for those sharing (statistical) properties with natural scenes. Consistent with this is the finding that neurons in the

V1 area of the brain show a preference for 1/f signals (Yu, Romero, & Lee, 2005).

Some authors hypothesize that the proposed fractal nature of the human mind/brain can illuminate the creation of fractal artwork. Essentially, such art should be understood as an exteriorization of the fractal aspects of brain functioning (Goldberger, 1996). However, what does such an account have to say about the aesthetic value of fractals? Different authors have described the perception of such fractal-like patterns in terms of a resonance between the fractal character of basic perceptual processes and the characteristics of the perceived pattern, or as Goldberger (1996) put it, "The artwork externalizes and maps the internal brain-work. . .Conversely, the interaction of the viewer with the artform may be taken as an act of self-recognition" (p. 102). Yet it is difficult to see how a resonance between the perceiver and the perceived can explain the aesthetic experience that is often associated with these images. What can an objective description in terms of noise signals tell us about subjective aesthetic experiences? Another critical point is that the explanation of biophilic responses toward fractals in terms of noise signals emitted by the nervous system must be situated on a different level than the evolutionary account presented here. The former explanation refers to the workings of the nervous system, but it does not explain why it is characterized by 1/f noise in the first place. Although it is true that some researchers believe it is the result of evolution in a natural world with similar fractal properties (Anderson & Mandell, 1996), it remains unclear how a connection with our evolutionary framework should be conceived precisely. In fact, 1/f noise occurs on all levels of human functioning, from human gait dynamics to neural functioning, whereas in our account it is proposed that the affiliation with natural form has its correlate in more discrete brain mechanisms.

Fractals and biophilic reactions: a critical evaluation. The previous review shows that there is convincing evidence that fractals capture some of the core geometric qualities of natural structures. Furthermore, there is also some support, both intuitively and empirically, that biophilic responses are associated with some typical fractal qualities (i.e., their degree of recursiveness). Still, this does not necessarily entail that it is the naturalness associated with fractals that is the underlying cause of these responses. Notwithstanding that this is perhaps the most obvious explanation, it could be equally hypothesized that fractals are quite complex patterns that give us the necessary degree of arousal that our visual apparatus desires. Such an explanation does not rule out the fact that fractals look natural, but it makes no recourse to naturalness to explain our emotional relation with such patterns.

It is clear that further research is needed on the topic of fractal aesthetics and the possible relations to biophilia. In this regard, it is interesting to note that some empirical research begins to unravel these issues. For example, Hägerhäll et al. (2004) have performed a more systematic inquiry into the relation between aesthetic preference and fractals. In the first stage of the study, 119 participants indicated which silhouette outlines of 80 nature scenes they preferred most. In a next stage, the fractal dimension of all these silhouettes was calculated. It is worthwhile to note that the photos of settings with water features and hills were left out of the total pool of pictures. The reason is that these elements have a strong influence on the visual inspection and aesthetic judgment of landscapes (e.g., Ulrich, 1981), which could distract participants from concentrating on the silhouette outlines. For the remaining 52 pictures, analyses showed a modest but significant correlation between mean preference and the fractal dimension of the silhouettes. Although further research is needed, this finding lends support to the claim that fractal characteristics play a significant role in our biophilic responses toward vegetated/natural landscapes.

Fractal architecture. The previous discussion tentatively suggests that the beneficial effects associated with certain natural objects (positive affect, liking reactions, stress-reduction) could be tapped with fractal characteristics but without the presence of actual representations or imitations of nature. Indeed, fractal structures seem to capture some essential features of naturalness, such as the recurrence of (similar) detail on subsequent scales of magnitude. However, the architecture of many modern environments is becoming predominantly euclidean. This trend is orthogonal to our (hypothesized) predilection for fractal structure, which could have subtle but definite psychological and physiological costs. This problematic situation can be countered (to a certain extent) by architectural work that implements some essential fractal characteristics. Our preference for a specific fractal dimension further indicates that the aesthetic effects of such buildings can be maximized for intermediate levels of complexity. Perhaps this reflects our preference for intermediately complex environments, such as savannas.

If true, the previous findings underscore the value of integrating fractal characteristics in architectural design. In essence, fractal architecture can be realized by repeating similar details on multiple hierarchical scales of an architectural design. Despite the growing attention for fractal aesthetics, which can be witnessed today, we am not aware of actual instances of fractal architecture explicitly rooted in the current theoretical framework. This, however, does not preclude that, historically, instances of fractal architecture have been constructed, albeit for other theoretical or ideological reasons. According to Michael Ostwald (2001), the first examples of architecture, referring to fractal theory, began to appear shortly after Benoit Mandelbrot's seminal book *Fractals: Form, Chance and Dimension*. Although there has been a rise in fractal architecture from 1978 to 1988, this trend did not persist during the 1990s. Yet, in recent years there is a renewed interest in integrating the complexity sciences and fractals in architecture. To a certain extent, this is due to the publication of Carl Bovill's *Fractals in Architecture and Design* (1996), in which fractal geometry is advanced as a useful design instrument. With his books *The New Paradigm in Architecture* (2002) and *The Architecture of the Jumping Universe* (1995), architectural theorist Charles Jencks has undoubtedly an important share in bringing the issue of fractal architecture to the attention of the architectural community. Nevertheless, some have argued that Jencks gives a skewed account of fractal architecture because he essentially misrepresents what a fractal actually is (Joye, 2006; Salingaros, 2004). This has led some to conclude that his use of the notion fractal in architecture mainly serves rhetorical purposes (Joye, 2007).

Fractals have been implemented in architecture in many ways, albeit consciously or intuitively (for a review, see Joye, 2007). Probably the most striking examples of fractal architecture have been intuitively constructed, before the systematic description of fractal geometry. For example, Leonard Eaton (1998) argues how Frank Lloyd Wright (unconsciously) emulated a fractal-like geometry in his Palmer House. Nevertheless, it should be noted that the fractality of this building is predominantly situated in ground plan, and this approach has been criticized by Joye (2007). Perhaps more convincing examples of three-dimensional fractal architecture can be found in Gothic architecture (Figure 5). In this regard, Goldberger (1996, p. 101) notes that "fractals capture several key features of Gothic architecture: its porous 'holeyness' or carved-out appearance, its wrinkled crenelated surfaces, and its overall self-similarity. . .From a distance, the sharp spires are the dominant feature. Closer proximity reveals that these spires are not smooth, but have spiny outgrowths. Yet closer inspection reveals even more pointed detail superimposed on these ornaments. The repetition of different shapes (arches, windows, spires) on different scales yields a combination of complexity and order."

In agreement with the Gothic, the shape of certain Hindu temples also has conspicuous fractal characteristics (Figure 6). The makeup of these buildings cannot be viewed separately from the Hindu worldview. In particular, Hindu cosmology is in a sense holographic in that all parts of the cosmological whole are the whole itself and contain all the information about the whole. Some schools of Hindu thought advance the (related) view that the macrocosm is encapsulated in the microcosm: "The entire cosmos can be visualized to be contained in a microcosmic capsule, with the help of the concept of subtle elements called 'tanmatras.' The whole cosmic principle replicates itself again and again in ever smaller scales. The human being is said to contain within itself the entire cosmos" (Trivedi, 1989, pp. 245–246). Both these cosmological conceptions can be straightforwardly related to fractal self-similarity, where the global formal structure recurs, on ever finer subscales, in the microstructure.

A potential problem for the argument presented here is that not much architecture displays the very profound fractality of Hindu or Gothic architecture, which could cast doubts on the hypothesized universal preference for fractal-like patterns. However, some claim that, historically, architecture has always had an important fractal component (Salingaros, 2006), in

Figure 5. Gothic architecture often has an important fractal component because it contains a wealth of architectural elements on increasing smaller scales of magnitude. (Copyright © Yannick Joye.)

that many buildings display architectural detail on different scales of magnitude, without having a more exact sense of self-similarity. Indeed, a consideration of some of the high points of Western architecture, ranging from, for example, the Gothic to Baroque and Organic Architecture, quickly reveals a remarkable tendency for a cascade of detail, going from the largest building structure to the smallest decorative element. This view is also empirically supported for divergent building styles (e.g., Bovill, 1996; Burkle-Elizondo & Valdéz-Cepeda, 2006; Capo, 2004; Crompton, 2002).

Still, when observing modern urban settings, it is also a matter of fact that not all architecture of all times contains references to natural form, which suggests that tastes are not exclusively dictated by biological predispositions. How can this be reconciled with the hypothesis that we are in a sense genetically predisposed to affiliate

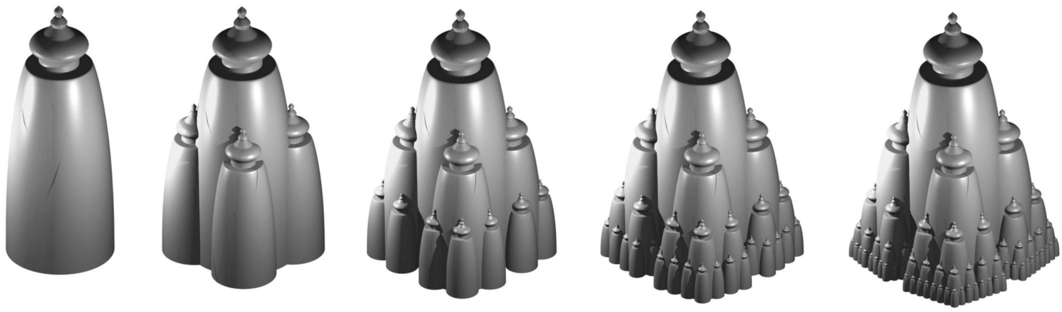

Figure 6. Three-dimensional generation of the central spire of a Hindu temple. One architectural element is repeated on subsequent scales, which results in a complex aesthetic object. (Copyright © Yannick Joye.)

with natural forms and to express this affiliation artistically? An answer is that inborn mechanisms do not imply genetic determinism but instead are in a sense open in that they can interact with cultural or experiential parameters. Although in this study we mainly focused on immediate affective responses to nature, Ulrich's (1983) psychoevolutionary model also leaves room for more cultural modes of aesthetic appreciation, which interact (in a complex way) with immediate affective responses. Consistent with this is that discussions on innateness are sometimes framed in terms of biologically prepared learning rules, where experiential, and hence cultural, influences are attributed a significant role (Cummins & Cummins, 1999; Ulrich, 1993).

Although it is plausible that changes can occur in artistic taste, [1] this does not in any sense invalidate the argument that the outlook of certain habitats is more attuned to a set of specific hardwired affiliations, which were discussed here. Again, it is unproblematic that people hold specific tastes by which they also become surrounded by nonnatural architectural forms. Problems could arise when the artistic expressions of these (more culturally colored) tastes gain dominance, with the result that chances for experiencing natural forms, and the associated biophilic responses, are significantly reduced. Of course, prevailing cultural tastes could clash with basic-level biological tastes, which could indicate that there is a complex interplay between the two modes of appreciation. Probably, architects are sensitive to what is culturally fashionable and are thus in a good position for coherently fusing biological and cultural tastes into a successful architectural expression.

Discussion

In this article, different research disciplines were drawn together, ranging from environmental psychology to architecture. This speculative and interdisciplinary study can, therefore, be understood as a contribution to the integration of (subfields of) the scientific and cultural worlds. The argument began with a survey of findings from the field of environmental psychology, which revealed that humans are affectively related to specific natural elements and settings, being the result of human evolution in a natural environment. Today, however, modern habitats contain increasingly less actual nature or artistic references to natural form or to the structural organization of preferred natural settings. Although such a trend undoubtedly has

[1] However, a question that immediately springs to mind is, who holds these tastes? Is it the general public or is it the artists themselves? If the artists, then it nevertheless remains an open question whether these changes in taste are also appreciated by the broad public, which is the audience for whom biophilic architecture is intended. In this regard, it can be noted that there is often a discrepancy between the aesthetic tastes of laypersons and those of experts (e.g., artists). For example, in a playful experiment, Russian artists Vitaly Komar and Alex Melamid found that people from different cultures preferred kitschy landscape paintings over nonrepresentational abstract art (see: www.diacenter.org/km/). Although it is premature to deduce definite conclusions from these observations, it nevertheless shows a more complex view than the adagio that tastes are essentially variable.

artistic and epistemological consequences, the more profound implication is that it can negatively influence psychological and physiological functioning. According to the argument of the current study, biophilic architecture can help in overcoming the discrepancy between ancestral and current habitats. More specifically, the architectural imitation of natural elements and habitats that promoted fitness (e.g., vegetative structures) can lead to the autonomous and quick onset of positive affective reactions, which can lead to positively toned feelings and stress reduction. It was argued how such imitations can be realized according to different levels of abstraction, ranging from literal imitations to the application of more abstract geometric features of natural objects (e.g., fractal geometry) and structural features of ancestral habitats. Applying fractal geometry to architecture could be a particularly successful creative strategy, because it is not directly restricted by stylistic conventions and thus does not exclude the expression of cultural or local tastes.

Nature-based architecture implies that the building enters into a dialogue with a specific set of human inborn affiliations. However, adherents of biophilic architecture should become aware that their work also has to relate to or become embedded in a social, historical, ecological, and individual context (Kellert, 2005). Indeed, the notions "should" and "has" are at their place here. It would be contradictory that, in a social–psychological project like the one presented here, attention is paid to a basic level of well-being while other factors that also contribute to it are totally neglected. The result is that an exclusive focus on biophilic interventions is not an automatic guarantee for a higher level of well-being. For example, it would be unthinkable for biophilic architecture to be interested in the short-term or immediate impact of architecture on well-being, while it remains apathetic for ecological issues, which are relevant for the well-being of our future selves and future generations. Some could claim that this line of thought weakens our argument for biophilic architecture. We believe the contrary and are convinced that a careful consideration of these factors can maximize the biophilic responses to architecture, because other interfering factors are controlled for.

A growing number of academics are involved in nature-based or biophilic design. In addition to providing a detailed account of this research topic, this study hopes to awaken further interest in biophilic design. This is necessary because the arguments presented here remain quite tentative. For example, on a theoretical level, it would be insightful to come to a finer grained account of how fractal forms are processed by the brain. Another more practical issue is the question of how to create successful biophilic architecture. It could be true that many architects have an intuitive feel for the importance of nature as a source of inspiration. However, looking at the modern built environment, it is also a fact that this intuition is not often put into practice. This report, therefore, tried to provide some practical guidelines. It should be noted, however, that it only has scratched the surface. In a sense, only a few grammatical rules were presented, and it is up to creative minds to work out a formal language with these elemental rules. Such a project can only succeed by a transdisciplinary approach, in which both architects and psychologists take knowledge of this new field of research.

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Received September 19, 2006
Accepted July 19, 2007 ■

Acknowledgment of Ad Hoc Reviewers

The Editor and Editorial Review Board take this opportunity to thank the following persons who reviewed submissions for volume 11, 2007.

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