A Tentative Argument for the Inclusion of Nature-Based Forms in Architecture

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Abstract (in Dutch)

Als gevolg van evolutie in een natuurlijke omgeving heeft de mens een esthetische voorkeur ontwikkeld voor bepaalde typische landschapsconfiguraties, en natuurlijke elementen. Onderzoek wijst uit dat deze eigenschappen ook een positieve invloed hebben op verschillende aspecten van het menselijke functioneren, en bijdragen tot stressreductie en een herstel van de gerichte aandacht. Men kan echter vaststellen dat er in moderne stedelijke omgevingen vaak steeds minder mogelijkheden zijn tot contact met natuurlijke elementen en landschapsconfiguraties. In deze doctoraatsthesis wordt beargumenteerd dat zo'n evolutie een subtiele negatieve impact kan hebben op ons psychologisch en fysiologisch welzijn. De centrale hypothese is dat dergelijke effecten kunnen worden tegengegaan door de architecturale imitatie, in de bebouwde omgeving, van vormeigenschappen die kenmerkend zijn voor natuurlijke entiteiten. Verschillende praktische voorstellen worden uitgewerkt, gaande van de letterlijke imitatie van natuur in architectuur, tot de implementatie van fractale geometrie in een bebouwde context.

Acknowledgments

Right now I am at the verge of closing a project that has dominated my life during almost five years. It is a little miracle that I have finished this doctorate. I must admit that I had almost abandoned this project last year. While I was quite content at the time, I took a job as an editor of a DIY magazine, but quickly realized that the grass was indeed much greener on the other side. Not in the least I missed the intellectual freedom and the creative thinking process. I am still very grateful to Sarah that she offered me the opportunity to quit this job, in spite of the fact that this would lead to my unemployment, and that it would put some financial pressure on is, with the care of our two newborn babies. Still, my family and dears convinced me that it was a once in a lifetime opportunity, and I am still thankful to all who motivated me to finalize this project.

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Yannick
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Introduction

The central problem

The central problem of this dissertation is that in the modern world human exposure to nature has been drastically reduced. While people often actively seek contact with nature during their leisure time (e.g. gardening, nature walk, zoo visit), nature is often pushed back from our daily functioning. It is no fiction for people to go to work by the underground subway, work in a windowless office, take the subway back home, and spend the evening indoors, in front of the television. We can now witness this estrangement from nature in our own regions, where villages are increasingly extended, and the countryside is steadily taken over by residential areas. The Belgian coastal strip seems to be an epitome of this trend, and only few is left of the original natural dune landscape. Moreover, many agree that the architecture that took its place excels in ugliness, and economic motives seem to prevail over aesthetic considerations. Similarly, in modern metropolises grid planning reigns and the geometrical forms and volumes that are typical of modern buildings seem to be of an entire different category than nature's forms. With increasing urbanization it is probable that such urban organizations will gain greater dominance, and will become a daily reality for even larger populations.

But why is this estrangement from nature problematic? Couldn't we just accept the fact of having less contact with nature? Of course there is no logical necessity to pursue contact with nature, neither is there something inherently wrong about our modern way of living. Still, many of us perhaps have the intuition that nature is in a sense good for us, or are intrinsically fascinated by it. In this dissertation we will argue that this intuition is to a certain extent supported by a firm body of empirical research. There is evidence that the gradual disappearance of nature from our daily lives is not a triviality, but is problematic because it has important physiological and psychological health effects. In essence, evidence is gathering that we have a non-negligible positive affective relation with certain natural entities (e.g. vegetative life), which is a remnant of human ancestral evolution in natural settings. Obviously, the effects of the reduction of nature are most noticeable in the radical alteration of the visual/formal outlook of settings. For instance, natural settings are characterized by roughness, curvature and richness in detail, whereas the modern buildings that often replace it are mostly characterized by straightness and blank surfaces. While the problem of decreasing nature-exposure can be dampened by integrating actual natural elements in the built environment, we will tentatively argue that it can also – to a certain extent – be overcome by integrating nature-based forms in architecture (see also Joye, 2006a-b, 2007a-b; Joye & Van Loocke, 2007).

Our approach is unique in that in the architectural society arguments similar to ours are quasi nonexistent, and a nuanced treatment of this issue is therefore at its place. With this dissertation we therefore aim to make a new and substantial contribution to architectural theory. The few and hesitant research that has been purported in this domain is sometimes also denoted as 'biophilic design', and it has been mainly executed by psychologists, not architects. Although some recent publications in this field have been made, the evidence for including natural forms in architecture is often unconvincing or held implicit. (There are, however, exceptions, but these are often more mathematical in nature than psychological (e.g. the work of Nikos Salingaros)). By offering a broad theoretical discussion we are among the first to present a more systematic treatment of this issue. The broad scope of the discussion is also important for application purposes. In particular, a strong theoretical baggage is necessary for those who want to attempt a creative translation of the current discussion (e.g. architects, designers, artists).

In architecture, nature has always been a perennial source of inspiration – both in architectural writing as in architectural form. Although this doctorate shares this common theme, the exact way in which we come to consider nature as a creative source differs in an important respect from the narratives and arguments proposed in architectural theory. For instance, the literature on the organic tradition, associated with Frank Lloyd Wright and Louis Sullivan, is replete with references to natural growth processes, and also shows a keen interest in natural forms. Yet, the theory on this tradition often remains vague and scattered, and some lines of thought even come close to pseudo-philosophy. To take an extreme example, according to Rudolf Steiner, the natural-like forms that are characteristic of his (organic) architectural work are the expression of supernatural or spiritual forces (Steiner, 1999; Adams, 1992; Biesantz & Klingborg, 1981). More recently, there has been a turn to natural form vocabularies in the field of generative architecture, and more specifically in what is sometimes called 'blob' architecture. This strand of computer-aided design often borrows from contemporary continental philosophy to justify the naturalistic forms of its designs (Lynn, 1998). Here, the proposed arguments are quite elaborate, and require profound familiarity with modern philosophy. Still, it seems that, in blob architecture, experimentation with new nonstandard form-typologies is the primordial motivation for pursuing natural-like or so-called 'biomorphic' forms.

In contrast to these approaches, we try to put forward an alternative justification for the inclusion of natural forms and organizational principles in architecture. Whereas our justification is often speculative – hence the word 'tentative' in the title of this thesis – it is based on empirical findings from diverse psychological subdisciplines, and therefore has a more pronounced scientific background. On the other hand, we do not pursue nature-based forms for their own sake. In contrast, our approach is essentially human-centered, in that there are reasons to believe that the inclusion of such shapes positively contributes to certain indexes of human wellbeing.

Abstract

Chapter 1. In the first chapter we will show that humans have an inborn positive affective affiliation with certain natural entities and landscape configurations, and we will discuss the underlying cognitive models and possible neural correlates. The implication of this discussion is that the gradual exclusion of nature from our daily lives has repercussions for our psychological and physiological health. First, we will give a survey of the typical structural landscape features and of the concrete natural elements that are found to correlate with positive aesthetic judgments. In the second part, research is discussed that shows that naturalness is also 'restorative' for certain aspects of human functioning. In particular, it leads to stress-reduction and it can rest one's capacity to direct attention. The third part will review some of the evidence that tugs into the possible neural correlates of the affective responses towards certain natural contents. This discussion is important for two main reasons. On the one hand, it can deepen the findings from environmental psychology by providing support at the neurological level. On the other hand, such a review adds some support to the genetic claims that are made throughout this chapter. The emphasis on 'innateness' is important, because it shows that the inclusion of 'naturalness' in architectural design can to a certain extent be anchored into a shared human biology, and is not a triviality. In the final section, a critical discussion of the overarching concept of 'biophilia' is presented, and it is shown in which sense it can be used most fruitfully.

Chapter 2. The second chapter demonstrates why the findings from the first chapter underscore the value of including nature-based forms in architecture. More specifically, in the first sections it is argued how reduced contact with nature has its influence on three (interrelated) levels of human functioning: creative, epistemological and emotional. It is argued that this highlights the value of so-called 'biophilic' design interventions in the human living environment. In the subsequent sections, different biophilic design strategies are proposed. First, it is discussed how typical preferred structural landscape features (e.g. 'complexity', 'mystery', 'legibility') can find an architectural implementation. In the next part, it is inquired how our preference for certain natural contents can find a meaningful and successful architectural translation. Different suggestions are made, ranging from the guideline to literally imitate nature in architecture, to the more speculative view to adopt specific abstract geometric features of natural entities, such as curves. These issues are complemented with discussions of relevant architectural examples, and their underlying design philosophies. In fact, a critical analysis of a recent

tradition of biomorphic architecture at the end of this chapter (i.e. 'blob' architecture) highlights the importance of embedding biophilic architecture in a social, cultural and personal context.

Chapter 3. The third chapter argues for the architectural integration of a conspicuous geometric quality of natural elements, namely their fractal structure. The structure of this chapter is as follows. First, the reader is made familiar with some core concepts from the field of fractal geometry, such as 'self-similarity' and 'fractal dimension'. In the following part, evidence is presented that shows that these fractal properties capture some essential features of natural structures. Next, some psychological studies are discussed that tentatively indicate that fractals elicit aesthetic reactions and stress reduction in humans. This seems to suggest that the biophilic responses associated with naturalness could be tapped without the actual presence of natural entities, but with some of its typical geometric features. In the subsequent part, a critical discussion follows of three frameworks that can explain these possible biophilic responses towards fractal patterns. The next parts consist of a discussion of the different ways in which fractal geometry has been appropriated within the field of architecture. Finally, several problematic issues, associated with the notion fractal architecture, are brought under attention, and it is shown how the current argument fits in with the different appropriations.

Conclusion. In the fourth part of this dissertation – the conclusion – the main argument is repeated, and some potential shortcomings of our approach are highlighted. We also consider the different critical points of our argument and point out which are more or less uncontroversial, and which are more speculative. We finish the conclusion with a proposal for a research project that can directly test some of the theoretical claims made in this dissertation.

Appendix. The final component of this dissertation is an appendix, in which a specific method for creating naturalistic ornamental forms is presented. We briefly discuss the mathematical operations underlying these shapes and then show how these mathematical objects can be successfully translated in a three-dimensional modelling environment.

Chapter 1

An inborn affective affiliation with natural forms and landscape configurations

1. Introduction

The starting point of this chapter is that humans have a specific set of inborn or 'hardwired' human aesthetic preferences for typical forms and spatial organizations. As one of the central themes of this dissertation is architecture, it is worthwhile to note that such a view is orthogonal to the predominant aesthetic suppositions underlying many architectural styles, where it is still often presupposed that mental organization, and the aesthetic preferences and tastes that are its outcome, are largely the result of sociocultural influences (Pinker, 2002). To name but one example, the incongruous structural organization of postmodernist architecture, seems to be at variance with the human mind's affinity with more coherent or ordered information (Salingaros, 2004; Pinker, 2002). Such artistic creations, and their underlying philosophy, therefore share one of the central 'dogmas' with what is called, within the field of evolutionary psychology, the 'Standard Social Science Model' (Tooby & Cosmides, 1992). Popularly framed, this model views the mind as a 'blank slate' or 'tabula rasa', where mental rules and organization are 'written down' by personal experience, socialization and culture (Pinker, 2002). The artistic or creative counterpart of such a view is the conclusion that aesthetic tastes are something very private to a certain person, culture or timeframe, and hence, mutually incommensurable.

While it is true that aesthetic experiences are to a certain extent influenced by cultural and social parameters, research in (among others) the field of landscape aesthetics suggests that this is not the whole story. Instead, in the following pages, we will argue that humans share a variety of aesthetic tastes, being a remnant of our shared evolutionary history in natural biomes. Our argument thereby fits squarely within the field of evolutionary psychology. This area of study claims that, just like certain bodily organs are adapted to perform a certain evolutionary relevant task (e.g. the human reproductive organs), the mind, as a result of natural selection, also consists of a set of mental organs or cognitive 'modules' that are dedicated to solve a specific, evolutionary-relevant problem (perhaps the most well-known of such evolved psychological faculties is our language instinct (e.g. Pinker, 1994)). An important and recurring problem for our human ancestors was finding a suitable habitat, and this will form the starting point of our argument. Following the line of evolutionary psychology, one should expect that a set of cognitive mechanisms will have evolved that are specialized in processing information that pertains to the habitability of a setting.

Importantly, the notion 'habitability' is multi-dimensional, in that there is range of factors that make a setting into a good place for living. Probably, a good habitat is one that does not contain too many dangers (e.g. predators), or at least contains elements that allow a quick and relatively easy detection of them, or display landscape features that offer protection against them. Another major factor in the selection of habitats is the fact that these should contain enough food resources, or should have cues that substantial amounts of resources will be present in the future. In the following sections we give an extended review of research into the factors that contribute to the perceived habitability of an environment. What will be found is that humans have an inborn positive affective affiliation with specific natural elements and settings, whereas such responses do not occur when humans are exposed to modern urban settings devoid of nature. This observation supports the problematic character of our estrangement from nature, and evidences the view that the integration of naturalness can positively contribute to (aspects) of human wellbeing.

2. What features make a place into a good habitat?

2.1. Appleton's prospect-refuge theory

Different models have been proposed to explain human aesthetic reactions to environments. In general, such aesthetic reactions are framed as 'liking' or 'disliking' responses. Although coming from a different research field, geographer Jay Appleton (1975, 1990) was one of the first to propose a model addressing the issue of preferred habitats with his 'prospect-refuge' theory. According to this theory, human beings' preference for landscapes correlates with two environmental qualities: namely prospect and refuge. The notion '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, by which predators or potential sources of food could be detected. On the other hand, 'refuge' points to settings that can provide shelter and protection. A well-known example is a cave, which can protect against predators and adverse weather conditions. Appleton holds that the preference for prospects and refuges has become part of the human genetic make-up. Those individuals who could easily detect and settle in environments that provided containment and an unimpeded access to environmental information survived better.

The previous preferences still influence our present behaviour and responses.

Appleton believes that this is especially clear in artistic expressions: they often seem to display a high level of prospect-refuge symbolism (Appleton, 1990) (figure 1). Although the prospect-refuge account has remained largely theoretical (Steg et al., 2004), the presence of prospects and refuges in art has been the subject of some empirical inquiries. For instance, Heerwagen and Orians (1993) showed that both predictors are present in landscape paintings. More importantly, it was found that the depiction of prospects or refuges depended on certain contextual factors: namely, 'time of the day' and 'gender-differences' (Heerwagen & Orians, 1993). The influence of these contextual factors was inquired by means of 64 landscape paintings. These paintings were selected from art books or books from exhibitions, and showed work from a variety of painters.

Figure 1: The scene depicted in this painting has both a prospect and refuge dimension. The lower right part shows a couple embracing. They are surrounded by bushes and a tall tree, which makes a good refuge for this intimate act, and avoids that they will be disturbed or caught by surprise. On the other hand, the vantage point of this painting must be situated on an elevation, which offers a good prospect on the far-away landscape. Note also that the setting contains a water-feature and has important resemblances with savanna-type landscapes.

For our ancestors, it was highly adaptive to be sensitive to the time of the day. Importantly this factor seems to be differentially related to either prospect or refuge. For example, when the sun was setting, this was the signal for searching for a safe refuge for spending the night. Earlier during the day, this was less important, and individuals could roam more far from their refuges. The differential relation between time of day and either prospect or refuge has found significant expression in the landscape paintings, which Heerwagen and Orians (1993) inquired. First, in the population of paintings, there are more paintings of sunsets than sunrises, which could point to the fact that being attentive to sunsets is more urgent than to sunrises. Second, it was found that paintings of sunsets had a higher degree of refuge symbolism, while paintings of sunrises had less refuge symbolism. Third, sunset paintings often depicted humans near places where they could spend the night, while sunrise paintings showed people in a greater variety of places. The latter observation is related to the fact that, at sunrise, there is no time pressure to find a refuge for spending the night. Finally, paintings of sunsets that were high in tension often portrayed people far away from a refuge, or showed how they were inattentive to cues of impending darkness.

The second contextual factor – gender differences – was examined with landscape paintings that were painted by either male or female subjects. During human evolution women and men have been involved in different tasks, and they are therefore supposed to assess environments differently. According to Heerwagen and Orians (1993) this will, be reflected in landscape painting. In general, they hypothesize that women will have more affinity with refuges, while males will be associated more with prospects. It was found that the paintings women had made more often displayed a high refuge symbolism than the paintings of men. Heerwagen and Orians (1993) argue that these results can be explained by the different reproductive activities and tasks in which our male and female ancestors were engaged. Because pregnancy, birth, and taking care of children requires a secure resting place, and because these activities made females vulnerable to predators, they show more affinity with refuge-like settings. The interest in refuges is also due to the fact that females were gatherers and because vegetable food resources are to be found in more closed and vegetated settings. Males, on the other hand, seem to have more affinity with prospects because they were hunters and because the large game herds roamed prospect-dominant settings. A content analysis of 'male' and 'female' landscape paintings further showed that female paintings contained more elements associated with refuge, while male paintings showed more prospect elements. For instance, in 58 percent of the male paintings the horizon covered at least half the width of the painting, as opposed to female paintings, where only 14 percent had wide views of the horizon. Furthermore, it was found that when male or female subjects were depicted in the landscape paintings, the latter were more likely placed in refuge-like settings, while the former were associated more with open spaces.

More recently, the relation between prospect, refuge and children's preferences for landscape paintings has been inquired by Fisher and Schrout (2006). Sixty-seven children, aged 9 to 14, participated in this study. From a set of 28 landscape paintings, they had to indicate how much they liked them, and had to judge the degree to which prospect, refuge and hazard were present. According to Appleton's theory, subjects should find those paintings having a high prospect and refuge dimension attractive. This observation was only partly confirmed. While Fisher and Shrout found a correlation between liking and degree of prospect, they did not discover an association between liking and refuge. It is plausible that the aesthetic attraction of refuges is to a certain extent dependent on the presence of hazard cues. Indeed, the need for a refuge gains importance when one is confronted with a certain hazard. The observed pattern can therefore be explained by the fact that the children rated the paintings low in hazard. Furthermore, the study indicated that boys, as opposed to girls, preferred paintings that were more hazardous than others. In fact, one would expect that hazard is negatively correlated with liking. The opposite finding can, however, be explained by the fact that hazards can provoke liking and awe, when the subject is in safe distance. Furthermore, there could well be sex differences in the appreciation of hazard. Indeed, male subjects tend to be more often involved in hazardous activities than female individuals.

2.2. The informational model of the Kaplans

Humans are in constant search for meaningful information. This informational perspective is the starting point of another model of environmental preference, which has been developed by Rachel and Stephen Kaplan. This model is often referred to as the 'preference matrix'. Stephen Kaplan (1987, 1988) describes two types of attitudes towards the environment that can respond to one's informational needs. On the one hand, one can be actively 'involved' in an environment (e.g. exploring the setting). On the other hand, one can try to 'understand' the environment. Kaplan argues that these two attitudes are facilitated by four structural landscape properties, which have been extracted from a large number of studies in landscape aesthetics (see Kaplan & Kaplan (1989) for a discussion). The degree to which these 'predictors' are present in a setting correlates with (aesthetic) preference.

Figure 2: A complex, but profoundly incoherent natural setting.

Figure 3: A very coherent, but minimally complex desert environment (Kalahari).

The structural properties that express, or enhance, the *involvement* in the environment, are 'complexity' and 'mystery'.

a. *Complexity*: this quality is defined as a measure for '... how much is "going on" in a particular scene, how much there is to look at' (Kaplan, 1988, 48). A tropical forest often is highly complex, because it contains many different forms, textures, colours, changes in density, and so on (figure 2). In contrast, a desert contains much less landscape features, and hence, is less complex (figure 3).

b. *Mystery*: refers to settings in which the available information promises the individual that more information can be acquired if he or she penetrates the scene more deeply. An example of a mysterious landscape element is a bending trial or a deflected vista (figure 4).

Figure 4: The deflected vista depicted here can lead to curiosity about what might lie beyond the bend in the road, which causes explorative behaviour.

Figure 5: This prominent rock can function as a point of orientation when viewed from the surrounding setting, and it thereby contributes to the legibility of the landscape.

The structural properties that facilitate an *understanding* of the environment are 'coherence' and 'legibility'.

c. *Coherence*: refers to the presence of visual features that contribute to the organization, understanding and structuring of the image, such as symmetries, repeating elements and unifying textures. For example, an even ground surface can draw dissimilar landscape elements together. Trees or tree-groups that have a similar appearance and that are more or less evenly spaced – like in a savanna – can also make a scene more coherent.

d. *Legibility*: concerns the interpretation of spaces, and refers to the capacity to predict and maintain orientation in the landscape as one further explores it. Think for example of a prominent rock/hill (figure 5), or a conspicuous tree-group, functioning as a point of orientation.

According to Kaplan (1988) landscape information can be presented to the perceiver in two different ways. On the one hand, there is the two-dimensional projection of the environment on the retina – the 'visual array' or the 'picture plane'. On the other hand, a scene can be unfolding three-dimensionally before the eyes of the observer. Each of the aforementioned predictors belongs to one of these groups: complexity and coherence are part of the two-dimensional pattern, while legibility and mystery belong to the three-dimensional scene. Kaplan (1987) mentions that the four structural properties can be classified into two further groups, depending on whether the information that they convey is either immediately available, or is 'promised' or can be predicted. The former applies to 'complexity' and 'coherence', while the latter is true for 'mystery' and 'legibility'.

Gimblett et al. (1985) have further inquired which features contribute to the mysteriousness of a setting. Their research reveals that mystery depends on five properties: namely, screening, radiant forest, physical accessibility, spatial definition and distance of view. 'Screening' refers to the degree in which views on the surrounding environment are blocked. Mystery increases with higher levels of screening. 'Radiant forest' is the situation in a forest where fore- and background are respectively shaded and illuminated, which contributes to mystery. 'Spatial definition' refers to the degree in which landscape elements surround the subject. An increase in the presence of this factor leads to increasing mystery. The two last factors are 'physical accessibility' and 'distance of view', which correlate respectively positively and negatively with the degree of mystery.

Kaplan (1987) holds that the assessment of whether certain informational features and natural contents are present in a setting is the result of a *cognitive* process. The notion 'cognitive' does, however, neither imply that the assessment is a conscious process, nor that it involves calculations. Sometimes, like in the case of complexity, it does not require much cognitive processing, and it is the result of a straightforward analysis of the (number of) elements present in the stimulus array. On other occasions, such assessments are fairly complex, inferential processes. Kaplan (1987) describes how this especially applies to the predictor mystery: 'What … [mysterious] scenes share is a complex relationship that exists between the observer and the environment. The relationship cannot be detected directly in terms of feature analysis. If one were attempting to build a computer model of such a process it would be exceedingly unlikely that any combination of features could be identified that would yield a consistently valid conclusion concerning Mystery. In contrast, a far more promising procedure might be to use the feature information to construct a rough conceptual model of the three-dimensional space represented by the scene. Then, by simulating locomotion within this hypothetical space, it could be determined if more information would be acquired' (22).

Like Appleton (1975, 1990), the Kaplans ground their theory in an evolutionary framework. The rapid, automatic and unconscious assessment of the presence of certain structural landscape features holds evolutionary benefits because it is an economical process, and because it allows the organism to keep up with new and incoming information. Kaplan (1987) holds that this process would be even more efficient if the environments were immediately 'liked' or 'disliked', or categorized as either 'good' or 'bad'. Such reactions are adaptive because they motivate or 'guide' the organism to undertake actions that contribute to its well-being and survival (e.g. flight or exploration). Finally, survival chances would further increase if these preferences had an inherited component. This entails that the organism does not have to invest time and energy in learning each generation anew which environmental configurations offer the best opportunities for habitability.

2.3. Roger Ulrich's psychoevolutionary framework

A third model that tries to chart the specific landscape configurations and elements that are associated with preferential reactions is Roger Ulrich's psychoevolutionary framework (Ulrich, 1983). The central notion in this framework is 'affect', which is used synonymously to the concept 'emotion'. Importantly, following the work of Zajonc (1980), Ulrich (1983) considers that the quick occurrence of generalized affect constitutes the first level of reaction towards an environment. Such affective states are essentially precognitive and independent of recognition. This means that '… we can like something or be afraid of it before we know precisely what it is and perhaps even without knowing what it is' (Zajonc (1980, 145) in Ulrich (1983, 89)). Note how this contrasts with a central tenet of the Kaplans' preference matrix, where emotional reactions towards certain informational features are to a large extent the result of more cognitive processes (Kaplan, 1987; 1988).

The quick onset of such affective reactions is essentially adaptive: on the basis of very little information the organism is motivated to quickly undertake actions that contribute to its well-being and survival. For example, if early humans came across a setting containing an important risk (e.g. turbulent water), this immediately triggered negatively toned affective reactions (e.g. dislike), ultimately leading to avoidance behaviour. On the other hand, if a setting contained features that were indicative of good opportunities for survival and reproduction (e.g. food), this would have caused liking reactions, which motivated to further explorative behaviour.

After the occurrence of these affective reactions, more cognitive evaluations of the environment can occur. These entail recognition, identification and a more detailed processing of the environmental information. Importantly, this evaluation can be accompanied by memories, associations, which, of course, can be culturally 'coloured'. These influence the initial affective response and concurrent physiological arousal. Ulrich gives the following example to make his point: 'As an extreme example, an aesthetically spectacular vista would likely elicit an initial affective reaction of strong preference and interest that could sustain a lengthy and elaborated cognitive process, involving detailed perception and processing of the visual information and thoughts as diverse as memories from a childhood vacation or an idea recalled from a poem' (Ulrich, 1983, 93). Note how this example illustrates how there can be a complex interplay between a set of primary biological responses, and culturally or experientially coloured thoughts and reactions.

Ulrich (1983) argues that several types of structural landscape properties of (natural) environments elicit immediate (positive) affective reactions. These features are sometimes referred to as 'preferenda'.

1. A first preferendum is *complexity*. This notion refers to the amount of independent elements that are present in a particular setting.

2. A second class of properties is described as *gross structural features*. These features promote the structuring and organization of the content of a particular visual scene, which facilitates the comprehension of the environment, and its efficient visual processing. This structuring can be obtained by patterning, homogenous textures, redundant elements, grouping of elements, focal points, and by connecting separated or dissimilar elements.

2. A third factor whose presence correlates with aesthetic preference is *depth* or *spatiality*. The reason is that open settings are more informative than closed environments. Furthermore, the latter possibly contains hidden dangers and could make escaping difficult.

3. The depth or spatiality of a visual scene depends on a fourth property, namely the *texture* of the ground surface. It is found that highest preference is associated with an even textural ground surface, as opposed to rough and uneven surfaces. Explanations are that settings with an even surface facilitate the extraction of information; they are more conducive to movement and exploration; and they are less disordered than uneven surfaces.

4. A fifth factor is the presence of *threats* or *tensions*. Research indicates that this property is negatively correlated with preference.

5. The sixth preferendum is coined *deflected vista*. This property refers to (natural or urban) settings where the line of sight turns away or is deflected, which gives the impression that new information is present beyond the scene that is visible from the point of view of the observer. Ulrich argues that deflected vistas correlate positively with aesthetic appreciation. Yet, the preference for this feature is not independent. The initial appreciation can decrease by the potential risk involved in reaching the promised information. Finally, note that Ulrich – like the Kaplans – points out that '[T]his property is highly cognitive, and therefore is probably not a major factor in the initial affective reaction' (Ulrich, 1983, 103).

6. The final component of the model is more tangible than the former structural properties. Research indicates that environments containing specific *contents*,

namely vegetation and water-features, are associated with high levels of preference.

2.4. Emotional affiliation with natural contents

In the following paragraphs, we turn away from our discussion of structural landscape features and look for natural elements that are found to be associated with aesthetic preference. In the literature on landscape aesthetics, these elements are often referred to in terms of natural 'contents'. Humans seem to display a consistent preference for four types of natural contents: savannas, water-features, vegetation, and flowers. Importantly, the widespread aesthetic appeal of these elements is found to be suggestive of an inborn predisposition to like such natural elements.

2.4.1. The savanna hypothesis

Within the field of environmental psychology it is often argued that humans have an innate preference for landscapes that share (visual) qualities with savannas, or park-like landscapes – settings that seem to display an ideal 'mix' of the previous structural properties or preferenda (Ulrich, 1983, 1993; Kaplan, 1987; Heerwagen & Orians, 1993; Appleton, 1975, 1990; Orians, 1980, 2001). The reason is that a substantial part of hominin and *Homo* evolution was spent in East-African savannas, and that it was adaptive to like the settings in which one thrived. Although different subtypes of savannas exist, they share some common features: a moderate to large 'openness'; the presence of scattered trees or tree-groups; a smooth ground surface and/or a grassy vegetation of uniform length (Ulrich, 1993) (figure 6).

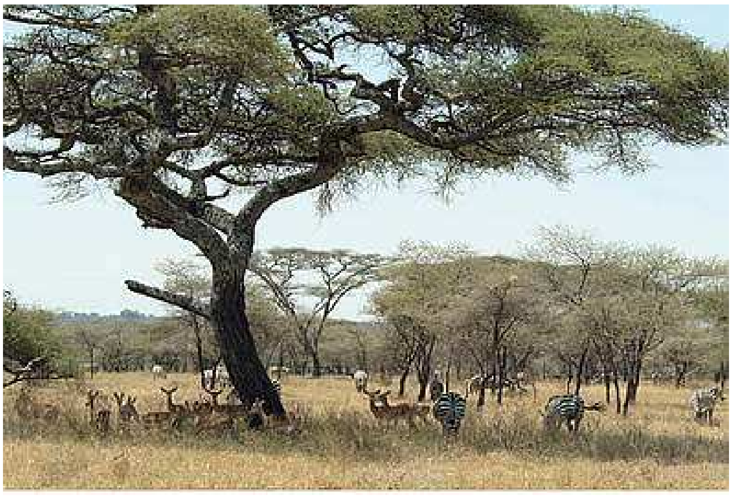

Figure 6: A Tanzanian savanna landscape.

But why do savannas offer good opportunities for survival? Several arguments have been presented. First, biomass and the available amount of meat are higher in savannas than in forests. Secondly, in tropical forests, most food sources can be found in the canopy, often inaccessible to terrestrial beings. In savannas resources are more easily accessible because they are generally located within two meters from the ground. A third reason is that savannas have a high prospect dimension. Their openness facilitates the anticipation and detection of (ambushing) predators, as opposed to dense forests, where there is less visibility and thus a greater risk of being attacked by surprise. This increased visibility is also of use for hunting, because game can be located from larger distances. Finally, the openness of savannas is conducive to movement and supports a nomadic way of life (Orians & Heerwagen, 1992; Orians, 1980).

2.4.1.1. The savanna hypothesis and aesthetic interventions

Several indications support the savanna hypothesis. A first is the finding that aesthetic enhancements to artwork or landscapes are often associated with an increase of features or configurations that are typical of savannas. The underlying thought is that, if people have a preference for savanna-type landscapes, then this should be expressed in aesthetic expressions.

For instance, Heerwagen and Orians (1993) have studied the landscape modifications carried out by the 18th century British landscape architect Humphrey Repton. Interestingly, Repton offered his clients 'before' and 'after' drawings of their estates. Because one of the primary purposes of the landscape modifications was aesthetically enhancing these landscapes, Heerwagen and Orians (1993) speculate that the changes made by Repton will have resulted in landscapes more similar to savannas. Indeed, content analyses of the 'before' and 'after' drawings reveal that the landscapes were made more savanna-like (figure 7). For example, Repton added trees to open fields, removed trees to open the horizon and opened up dense settings by removing trees. Furthermore, he expanded water elements or made them more conspicuous, and made visual access to water features easier. Finally, in the designs that were analyzed almost 200 grazing mammals were placed.

Figure 7: Humprey Repton's 'before' (top) and 'after' (bottom) sketches of the South Avenue of Hanslope Park (England). Most notable about the changes is that the strict ordering of the trees is broken down, and instead the trees are spaced more freely in the landscape, much like in a savanna-type setting.

Heerwagen and Orians (1993) also note how landscape painters sometimes change the content of their work to make it more aesthetically appealing. In this regard, they analysed sketches of the 19th century British painter John Constable, and compared them with paintings based on these sketches, but that were modified with respect to the latter. There were a total of nine of such sketch-painting pairs. In agreement with the savanna hypothesis, the changes to the paintings tended toward features characteristic of savanna-type landscapes: '… the most frequently made changes involve the addition of houses, people, and animals, as well as alterations in vegetation that open views to the horizon or to the refuge and alterations in water features to make them more conspicuous' (Heerwagen & Orians, 1993, 156).

Heerwagen and Orians (1993) also point out that artificial changes and selections to certain plant species – with the goal of aesthetically enhancing them – are accompanied by an increase of features that are characteristic of savanna vegetation. More specifically, they analyzed the changes that were produced in cultivars of the *Acer palmatum*, a Japanese maple often used in Japanese gardens. They found that there has been a strong selection for three important features. First, there was a tendency to select for a reddish coloration of the leaves. This is consistent with the observation that bright coloration in trees (e.g. by flowers) is strongly preferred, because it is a conspicuous sign of (future) food sources. Being sensitive to such features is claimed to be evolutionary favourable. Second, there was a selection for deeply lobed leaves, and more than half of the cultivars was lobed up to the base of the leaves, by which it appeared palmately compound. This is similar to the leaves of savanna-type trees, which are often small and compound. Finally, many of the cultivars tended to have the characteristic form of savanna trees: shrubby, more broad than tall, and drooping branches (Heerwagen & Orians, 1993).

Another artistic indication for an aesthetic predilection for savanna-type landscapes comes from a (playful) experiment by the Russian artists Vitaly Komar and Alex Melamid. Because it has not been subject to strict empirical and statistical procedures, it shouldn't be taken too seriously. Nevertheless, it shows a pattern, consistent with the savanna hypothesis. In essence, the central goal of the artists was to know what a 'people's art' would look like. Via a web poll beginning in 1994, they tried to find out which elements were most desired in a painting. In a first phase, the survey was done for subjects from the United States only, but later subjects from other countries also became involved. Overall, there seems to be a cross-cultural consistency in the choice. The most wanted paintings depict an idealized rural landscape, dominated by green and blue colours, with a large body of water, one or more trees, a hill and some animals and people. On the other hand, the least wanted paintings are (mostly) non-representational and abstract in nature.

The contents depicted in the most wanted paintings are consistent with the savanna hypothesis, and the cross-cultural similarity in preferences seems to be an indication of universal aesthetic preferences. In this regard, it is worth mentioning that this universalistic claim has been criticized by Arthur Danto (see Pinker, 2002; Dutton, 2003), who argues that the most wanted paintings may as well be a reflection of our familiarity with calendars (or posters) depicting these contents. However, as Dennis Dutton correctly notes, this begs the question as to why people seem to like such calendars so much in the first place (Dutton, 2003). Perhaps, as Pinker notes, the success of such calendar landscapes can be a sign that it is '… not an arbitrary practice spread by a powerful navy but a successful product that engages a universal human aesthetic' (Pinker, 2002, 409).

A final 'aesthetic' or 'artistic' clue for the positive interest in savannas can be found in literature, where features characteristic of such settings are often evaluated positively, while environments such as dense forests can elicit more negative emotional reactions. For example, Orians (1980) notes how forests are often associated with frightening creatures, such as gnomes, trolls, witches, devils, gremlins, and so on (Orians, 1980). Also, horror movies, such as *The Blair Witch Project*, seem to tap into our (inborn) fear of dense forests. The interest in savannas is also evident from the outlook of environments that are mainly created for aesthetic purposes. This especially holds for parks, which are remarkably similar to savannas (Orians, 1980). People will also pay more for land that shares typical characteristics with savanna environments (Orians, 1980).

2.4.1.2. Tree shapes typical of savannas

If the savanna hypothesis is correct then people should find trees that flourish in this type of environments more appealing than tree-shapes characteristic of other biomes. In particular, savanna-type trees '… have canopies broader than they are tall, trunks that terminate and branch well below half the height of the tree, small leaves, and a layered branching system' (Heerwagen & Orians, 1993, 157) (figure 10). The low trunks allow that such trees can be relatively easily climbed, which can prove important for escaping predators, or for providing prospects on the surrounding landscape. However, it should also be noted that savanna vegetation is often quite thorny, so it is probable that climbing only occurred in the case of emergencies, when the predatory risk outweighed the risk of suffering quite severe flesh wounds (Coss, 2003). In addition, the broad canopies can provide shade from the sun, and protect against intense rainfall during the wet season.

Heerwagen and Orians (1993) have inquired the reactions toward trees that are characteristic of high-quality East-African savannas. More specifically, from a pool of photos from the *Acacia tortilis*, trees were selected that varied in canopy layering, height/width ratio, and height at which the trunk bifurcated. A survey involving 102 respondents indicates that the reactions to these variations are consistent with a functional-evolutionary perspective. The most attractive trees are those that have a high to moderate canopy layering, a lower trunk, and a higher canopy width/tree height ratio than less attractive trees (see also: Orians & Heerwagen, 1992).

Figure 10: Typical savanna trees, with wide spreading canopies and relatively short trunks (Umbrella Thorn, Acacia Tortillis, South Africa).

Similar results were obtained in Sommer and Summit's (1995) exploratory study of preferred tree form. In this inquiry, tree icons were varied in canopy size, trunk height and trunk width, and subjects had to rate the attractiveness of these variations. One of the main findings was that subjects strongly prefer large canopies and small trunks. These results were confirmed by a later study by Summit and

Sommer (1999). The stimulus material consisted of five tree types: acacia, oak, conifer, eucalyptus and palm tree. It was found that subjects strongly preferred the acacia over the other tree types when the trees were not placed in a context. Furthermore, there is also a consistent preference for shorter and wider tree-forms. These findings are consistent with the savanna hypothesis. A recent inquiry into preference and tree form has been undertaken by Lohr and Pearson-Mims (2006). In agreement with the savanna hypothesis, they found that spreading savanna-type trees were rated as more attractive than rounded or columnar trees. Moreover, subjects also reported feeling happier when viewing this type of tree.

Still, it should be noted that not all research into preferred tree shapes is consistent with the savanna hypothesis. For example, in a study by Coss and Moore (2002; see also Coss, 2003) children were presented four trees: Australian Pine, Fever Tree, unbrowsed Umbrella Thorn and browsed Umbrella Thorn. The children were aged 3 to 5 years, and came from Israel, Japan and the US. In contrast to the savanna hypothesis, most of the children considered the Australian Pine to be the prettiest. On the other hand, adults found the unbrowsed Umbrella Thorn most beautiful. What is, however, consistent with the savanna hypothesis is that most of the children considered the unbrowsed Umbrella Thorn as the best tree to stay under to keep cool, to climb to hide, and to feel safe from a lion. These results are somewhat surprising, especially since these children had no prior tree-climbing experience. Coss (2003) therefore thinks that this '… suggests a precocious understanding of tree affordances useful historically and currently to avoid predators and to prevent dehydration' (84).

2.4.1.3. Biome preferences of children

If the preference for savannas is in some sense inborn – as proponents of habitat theory seem to suggest – then one would expect that young children, who haven't had extensive contact with landscapes, will prefer savannas over other types of biomes. Note how this conclusion is contradicted by the study discussed in Coss (2003), mentioned in the previous section. For data supporting this hypothesis, often reference is made to an early empirical study by Balling and Falk (1982). They conducted an experiment in which the preference for different types of natural landscapes was analyzed for subjects belonging to six different age-groups: 8, 11, 15, 18, 35 and 70 or older. The landscapes included savanna, tropical forest, coniferous forest, deciduous forest and desert. It was found that 8 year old children showed a significant preference for high quality savannas. On the other hand, from the age of 15 on, subjects preferred coniferous forest, deciduous forest and savanna equally. Balling and Falk hypothesize that the choice of the 8 year old children suggests the possibility of an innate preference for savannas. The decreasing preference for savannas with increasing age can be explained by the familiarity of older subjects with other types of environments. Recently, Erich Synek (1998) has conducted experiments that confirm the conclusions of the Balling and Falk study (1982). Subjects from different age groups were shown computer-generated illustrations of landscapes, varying in relief, vegetation and complexity. For each landscape, the subjects had to indicate in which one they would prefer to live, and spend their holidays. Overall, it was found that pre-puberty individuals preferred low-complexity savannas. Post-puberty subjects showed preference for high-complexity environments, and mountainous woods.

2.4.1.4. Criticisms of the savanna hypothesis

Within the field of landscape aesthetics the savanna hypothesis is often taken for granted, and has remained mostly undisputed. However, some problems have to be brought under attention. First, the amount of research into the savanna hypothesis is fairly small, and it is therefore quite speculative to draw definitive conclusions from the existing data. Furthermore, there is an inherent difficulty in using analyses of aesthetic interventions as support for the savanna hypothesis, such as Heerwagen and Orians repeatedly do. It could be argued that one can always find some art or aesthetic interventions that will be consistent with this hypothesis. However, a lot of artwork remains undiscussed and it is still an open question whether these will also contain savanna features, more than could be expected by chance.

A more troubling problem is that almost no attention is paid to recent discussions in the field of paleoanthropology (for an exception see: Ke-Tsung, 2005). For instance, Wilson (1993) argues how our preferences for nature, and in particular for savannas, 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 adaptiveness. One alternative view is the 'woodland-mosaic' hypothesis, which states that hominins (*Australopiths*) lived in a 'mosaic' of woodlands and open grasslands, where foraging for food occurred both on the ground and in the trees. This entails that hominins were also adapted to more closed habitats. Furthermore, by the late Miocene and early Pleistocene, open grasslands – which are a typical feature of savannas – were not a regular feature of East African landscapes (Potts, 1998). However, both the savanna and the woodland-mosaic hypothesis presuppose that the biome in which hominins evolved remained more or less constant. However, 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 Hominins, there was quite some variation in the environments which they inhabited, ranging from forests, savannas and open-canopy woodlands (see also: Potts, 2006). Similarly, Andrew Chamberlain (2000) notes that '… there is an increasing consensus among palaeoanthropologists that there is no single unitary environment to which earlier human species were optimally adapted' (unpaged[1]). Furthermore, it seems that early *Homo*, when appearing in higher latitudes in Asia and Europe did not exclusively occupy savanna type biomes (Chamberlain, 2000). This point is stressed by Jared Diamond (1993), who notes that there is '… an exaggerated focus on savanna habitats as a postulated influence on innate human responses. Humans spread out of Africa's savannas at least 1 million years ago. We have had plenty of time since then – tens of thousands of generations – to replace any original innate responses to savanna with innate responses to the new habitats encountered' (253-254). These issues need to be addressed by proponents of the savanna hypothesis. Of course, the truth value of the savanna hypothesis does not have any bearing on the finding that humans are adapted to natural environments. Or as Kahn (1999) 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' (39).

2.4.2. Water features, vegetation and flowers

Apart from the preference for savanna-type landscape, humans also seem to show a universal appreciation for environments with water-features, flowers and plants. The preference for these contents can be explained by the fact that it was adaptive to like those features that contributed to survival and by the fact that these preferences became part of the human genetic make-up. These natural elements probably had an important survival value for ancestral humans. Flowers, for example, signalled the presence of food resources and were cues for future foraging sites. Because plants are green when not in bloom, brightly coloured flowers helped in locating plants that offered different resources (Orians & Heerwagen, 1992). Trees offered protection against the rain, and when climbed, they could protect against dangers (e.g. a predator), and gave early humans views on the surrounding environment (Orians & Heerwagen, 1992).

Because appropriate emotional responses to these natural elements contributed to survival, one can understand how still today these natural features elicit interest and positive emotional states. For example, in interior spaces, such as offices, the

[1] In this and the following chapters we will sometimes use the notion 'unpaged' when citing a bibliographic reference. With this we want to make clear that the citation is from an electronic html version of the document, which does not have the original page numbering as the 'paper version' of the cited work. In order to avoid confusing, we give no page numbering, and mark the citation as 'unpaged'.

presence of plants is found to increase the aesthetic attractiveness of the setting (Larsen et al., 1998). Furthermore, when subjects are asked to make a forced choice between an urban environment without vegetation, and a natural, vegetated landscape, then the latter are consistently found as most aesthetically appealing. When urban environments are mutually compared, then those urban settings that also contain some vegetation (especially trees) or a water feature are preferred most (for reviews see: Ulrich, 1986; Thayer & Atwood, 1978; Smardon, 1988).

Yet, a critical note is at its place here. When vegetated landscapes and nonvegetated (urban) architectural settings are mutually compared, then the latter most often involves pictures of quite modern buildings, or at least buildings that are not very 'rich' in form. However, in the following chapters it will be pointed out that nature is often characterized by a typical sort of geometry (fractal geometry), which mostly 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 must (to a certain extent) be drawn back to the underlying geometrical features of the scene. It would therefore be interesting to compare natural settings with buildings or urban scenery that have a more natural geometry, such as Gothic cathedrals. Perhaps, categorizations along the lines of 'natural' versus 'built' would become meaningless, and a finer grained distinction between 'settings with fractal forms' and 'settings with Euclidean forms' needs to be made.

While the previous hypothesis could well bear some truth, it must be admitted that the facts teach us that vegetation is still a strong predictor of aesthetic preferences (Herzog, 1989; Herzog et al., 1982) and this conclusion has been replicated many times and across different populations and cultures (see Ulrich (1993) for a good review). On the other hand, almost no empirical research has been dedicated to the aesthetic value of a subclass of vegetative elements, namely flowers. Intuitively, the beauty and attractiveness of flowers will seem evident to many. They are often used as gifts and frequently feature in ornament and embellishments. Furthermore, people seem to spend much time, money and energy in cultivating flowers, without this having any immediate utility. One of the few experiments involving flowers has been conducted by Todorava et al. (2004). First, they replicated the finding that trees were highly preferred in streetscapes. Interestingly, they also found that brightly coloured flowers were favoured to fill up the space beneath the trees. Analyses revealed that the flowers were not only appreciated for their aesthetic value, but also for their positive influence on psychological wellbeing. Consistent with this, Yamane et al. (2004) found that working with flowering plants had a more positive impact on emotions than their non-flowering counterparts.

Haviland-Jones et al. (2005) have inquired the positive emotions that flowers can induce in three studies. In the first study 147 adult women received a present, which either was a floral bouquet, a basket of fruits, or a candle. It was found that 100% of the subjects that received the flowers displayed a Duchenne smile[2], while this did not always happen in the other conditions. This first study also showed that only subjects that had received flowers reported an increase in positive emotions. In the second study, 122 male and female subjects entering an elevator received either a flower, were exposed to a flower, or were given a pen. As opposed to the other conditions, the subjects who got a flower were more likely to smile, to engage in a conversation with the experimenter, and to stand at a social, instead of an impersonal distance. In a third study, 113 senior retirees either received flowers on several occasions over a two-week period, or received nothing. Similar to the previous studies, participants in the flower condition reported more positive moods than those without flowers. Interestingly, the former group also performed better in a memory task, compared to the latter group. These findings confirm the hypothesis that flowers trigger positive emotional states in humans. The better performance in the memory task can be explained by the fact that natural elements can restore the capacity to direct attention. It is found that this quality is essential for successfully engaging in cognitive tasks (see section 3.2 of this chapter for a further discussion of this topic).

It should be noted that directly experiencing actual natural entities is not necessary to cause positive emotional reactions. For example, in tests rating these emotions, often use is made of videos, photographs or slides. Furthermore, these natural contents are frequently present in ornamentation, wallpaper, dresses, fabric, and so on, which seems an indication of their strong aesthetic appeal. The emotional influence of artistic representations of nature is also clear from an anecdotal report by Roger Ulrich (1993; see also Ulrich & Gilpin, 2003). In a psychiatric institution, rooms were cheered up by different types of pictures. From the behaviour of the patients, it could be inferred that not all illustrations were appreciated equally. Over the course of several years, numerous abstract pictures were damaged or destroyed, while during the same period, illustrations depicting natural contents were left untouched. This suggests a consistent preference for natural contents, even if they are represented artistically. Ulrich and Gilpin (2003) come to a similar conclusion. They found that representational art containing references to natural contents (e.g. water, flowers, landscapes, and so on) could reduce stress and improve pain. On the other hand, more abstract artwork can lead to more negatively toned emotions.

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[2] The Duchenne smile is considered as an involuntary and genuine smile, where both muscle groups near the mouth (*zygomaticus major*) and near the eyes (*orbicularis oculi*) are recruited.

2.4.3. Unthreatening animals

Until now, we have focussed on natural landscapes and vegetative elements. Yet, there is evidence that unthreatening animals have a similar positive effect on several aspects of human functioning. For example, Frumkin's review (2001) of our relation with animals indicates a range of positive effects on human health: reduced stress, less general health problems, lower systolic blood pressure and cholesterol, and so on. An experiment by Friedmann and Thomas (1995) reveals that survival chances of persons who had survived a myocardial infarction was higher after one year for patients who owned pets, and specifically dogs, in contrast to non-dog owners. Similarly, Katcher and Wilkins (1993; Katcher et al., 1983) describe how watching fish in an aquarium decreases blood pressure in normal subjects and hypertension patients. Another experiment revealed that contemplation of the aquarium was as effective as hypnosis in inducing relaxation and comfort in subjects who were ready to undergo dental surgery (Katcher & Wilkins, 1993; Katcher et al., 1984).

Besides these psychological and physiological effects, contact with unthreatening animals is also found to have influence on behavioural states. Katcher and Wilkins (1993) argue that human contact with animals has a positive influence on humans with pathologies. Introducing animals to autistic children and to persons with chronic brain damage can ameliorate attention, social responsiveness, positive emotions and speech. Research into the influence of companion animals on Alzheimer disease patients indicates ameliorations in socializations and less agitated behaviour (Baun & McCabe, 2003). Research into the influence of a nature education program for boys with ADHD shows persistent ameliorations of behaviour and attention, of speech, of non-verbal expression of emotions, and of the interaction with educators (Katcher & Wilkins, 1993). In line with this research, Melson (2003) reports that animals can have an important effect on the cognitive development of children: they arouse curiosity, are perceptually interesting and hold the children's attention. Pets are also an important source of emotional support, and offer the child the opportunity to learn to nurture another living being. People who live in emotionally and perceptually harsh environments can also draw a lot from animals. This is clear from the introduction of animal programs in prisons and from their general effect on the prison atmosphere. Strimple (2003), for example, discusses how the first successful animal therapy program in the Oakwood Forensic Center (Ohio) resulted in a decrease of the administration of medication, and in less violence and suicide attempts. There was also amelioration in social behaviour among inmates and an improved relationship towards peers.

Some critical questions should be raised with regard to this short review of positive effects of interaction with, and exposure to animals. First, it should be noted that not all animals elicit positive emotional states in humans. In extreme cases, animals, such as spiders or snakes, can cause phobic responses and severe stress in individuals. In contrast, it seems that vegetative elements are more universally liked. These observations imply that the application of animal form in architecture should perhaps be given more care than integrating vegetative features. Architectural forms, or configurations of shape, which refer to animals that posed constant threats during much of human evolutionary history, will perhaps cause more stressful or agitated responses in subjects. Second, a possible point of critique is that it is plausible that not the animals themselves are at the root of the reported positive emotional responses, but (say) the interactive relationship between the individual and the animal. Perhaps other responsive entities can induce similar states, while having no further formal resemblances with any animal whatsoever (think, for example, of the digital pet 'tamagotchi'). Third, and somewhat related, is that it could well be that the stress reducing effect of aquaria is not because of the presence of fish, but due to the specific slow 'organic' movements they make. Or as Kahn (1999, 41) notes: 'It is equally possible … that slow-moving globs of multicoloured light decrease blood pressure…'. Yet, it is questionable whether these criticisms can pose a serious threat for the claim that certain animal entities have a positive influence on us. Organic movement and responsiveness are qualities that are essential to animals, as opposed to, say, artefacts. While it could be plausibly claimed that is not the animal *in se* that causes these reactions, it can still be noted that it is something typically natural that is underlying such responses.

2.5. Critical evaluation: rapid affective processing of natural stimuli

Now that we have completed our review of preference studies, it is worthwhile to highlight some of the differences and similarities between the different accounts of landscape aesthetics. It must be clear that the preferenda of Ulrich (1983) overlap to a large extent with the informational predictors proposed by the Kaplans (Kaplan & Kaplan, 1989). Consider the gross structural properties in Ulrich's model. Because these function as ordering principles, they can contribute to the quality of 'coherence', featuring in the model of the Kaplans. Other preferenda, such as the degree of spatiality and an even ground texture, can facilitate visual access to the surrounding environment, and can thereby enhance the legibility of the landscape. These structural landscape features can also be linked to Appleton's prospect-refuge theory. For example, a landscape can offer good opportunities for prospect when it is not too complex, or when its complexity is 'coherent' or 'organized'. Prospect is also enhanced by wide, open landscapes with a relatively even ground surface. When confronted with too much complexity or topographical variation, the visual system can be overloaded, with the result that not all environmental information will be easily apprehended from the prospect. However, the outlook and spatial organization of a landscape can neither be too simple. It should still contain enough elements or variation for providing refuges, or opportunities to hide.

Recall how one of the crucial differences between Ulrich's psychoevolutionary approach and the Kaplans' informational model is the way in which both structural organizations of landscapes and natural contents are processed. While according to Ulrich, preferenda are subject to immediate affective processing, the Kaplans consider the responses to landscape features and layouts more cognitive in nature, and hence, slower. Indeed, it could be argued that natural contents (e.g. trees) are visually quite complex stimuli. It could therefore be expected that they place constraints on the processing capacities of the brain, with the result that such stimuli will be processed rather slowly. However, it should be noted that current research indicates the contrary, and shows that complex stimuli can be processed very quickly. For instance, Thorpe et al. (1996) have conducted an experiment in which subjects were presented a stimulus for 20 milliseconds, and immediately had to judge whether it contained an animal or not. The median reaction time for trials when there was an animal present ('go' trials) was 445 milliseconds. Because a behavioural response requires processing time, the researchers also inquired when the *brain* exactly made the actual categorization. They found that there was a remarkable divergence in neural activity between 'go' ('animal present') and 'no-go' ('no animal present') trials at 150 ms, suggesting that the brain already performed an ultra-rapid categorization around that time. What is even more surprising is that such rapid categorizations can occur in the absence of attention. More specifically, Li et al. (2002; see also Braun, 2003) performed an experiment in which subjects had to focus on attentionally demanding task while a stimulus was flashed in their peripheral field of vision, during a very short amount of time. It was found that for complex stimuli, such as cars and animals, performance was as good as when the task was performed when the stimuli were the focus of attention. For simple geometric stimuli (e.g. letters), however, performance was much worse when they were presented outside the scope of attention. These findings not only suggest that using simple geometric shapes in psychophysics experiments should be reconsidered, but it also shows that the processing of environmental stimuli can be a very rapid process that does not require much attention, which is consistent with Ulrich's theoretical account.

To our knowledge, not many studies have directly tested the rapid affective processing of natural contents versus unnatural (urban) scenes. An exception is the research by Korpela et al. (2002), who found that the rapid processing of certain classes of stimuli is accompanied by specific affective responses. In this experiment, subjects were first exposed to either a natural or an urban setting. Immediately hereafter they were presented vocal expressions and were instructed to indicate as fast as possible whether these expressed either joy or anger. According to the affective priming paradigm reaction times will be faster when the initial stimulus and target are affectively congruent. In agreement with Ulrich's psychoevolutionary framework (Ulrich, 1983; Parsons, 1991), reaction times for anger expressions were shortest when presented an urban setting, while the reactions for joy were most rapid for natural settings. This could indicate that environments are automatically processed according to their affective valence, and supports a central claim of the psychoevolutionary model. Moreover, the finding that this process takes place very rapidly (within a few hundred milliseconds) supports the automatic and immediate character of these affective responses. Note, however, that this conclusion is only partly supported by a similar study by Hietanen and Korpela (2004). It showed that only negative environmental scenes (i.e. urban settings) elicit rapid affective processing.

3. The physiological, psychological and behavioural value of natural elements

The aesthetic appeal of natural contents is well-established. Today, research into the affective valence of natural environments mainly concentrates on their possible 'restorative' potential for human individuals. Two important restoration theories have been proposed, and these will be extensively discussed in the following sections.

3.1. Restoration as stress reduction

The first influential interpretation is part of Ulrich's psychoevolutionary framework, and it considers restoration as stress-reduction. In particular, restorative responses are claimed to be remnants of human evolutionary history in natural settings, where early humans were often confronted with threatening and demanding situations (e.g. a predator). As discussed in the context of Ulrich's psychoevolutionary framework, such confrontations lead to the quick onset of negatively toned affective reactions and corresponding adaptive behaviour (e.g. flight). Ulrich (1993) notes how the immediate effects of such responses are beneficial for the individual. For example, an immediate negatively toned affective response to a predator motivates to avoidance behaviour, which prevents that the organism would become wounded or killed. Yet, such reactions also have a certain cost in that the flight response is accompanied by physiological and psychological stress (e.g. high blood pressure, feeling depressed). Therefore, when the threat has vanished, the individual is in need of restoration from the stress the former has 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, 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 food, which reduced stress related to the uncertainty of finding these resources (Ulrich, 1993).

3.1.1. Empirical research into restoration as stress reduction

The stress-reducing effect of nature is still effective today because those individuals that could respond restoratively to stressful situations survived better. The hypothesis of restoration as stress-reduction has been empirically tested on several occasions. In the following sections we extensively describe two of such experiments. The rationale is to illustrate the strong methodological constraints, and the care with which these experiments are devised and executed. In the subsequent section we mention some more research, but discuss it more briefly. As will become clear, there is quite convincing evidence that nature can reduce physiological and psychological stress in humans.

A first experiment which we will discuss is Roger Ulrich (1981) study into the effects of different classes of environments on the psycho-physiological states of individuals. These environments were displayed to the subjects on slides and were 'nature with a water feature', 'nature dominated by vegetation', and 'urban environments without water features or vegetation'. Before and after viewing each environmental category, subjects had to rate their feelings according to two types of psychological measures. The first measure was a (semantic) questionnaire assessing the feelings and mood of the subjects during the test. The second measure was a Zuckerman Inventory of Personal Reactions (ZIPERS). This is an instrument that determines how subjects feel with regard to five affective states: fear arousal, positive affect, anger/aggression, attentiveness and sadness. For each item subjects give a score, ranging from 1 (very little) to 5 (very much), and this indicates the degree to which the affective state applies to the subject's current mood (Custers, 2006).

Before, during, and after the experiment two types of physiological variables were measured. First, by measuring the electrical activity in the brain, the alpha amplitude was registered, which correlates with states of consciousness and alertness. High alpha amplitudes correspond with lower levels of physiological arousal, and low alpha is an indication of higher arousal. The second physiological parameter was heart rate. Generally, an increase in heart rate correlates with higher arousal.

The ZIPERS and the semantic questionnaire revealed that vegetation, and especially water features, had a positive influence on the subjects' mood and feelings. Similar results were obtained for the physiological tests: alpha amplitudes tended to be higher when viewing vegetation, as opposed to urban scenes. This indicates that subjects felt more relaxed in the former condition. Furthermore, it was also found that alpha was higher for water features than for urban illustrations. A higher heart rate was recorded when subjects were exposed to water or vegetation pictures than when they were shown urban environments. Ulrich believes that these findings are consistent with view that nature scenes are more successful in eliciting arousal and attention. From this experiment, Ulrich concludes that nature does not immediately affect global psychophysiological states, but that it has a positive influence on a rather specific cluster of feelings: namely, feelings of arousal, fear and stress. He holds that the restorative effect of natural elements, as opposed to urban settings without nature, is most pronounced when humans are highly aroused or anxious.

Whereas the previous experiment involved non-stressed individuals, Ulrich et al. (1991) have studied the effects of nature versus urban views on stressed individuals. The study consisted of two phases. In the first phase, subjects were confronted with a stressor. This was a videotape about the prevention of working accidents, showing injuries, blood, and mutilation. After this stressor, subjects viewed videotapes of natural and urban settings (recovery phase). The goal of this experiment was to determine the stress reducing effect of natural elements on stressed individuals, and to see whether urban settings would hamper such recuperation.

The influence of the stressor and of the urban and natural environment on the subjects was determined by physiological and psychological measures. The psychological measure consisted of a ZIPERS, registered before and after the stressor, and after the recovery tape. Physiological measures were registered continuously during the stressor and the environmental tapes. They recorded EKG (electrocardiogram), PTT (pulse transit time), SCR (spontaneous skin conductance responding), and EMG (electromyogram of frontalis muscle tension). In stressful conditions EMG and SCR increase, while they decrease during recovery. On the other hand, PTT decreases during stress, while it increases during recovery. The relation between heart rate and stress is less straightforward, because changes in heart rate depend on the characteristics of the stressor. If the stressor involves problem solving, or the manipulation, storage and retrieval of information, then heart rate increases. If a certain stimulus elicits intake, attention/interest, then heart rate decreases.

Analyses showed that the prevention tape was successful in eliciting both psychological and physiological stress. Measurement of three physiological variables (PTT, SCR and EMG) during the recovery phase revealed a faster and more complete stress recovery when subjects were confronted with natural settings, as opposed to urban settings. With regard to heart period, there was a deceleration in the case of nature settings and an acceleration for urban environments. According to Ulrich et al. (1991) these results suggest that intake or attention was higher when subjects saw nature views, than when they viewed urban environments. Similar to the physiological measures, nature was more effective in reducing psychological stress than urban settings. More specifically, subjects that were exposed to nature views scored lower for the factors Anger/Aggression and Fear, and reported higher levels of Positive Affects. The influence of nature on feelings of Sadness and on Attentiveness/Interest was found to be statistically insignificant. In sum, natural settings, as opposed to urban environments, have a more positive influence on subjects' psychological and physiological states, and lead to higher levels of attention and intake.

3.1.2. Further research into the relation between stress and nature

The previous experiments indicate that nature can reduce psychological and physiological stress in individuals. Other experiments have confirmed this finding. A study by Lohr et al. (1996) shows that subjects performing a cognitive task in a room with plants have a systolic blood pressure[3] that was one to four units lower than participants tested without the plants. Subjects watching a video of a natural environment are found to have a lower heartbeat than participants watching an urban environment (Laumann et al., 2003). Yamane et al. (2004) found that working with flowering and non-flowering plants promotes physiological relaxation (measured by electroencephalogram (EEG), electromyogram (EMG) and eye-blinking), as opposed to filling flower pots with soil. Nakamura and Fujii (1992; described in Ulrich, 2002) found that viewing a hedge of greenery had relaxing effects on subjects, whereas watching a concrete fence had stressful influences. In her doctoral dissertation Custers (2006) inquired, among others, the effect of gardening on physiological stress, which was measured by the cortisol levels in subjects' saliva (in the face of a stressor, cortisol levels rise). In agreement with the previous findings, there was a decrease of physiological stress in subject engaging in gardening, as opposed to subjects that were reading.

Stress is often related to our professional lives, and sometimes begins to build up even before we arrive at work, when engaged in traffic. We can become frustrated about the heavy traffic and traffic jams, worry about not arriving on time at work, or

[3] Systolic blood pressure is the first number in a typical blood pressure reading, and refers to the pressure when the heart contracts. Diastolic blood pressure is the second number, and is the pressure in the arteries when the heart rests between subsequent beats.

are irritated about asocial and aggressive driving behaviour. Morning fatigue makes it sometimes difficult to cope with such stressful situations. Yet, there exists some research that indicates that the presence of roadside vegetation can mitigate the stress associated with driving. For example, Parsons et al. (1998) studied the effects of subjects that performed simulated drives through outdoor environments, which were either nature-dominated or artefact-dominated. Two main conclusions were obtained. First, artefact-dominated environments were associated more with physiological indicators of stress (e.g. rise in skin conductance) than nature-dominated settings. Second, recovery from stress was slower, and impeded for subjects exposed to artefact-dominated settings, than for those exposed to nature-dominated settings. It was also found that subjects in the latter condition were more 'immune' to a future stressor. Similar to these findings, Cackowski and Nasar (2003) found that subjects displayed a higher frustration tolerance when the simulated highway drives to which they were exposed contained vegetated scenes.

There has been quite some attention to the influence of nature in healthcare contexts. For example, in an often-cited article in *Science*, Ulrich (1984b; see also Ulrich, 1984a) discusses a study of hospital patients that had undergone a gall bladder operation and had rooms with views on either a small tree group or on a brown brick wall. As opposed to patients with the brick wall view, Ulrich found that patients with the tree view had shorter hospital stays, received less negative comments from the nurses, required less moderate and strong analgesics and had slightly fewer postoperative complications. Similarly, Ulrich et al. (2003) found that subjects that underwent a stressful procedure (blood donation) had lower pulse rates when they had watched television with nature scenes in a waiting room, as opposed to subjects who had viewed urban scenes. Whall et al. (1997) provide evidence that agitation in late-stage dementia patients decreased during showering, when subjects could use shower rooms that contained references to natural elements (i.e. nature sounds and pictures). This effect did not occur in the shower rooms without natural contents. Consistent with this, Diette et al. (2003) found that exposure to nature sights and sounds reduces pain in patients during flexible bronchoscopy. Similarly, subjects that watched a soundless video of natural scenery had a higher pain tolerance and pain threshold, compared to individuals that watched a static blank screen (Tse et al., 2002). Although not performed in a healthcare setting, Lohr and Pearson-Mims (2000) found that subjects in rooms with plants were willing to experience more prolonged physical discomfort (i.e. placing their hands in ice water) than when there were no plants in the room, although the room was equally interesting and colourful. Similar results have been obtained by Park et al. (2004). Female subjects watching either flowering and foliage plants, or foliage plants only, could longer tolerate immersing their hands in 0° C water, and reported lower pain intensities, as opposed to subjects that were not exposed to plants. Moreover, pain tolerance was strongest in the case of exposure to flowering plants.

These findings can prove very useful for healthcare settings. The admission in a healthcare setting can be experienced as stressful to subjects, with the prospect of a medical intervention and the associated pain, and being detached from one's home and dears for a certain amount of time. Basic interventions such as integrating greenery (figure 12), seem to be capable of dampening these and other sources of stress, and can make people immune to future sources of stress. Furthermore, the previous findings suggest that the inclusion of these elements can even lead to a significant rise in pain tolerance, with the result that people will probably have less physical complaints and discomfort, and need to be administered fewer analgesics.

Figure 12: In hospital settings it is not always possible to integrate actual natural elements. A solution is to integrate realistic representations of nonthreatening nature.

3.2. Attention Restoration Theory (ART)

A second interpretation of restoration has been proposed by Stephen and Rachel Kaplan (e.g. Kaplan & Kaplan, 1989). In essence, the researchers hold that restorative experiences imply the recovery of the capacity to 'direct attention' or to 'focus'. This capacity is deployed during tasks that require profound concentration, such as proofreading or studying. Directed attention can be characterized by different qualities: it requires effort; it is essential for achieving focus; it is under voluntary control; it is susceptible to fatigue; and it inhibits activities that could distract attention. Note that this interpretation of restoration is narrower than Ulrich's view, which applies to a broader context than attentional capacities. In the psychoevolutionary framework, stress can occur even when directed attention is not fatigued (e.g. Ulrich, 1993; Ulrich et al., 1991; Parsons, 1991).

When directed attention is fatigued, restorative environments can recover this capacity by resting it. According to Kaplan (1995) such environments have four typical properties. First, restorative environments elicit 'fascination'. Fascination is effortless and involuntary, and therefore allows the voluntary or directed attention to rest. A second property is 'being away' or freeing oneself from the sources that are demanding for one's directed attention. Third, the restorative environment should have 'extent', which means that it must be rich and coherent enough to keep an individual interested and fascinated, i.e. to keep the mind busy. Fourth, there must be 'compatibility' between the restorative environment and one's purposes and inclinations. What one would like to do and what one is trying to do should be in close harmony with the characteristics of the setting. This implies that no attention should be paid to whether one's behaviour is appropriate for the environment.

According to Kaplan (1995) nature closely meets the aforementioned restorative properties, and is therefore especially effective in resting directed attention. First, natural environments (e.g. mountains, parks, seaside, and so on) are very popular destinations for being away, and for freeing oneself from the sources that require directed attention, such as work. Second, natural environments are often intrinsically fascinating: they keep the mind interested without effort and therefore rest directed attention. Think for example of the fascination elicited by viewing a waterfall, a mountain range, or (nonthreatening) wildlife. Third, natural settings are often large in extent, and thereby offer the fatigued mind enough 'material' to keep it going without effort. Fourth, nature is often highly compatible with human inclinations. Kaplan (1995) mentions how people feel that they often function more effortlessly in natural settings than in urban or civilized environments, even if they are more familiar with the latter. (Note that the finding that nature could be an ideal place for restorative experiences does not rule out that such experiences are also possible in other settings, or during other activities. For example, there is some evidence that monasteries (Ouelette, et al., 2005) or museums (Kaplan et al., 1993) are characterized by some of the qualities that are typical of restorative environments).

A final note should be made about 'fascination', a central characteristic of restorative settings (see e.g. Herzog et al., 1997; Custers, 2006). This quality can range from 'hard' to 'soft' fascination. Hard fascination is very intense and grabs attention, without leaving much room for thinking. Think for example of playing a video game or watching a sports manifestation, which are activities in which one can become totally immersed. On the other hand, while soft fascination can hold attention, it is more moderate, and thereby leaves place for reflection about certain important issues. Soft fascination is mostly associated with natural settings. Exposure to these is often accompanied by aesthetic reactions, and these are able to moderate the pain or unpleasantness associated with thinking about serious matters (Herzog et al., 1997).

3.2.1. Empirical research into Attention Restoration Theory

What is the evidence supporting the view that natural settings can restore directed attention? Hartig et al. (2003) have recently carried out an elaborate experiment, in which the influence of nature on both (physiological and psychological) stress and directed attention was inquired. Like in the previous sections we will first provide a detailed account of this experiment. In the subsequent sections, some more studies will be discussed more briefly.

Subjects participating in the Hartig et al. (2003) experiment were divided into two groups: a task group and a non-task group. The test consisted of a pre-treatment condition and an environmental treatment, in which subjects were exposed to either an urban or a natural setting. During pre-treatment, subjects underwent a set of physiological and psychological tests. First, diastolic (DBP) and systolic blood pressure (SBP) were measured. Second, subjects completed a ZIPERS, which measured how they felt. Third, subjects carried out two tasks that required directed attention. On the one hand they performed the Necker Cube Pattern Control Task (NCPCT). An essential property of the Necker Cube is that it is an ambiguous figure: the front and back sides can change their relative position for the viewer (figure 13). The task was to focus on one interpretation as long as possible, and to signal possible reversals. Pattern reversals are believed to be an indication of attentional fatigue. The other attentional task was to memorize five letters, and to identify and locate them in strings of letters (SMT).

After this pretest (but still during pre-treatment) subjects were assigned to drive to a field site. On arrival, blood pressure (BP) was recorded for all subjects. Next, the subjects of the task group had to undergo two tasks during one hour. This allowed the experimenters to vary the restoration needs among the different subjects. In the first task subjects were presented names of colours, which were printed in other-coloured ink (Stroop task). For example, the word RED was printed in blue ink. The instruction was to name the colour of the ink. The second task consisted of classifying numbers as even or odd and determining whether their value was high or low with regard to a given criterion.

For task subjects the environmental treatment began after the task, while for non-task subjects, the treatment followed immediately after the previous BP recording. The first part of the treatment period consisted of sitting quietly in a room for ten minutes. Either this room had views on trees, or it had no views at all. During and after this condition BP was recorded. The second part of the treatment was a fifty minute walk in either an urban or a natural environment. During this walk BP was registered several times. Also, subjects had to perform an NCPCT and indicate on a thermometer-like graph how happy they felt. After this walk subjects returned to the field lab, where additional ZIPERS, NCPCT and SMT were completed, and BP was measured.

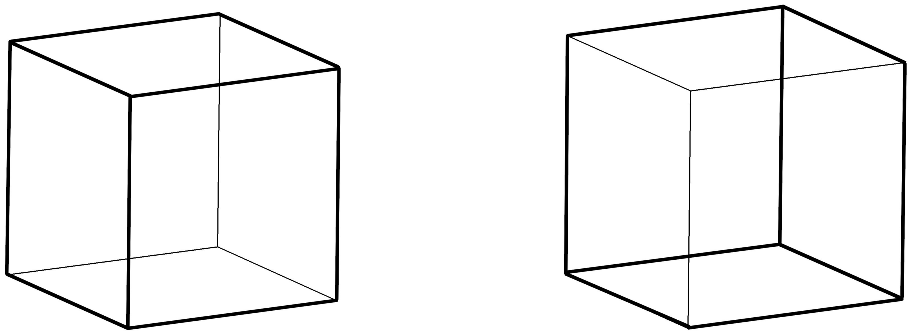


Figure 13: The two possible interpretations of a Necker cube.

Analyses of this experiment indicate that natural settings, or environments with natural features, are accompanied by restorative responses. First, the physiological measures reveal that subjects sitting in a room with tree views had a more rapidly decreasing DBP than subjects in a room without views. Similarly, BP decreased during the walk in the natural environment, while it increased when walking in the urban setting. Yet, this effect was largely lost at the end of the walk. Second, nature clearly had a positive effect on subjects' psychological states. Positive affect increased after the nature walk, as opposed to the urban walk, where it decreased. Also, feelings of anger and aggressiveness declined during the former situation, while they inclined in the latter condition. Third, it was found that nature had positive influence on tasks that necessitated directed attention. In all subjects there was a decline in attentiveness from pretest-to-posttest condition, independent of the environment or task situation. Yet, natural and urban environments had a different effect on the performance for the NCPCT. There was a decrease in the ability to concentrate on one Necker Cube interpretation for both task group and non-task group subjects that had walked in urban settings. In contrast, there was a slight increase in performance for task group and non-task group subjects that had made the nature walk. These findings support the attention restoring capacities of contact with natural settings.

3.2.2. Further empirical research into the restorative power of natural settings

More support for the restorative potential of natural settings comes from two studies, performed by Hartig et al. (1991). In these experiments, individuals were divided into two groups, depending on the place in which they would spend their holidays. Either this was in 'free' nature, or in an urban environment. Before and after their holiday, subjects had to undergo a proofreading test. According to Kaplan (1995), this task is very demanding for one's directed attention. Both studies revealed that subjects who had spent their holiday in nature scored better in proofreading than before their departure. In contrast, individuals who had made a city trip scored lower after their trip than before. In agreement with these results, Tenessen and Cimprich (1995) showed that students with views on nature from their dormitory windows performed better on attentional tasks than students without such views. Recently, Berto (2005; see Custers, 2006) has conducted an experiment where, in a first phase, subjects had to perform a test that was demanding for the ability to direct attention. In a next stage, they either viewed images of natural environments or of urban/industrial settings. After this, subjects had to perform the attention test again. Participants in the nature group performed faster than the other groups, which is indicative of a better recovery of directed attention. Another line of research indicates that women in their third trimester of pregnancy – a time when increasingly more attention is invested in future parenting and birth – can concentrate better if they performed activities involving nature (Starks, 2003). Faber Taylor et al. (2002) found that the greener a girl's view from home, the better she scores on tests on self-discipline – a quality that is found to tap into directed attention. Wells (2000) inquired the influence on children's cognitive functioning when they moved from housing settings that were surrounded by only few natural elements, to homes that were situated in more natural environments. She found that the children that had the most improvement in naturalness of their homes showed also the largest increase in the ability to direct attention.

There is some evidence that the presence of vegetative elements is also advantageous for cognitive functioning. This can be tentatively explained by the fact that natural contents rest directed attention, whereby attentional resources become (more) fully available for tasks requiring this capacity. Shibata and Suzuki (2002) have studied the effect of plant foliage on the mood and task performance of male and female subjects. This experiment consisted of an association and sorting task, which were either performed with a foliage plant in front of the subject, beside the subject, or without plants in the room. Analyses revealed that male subjects scored better in the association task when there was a plant in front of them than under the other two conditions. No significant influence on mood or on the performance of female subjects was recorded. A study by Lohr et al. (1996) revealed that subjects felt more concentrated and attentive when they had performed a computer test in a room with plants, compared to subjects that made the test without the presence of plants. Furthermore, reaction times in the computer task were 12% faster in the plant condition than in the no-plant condition. This indicates that the presence of plants can positively influence productivity. Yet, it should be noted that a study by

Larsen et al. (1998) is inconsistent with the outcomes of the previous studies. Subjects performing a simple search task in an office with many plants had the lowest scores for productivity, while subjects in an office without plants were most productive. The authors argue that plants will probably have a greater influence on tasks involving creative problem solving, and not on simple repetitious tasks. A possible explanation lies in the fact that plants are associated with positive moods (e.g. liking), and these are found to facilitate creative problem solving (Larsen et al., 1998).

The previous empirical studies show that exposure to nature can rest directed attention. Yet, there is also growing evidence that nature can reduce the undesired consequences that can occur when this capacity is fatigued. In this regard, different lines of evidence have been gathered by the *Landscape and Human Health Laboratory*, headed by William Sullivan. A remarkable finding is that children with an Attentional Deficit Disorder (ADD) benefit from the attention restoring capacities of nature. In particular, Faber Taylor et al. (2001) found that the greener a child's playing area, the less severe the symptoms of his or her deficit. Other research by this lab has mainly focussed on the relation between crime, aggression, violence and nature. For instance, Kuo and Sullivan (2001a) have inquired the relation between vegetation and crimes in a large public housing development (Ida B. Wells) in Chicago. The amount of greenery outside the apartments varies considerably: from completely barren, small trees and grass, to high-canopy trees. The experimenters quantified the crime rate of 98 apartments by using police crime reports over a two year period. It was found that the greener the apartment's surroundings, the fewer crimes had been reported. The researchers note that '[c]ompared to buildings with low levels of vegetation, those with medium levels had 42% fewer total crimes, 40% fewer property crimes, and 44% fewer violent crimes … Buildings with high levels of vegetation had 52% fewer total crimes, 48% fewer property crimes, and 56% fewer violent crimes than buildings with low levels of vegetation' (Kuo & Sullivan, 2001a, 355).

The authors propose two mechanisms to explain the observed effects. On the one hand, it is probable that nature is used as an outdoor recreational space, which implies that more people come outside, resulting into more opportunities for surveillance. On the other hand, violence can be the result of mental fatigue. In particular, Kaplan notes that '… one of the costs of mental fatigue may be a heightened propensity for "outbursts of anger and potentially… violence"' (S. Kaplan (1987, 57) in Kuo & Sullivan, 2001a, 347). The introduction of natural elements can therefore mitigate some of the psychological precursors of violent behaviour.

Note how similar results were obtained by Kuo and Sullivan (2001b). In this study levels of aggression and violence were measured for 145 inner city public housing residents (Rober Taylor Homes, Chicago). It was found that people surrounded by higher levels of greenery reported less violence and aggression than subjects living in more or less 'barren' situations. Importantly, attentional tests revealed that subjects of the barren condition were also more attentionally fatigued than individuals in the former situation. Moreover, the study showed that attentional functioning was the underlying mechanism ('mediating factor') in the relation between greenery and aggression.

It is worthwhile to mention that Kuo (2001) also inquired how effectively individuals of the same residence (i.e. Robert Taylor Homes) could cope with major life issues (e.g. birth, death, getting a job, and so on). It was found that the subjects living in greener settings were less attentionally fatigued and could better handle major life issues, as opposed to their 'barren' counterparts. Again, statistical procedures showed that attentional functioning was the underlying mechanism. In particular, green spaces facilitate handling major life issues because they rest directed attention. Note that research by Wells and Evans (2003) comes to similar conclusions. It revealed that nature could buffer or moderate the impact of life stress on children. Similar to Kuo (2001), they argue that nature can restore attentional resources, by which children can handle stressful issues with more cognitive clarity. In turn '[g]reater cognitive clarity may enable children to seek out activities or resources to fortify themselves against life stress as well as enable them to resist the inclination to react to certain stressors or potential distractions' (Wells & Evans, 2003, 325).

3.2.3. Critical notes

To date, the strongest support for the attention restoring potential of nature comes from the line of research, initiated by Terry Hartig and colleagues (e.g. Hartig et al., 2003; Van Den Berg, 2007). However, for those without specific training in statistics, it is sometimes difficult to correctly judge the quality of studies that make use of sophisticated statistical methods. In this regard, it is interesting to note that Van Den Berg (2007) has critically examined some of the studies, discussed in the previous sections. Essentially, she found that the conclusions are generally weak, and that alternative explanations can be generated. Take the Faber Taylor et al. (2001) study, which found a correlation between the naturalness of playing grounds and the severity of children's ADD symptoms. While a plausible explanation is that nature restores the child's ability to direct attention, and thereby dampens the severity of its attentional deficit, some other explanations are equally possible. For instance, it could well be that when children with ADD feel better, they tend to go more frequently to green playgrounds. Furthermore, it could be noted that vegetation can moderate noise levels, which makes it possible that not nature, but exposure to less noise in green playgrounds is at the basis of the less severe ADD symptoms. Different explanations can also be generated for the Wells and Evans (2003) study, which indicated that nearby nature can buffer life stress. Perhaps, the children in rural/natural areas have parents with a higher educational degree, who have learned their children to more rationally approach certain emotional experiences, which can help in coping with them and putting things in perspective. Wells' (2000) study into the effects of moving to greener environment on directed attention is confronted with similar problems. It can be pointed out that it is essentially a longitudinal study, which does not rule out the possibility that changes in the individual (e.g. maturation) are at the root of improved cognitive functioning. Another possibility that could explain the observed pattern is that in more natural settings there is often less noise and pollution, which could positively influence the capacity to direct attention. In sum, while some of the previously described studies are consistent with the ART framework proposed by the Kaplans, the critical review of Van Den Berg (2007) entails that some of the conclusions and research are still preliminary, and should therefore be regarded with the necessary caution.

4. Brain correlates of the emotional affiliation with natural contents

What can be learned from the previous sections is that humans show a consistent aesthetic preference for certain typical natural elements, and that these can also engender restorative responses. Interestingly, there has been some speculation about the neural correlates of these affective affiliations. In particular, Russ Parsons (1991) has elaborated some of the neural underpinnings of Ulrich's psychoevolutionary framework. Relying on Ledoux (1986), Parsons argues that an encounter with an environment will result in two types of affective analyses. The first is associated with the amygdala, is immediate and entirely subcortical. In this analysis, the amygdala acts as a kind of feature detector that attaches a certain affective valence to an environmental configuration or 'preferendum'. The second analysis is slower, more cognitive and deliberate. In particular, incoming information is compared with stored information in the hippocampus. Probably, the outcome of this comparison is communicated to the amygdala, which initiates an appropriate (affective) evaluation. Note how these two types of analyses seem to reflect the 'fast' affective, and the more 'slow' cognitive or 'cultural' reaction towards environmental stimuli or configurations (Steg et al., 2004), discussed in the context of Ulrich's psychoevolutionary account (figure 15).

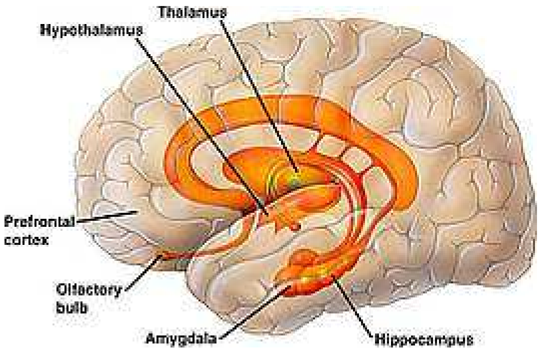


Figure 15: The different parts of the brain's limbic system.

An essential aspect of Ulrich's psychoevolutionary framework is that settings that lead to the quick onset of negatively toned feelings can cause psychological and physiological stress (see section 2.3 of this chapter). Parsons (1991) argues that there is evidence that the brain areas associated with the two affective analyses are also involved in the response mechanisms toward stressful stimuli. In particular, he notes that the hippocampus can be linked to the General Adaptation Syndrome (GAS) and the associated hormonal responses (i.e. release of corticosteroids). GAS can be described as the '… sequence of physical responses to stress [which] occurs in a consistent pattern and is triggered by the effort to adapt to any stressor' (Bernstein et al., 1997, 433)[4]. On the other hand the amygdala has been associated with FOF (fight or flight) hormonal responses and behaviour

In the following sections, tentative steps are made to somewhat flesh out some of Parsons' suggestions. The main focus will be on research that could shed light on the neural correlates of specific natural contents. A research area in which such type of entities plays a prominent role are discussions about how concepts (e.g. 'pen', 'apple', 'car', and so on) are stored and organized in the brain's semantic memory. Within this field, crucial information about the way in which concepts are represented is drawn from subjects with so-called 'category-specific deficits' that result from brain damage. Such deficits imply that patients have impaired knowledge for a certain category of objects, and the specific character and severity of such deficits are probed with different kinds of tests. What is interesting for our argument is that in the majority of cases knowledge about living things is impaired, although cases with a deficit for non-living things have also been reported. In order to explain such deficits, three major theories about the organization of conceptual knowledge in the brain have been proposed. In order to present a coherent

[4] The GAS consists of three important phases. First, there is the 'alarm' reaction – think for example of running away when confronted with a dangerous animal. Next, when the stress is persistent, the 'resistance' phase begins, when the body tries to resist and adapt to the stressor by mobilizing the necessary energy systems. When, after a while, the body's energy reserves to cope with the stressful situation become depleted, the third stage begins, that of 'exhaustion'.

framework, we will briefly discuss this complex field of research.

4.1. Sensory Functional Theory

The received theory to explain category-specific deficits is the 'Sensory Functional Theory' (SFT) (see Warrington & McCarthy, 1983, 1987; Warrington & Shallice, 1984; Crutch & Warrington, 2003; Farah & McClelland, 1991; for a related view see Humphreys & Forde, 2001). According to SFT, knowledge in the semantic system is organized into subsystems that each process some type or modality of knowledge. In particular, it is claimed that the recognition of the category of living things relies on the 'perceptual' semantic subsystem (e.g. the concept 'zebra' activates perceptual concepts, such as 'has black and white stripes'), while the 'functional' semantic subsystem is most crucial for recognizing non-living things (e.g. the concept 'key' activates functional concepts such as 'locking'). SFT makes three important predictions (Caramazza & Mahon, 2003) (figure 17).

(1) There will be no dissociations within the category of living things because knowledge about living things depends on the same semantic subsystem – i.e. the 'perceptual' semantic subsystem. This means that there cannot be impairments for one class of living things (e.g. vegetables), while other classes are spared.
(2) Damage to the perceptual and functional semantic subsystem leads to disproportionate category-specific deficits for knowledge about living and non-living things, respectively.
(3) Individuals with category-specific deficits for living and non-living things should have disproportionate difficulties with perceptual and functional knowledge, respectively.

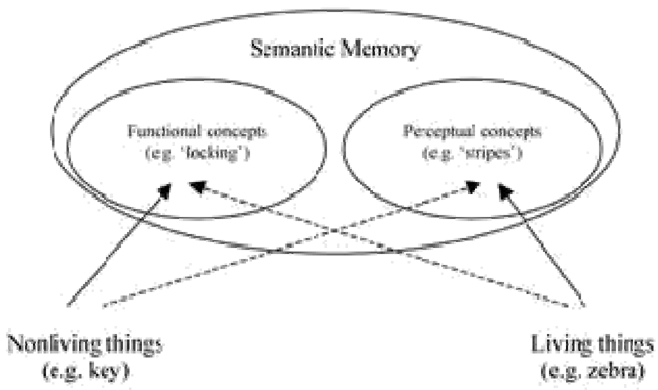


Figure 17: Schematic representation of the Sensory Functional Theory.

Important support for SFT comes from a simulation by Farah & McClelland (1991). The simulation was a neural network, consisting of three important parts: input and output systems and a semantic system (figure 18). In accordance with the Sensory Functional Theory the semantic system was divided into visual and functional units. In a first phase the network was trained and adjusted in order to produce the correct output when presented with either living or nonliving input. For example, it was presented a name and it had to associate the correct picture with it, or vice versa. In a next phase, the central tenets of SFT were tested. This was done by lesioning the semantic subsystems of the model and evaluating its performance in associating names and pictures of living and nonliving things. Analyses of the performance of the network show how it replicates the central claims of the Sensory Functional Theory. In particular, Farah and McClelland note that '[d]amage to visual semantic memory impaired knowledge of living things to a greater extent than nonliving things, and damage to functional semantic memory impaired knowledge of nonliving things to a greater extent than living things' (346). This simulation shows that a modality-specific organization of the brain's semantic memory can lead to the clinically observed category-specific deficits.

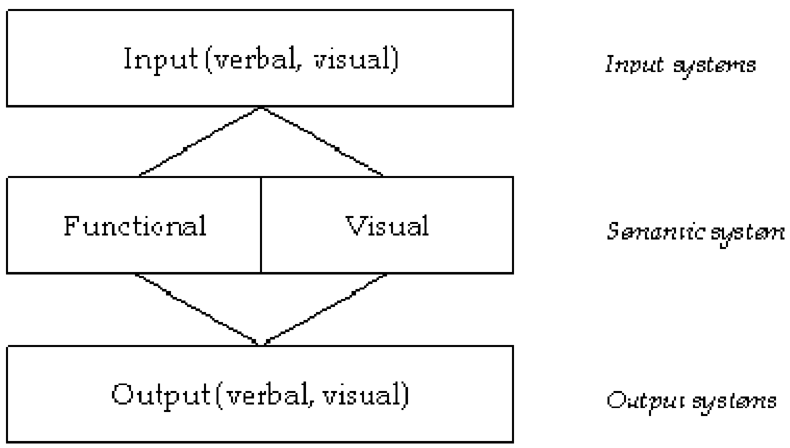


Figure 18: Schematic representation of the neural network described in Farah & McClelland (1991).

Recently, SFT has been subject to some strong criticisms, and there are indications that its predictions are at variance with several empirical findings. With regard to the first prediction, numerous studies report dissociations within the category of living things. For example, patient EW (Caramazza & Shelton, 1998) is impaired for semantic knowledge about animals, while the categories of fruit, vegetables and plants are spared. Similarly, Samson and Pillon (2003) discuss patient RS, whose semantic knowledge for fruit and vegetables is poor, while unimpaired for other categories of knowledge (e.g. animals). Crutch and Warrington (2003) also discuss the case of a gentleman (FAV), who has had a left temporo-occipital infarction, associated with a category-specific deficit for living things. However, different tests revealed that FAV had a more fine-grained deficit for fruit and vegetables while his knowledge about animals and nonliving foods was relatively spared.

Crutch and Warrington (2003) argue that these findings necessitate a broadening of the Sensory Functional Theory. They coin their proposal the Multiple Processing Channels Theory, which states that the broad sensory and motor/functional channels consist of fine-grained, specialized channels. Essentially, the broad modalities of sensory and motor information can be broken up into constituent submodalities or channels. The crux of the theory is that '[i]tems from diverse categories receive differentially weighted inputs from these channels' (Crutch & Warrington, 2003, 367). But how can such an approach account for fine-grained category-specific deficits, like the one of FAV? The answer is that animals and fruit/vegetables are processed by different subchannels of the main sensory channel. For instance, Crutch and Warrington note that colour, form and taste information is most important for recognizing fruit and vegetables. On the other hand, animal-recognition is more dependent on form and movement information. Subsequently, if there is damage to the colour subchannel, then this can lead to an impaired knowledge of fruit and vegetables, while animal knowledge might be more spared. Yet, this account seems difficult to reconcile with the case of IOC, who has brain damage to the left temporal and occipital lobes and left hippocampal atrophy (Miceli et al., 2001). Although her colour perception is intact, IOC's lesions are associated with a deficit for colour knowledge. Despite this deficit in colour knowledge, the subject does not have a deficit for the subcategory of fruit and vegetables, which runs counter to the claim that knowledge about this class of objects depends to a large extent on colour information.

Finally, note that the third prediction of SFT cannot account for the fact that patient EW has a category-specific deficit for living beings, while both her functional and perceptual knowledge about animals is damaged (Caramazza & Shelton, 1998). A similar conclusion can be drawn from the meta-review by Capitani et al. (2003). This broad study reveals that there is no systematic association between type of knowledge and category-specific deficits.

4.2. Correlation theories

A second set of theories that attempts to explain category-specific deficits are coined 'correlation theories'. The central claim is that conceptual knowledge of living and non-living entities does not depend on modality or type of knowledge, but instead this knowledge is represented by patterns of activation in a single distributed network. Category-specific deficits are the result of random damage to this network and the particular internal structure of categorical concepts. An influential correlation theory has been proposed by Tyler and Moss (2001; 1997; for a related account see Devlin et al., 1998) and is coined the Conceptual Structure Account (CSA). CSA makes the following assumptions with regard to the internal structure of categorical concepts.

(1) Living things have many shared properties that are highly intercorrelated (e.g. 'having legs' strongly correlates with 'having a head').
(2) Living things also have distinctive properties (e.g. a zebra's stripes), but these are not strongly intercorrelated with other properties of living things.
(3) Non-living things have few shared properties and these tend to be weakly intercorrelated.
(4) Non-living things have many distinctive properties, and these properties are governed by strong form-function correlations (e.g. a 'blade' strongly correlates with 'cutting').

According to CSA, highly intercorrelated features are more resistant to brain damage than weakly correlated features. This entails that the distinctive properties of living things and the few shared properties of non-living objects are more vulnerable to brain damage than the shared properties of living things and distinctive features of non-living things. Relatively mild brain damage will therefore cause a category-specific deficit for living things, and will impair some of the shared properties of non-living things.

CSA draws support from several sources. First, Tyler and colleagues have developed a simulation (i.e. a neural network) of the theory and successfully mimicked the effects of brain damage (see Tyler & Moss, 2001). Second, a PET study by Tyler et al. (2003) inquired whether specific regions of the brain are specialised in processing knowledge about different categories. More specifically, subjects were presented three target pictures (e.g. sheep, cat, horse) and quickly had to decide whether a fourth picture (e.g. donkey) belonged to the same or a different subcategory. The results show that living and non-living things both activated a large network in occipital, fusiform and frontal regions. This finding is consistent with an approach where conceptual knowledge is represented in a distributed network. Third, an important advantage of CSA is that it allows for dissociations within categories. For example, the theory claims that fruit and vegetables will be vulnerable to brain damage because they have only few distinctive properties and these tend to be only weakly correlated.

Yet, CSA also faces some difficulties. For example, Caramazza and Shelton (1998) describe patient EW, who has a *mild* category-specific deficit for animals, but whose semantic knowledge about fruit and vegetables is as good as unimpaired. Similarly, CSA cannot accommodate the fact that patient JJ (Hillis & Caramazza, 1991; Caramazza & Mahon, 2003) has a severe deficit for non-living things but is unimpaired for living things. Furthermore, according to CSA, the category-specific deficits of subjects with progressive brain damage, such Alzheimer disease patients, should follow a specific pattern (i.e. a natural kinds advantage in an initial stage, and a catastrophic loss of this category in later stages of the disease (Garrard et al., 1998)). However, a cross-sectional analysis of Alzheimer disease patients at different stages of their disease did not reveal a specific pattern (Garrard et al., 1998; Caramazza & Mahon, 2005).

4.3. Domain Specific Account

To recapitulate, we have seen how some theories suggest that knowledge about living things is organized in a distributed network (correlation theories), while other theories claim that this knowledge is organized by perceptual features (SFT). While it was shown that these theories are confronted with problematic issues, it should also be noted that this complex field of research is still developing, and it would therefore be premature to rule out certain theories. A third approach, which is of particular importance for the current discussion, is referred to as the 'Domain Specific Account' (DSA). According to DSA, knowledge about living things is organized by category (Caramazza & Shelton, 1998; Caramazza & Mahon, 2003). This view implies that specific neural circuits are dedicated to knowledge about different object-domains and that category-specific deficits can occur when this circuitry is damaged.

Importantly, it is argued that the driving force of this regional specialization was evolution (Duchaine et al., 2001). It is speculated that neural mechanisms are associated with those entities that had evolutionary significance for human beings: namely, animals, vegetable life, conspecifics and possibly tools. 'It is not implausible to assume that evolutionary pressures led to specific adaptations for recognizing and responding to animal and plant life (the latter operationally represented by fruits and vegetables in research on category-specific deficits). … In perceptual and cognitive terms, these adaptations might consist of specialized processes for the rapid and accurate classification of objects as animals, as plant life, or as neither of these two categories of objects. In terms of neural mechanisms, the relevant adaptations might consist of dedicated neural circuits for processing animals and plant life. And because of the clear affective/emotional component associated with flight and feeding responses to animals and plant life, it is not implausible to further assume that the neural adaptations would involve circuits that include the limbic system' (Caramazza & Shelton, 1998, unpaged). Note that, when the domain-specific areas dedicated to living things are lesioned, this can result in category-specific deficits for the class of living things (figure 21).

DSA makes the following predictions:

(1) The grain of category-specific deficits can be as fine as the evolutionary relevant categories. This means that dissociations within categories can occur.
(2) There is no association between the type of category-specific deficit and modality of knowledge.
(3) Knowledge about evolutionary relevant categories has a genetic basis and will therefore be hard to recover when damaged.

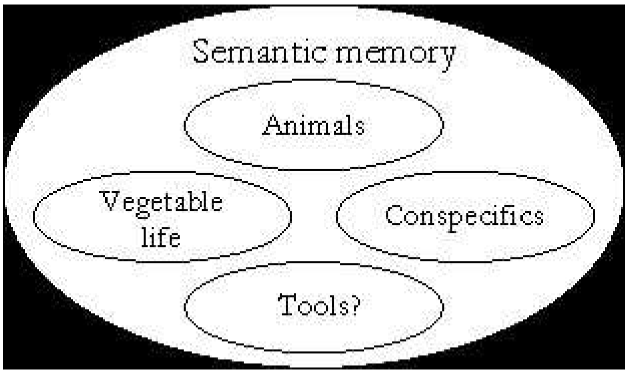


Figure 21: Schematic representation of the central claims of the Domain Specific Account.

The first two predictions are supported by research which was already discussed in previous paragraphs. For example, patient EW (Caramazza & Shelton, 1998) is impaired for semantic knowledge about animals, while the categories of fruit, vegetables and plants are spared. Furthermore, the meta-review by Capitani et al. (2003), in which all the case studies of category-specific deficits until that date are closely analyzed, indicates no systematic association between type of conceptual knowledge and category-specific deficits.

The third prediction receives support from a remarkable case study of patient Adam, described by Farah and Rabinowitz (2003). Due to meningitis, Adam has experienced brain damage ('bilateral occipital and occipitotemporal lesions') when he was 1 day old. Among others, this brain damage is associated with a persistent category-specific deficit for the class of living things. More specifically Adam has more difficulty in naming pictures of living things (40% correct) than in naming pictures of nonliving things (75% correct). Furthermore, an inquiry into his knowledge about living and nonliving items shows that his performance on questions about living things was at chance level, whereas it was quite normal for the nonliving items. Farah and Robinowitz (2003) propose that Adam's deficit for living things, and the fact that this deficit is present since birth, are suggestive of a genetic contribution to the distinction between living and nonliving entities: 'Whatever tissue was destroyed when Adam was a newborn had different relations to semantic memory for living and nonliving things. Specifically, it was essential for acquiring semantic memory about living things and not essential for semantic memory about nonliving things. If the distinction between living and nonliving things were not fixed at birth, how then would localised perinatal brain damage have been able to prevent the acquisition of knowledge about living things while allowing the acquisition of knowledge about nonliving things? Conversely, phrased in terms of Adam's surviving brain tissue, despite its adequacy for acquiring semantic memory about nonliving things, it could not take over the function of semantic memory for living things. This implies that prior to any experience with living and nonliving things, we are destined to represent our knowledge of living and nonliving things with distinct neural substrates. This in turn implies that the distinction between living and nonliving things, and the anatomical localisation of knowledge of living things, are specified in the human genome' (Farah & Rabinowitz, 2003, 407-408).

The proponents of the domain-specific view can also find support for their view in some recent brain-imaging studies. For example, a study by Chao et al. (1999) indicates that different brain areas are specialized in processing knowledge about different object-categories (see also Kawashima et al., 2001; Kreiman et al., 2000). They found an association between biological kinds (faces, animals) and the lateral fusiform gyrus, while non-living things (tools, houses) activated the medial fusiform gyrus. Furthermore, the study showed that animal kinds activated the right posterior superior temporal sulcus, while tool stimuli were associated with activations in the left middle temporal gyrus. This pattern of activations has been replicated by several brain imaging studies (Caramazza & Mahon, 2005).

Essentially, the domain specific account claims that the brain consists of a specific set of modules that are each specialized in processing information about a particular semantic domain (e.g. animals). It is worth mentioning that this view has not remained undisputed, and has been criticized on both empirical and theoretical grounds. On the empirical side, Rogers and Plaut (2002) argue that it is difficult to see how DSA can explain the observation that individuals with category-specific deficits will almost never be completely unimpaired for the 'spared' domain. If one or more modules is damaged, then why is there often a slight deficit for the semantic domains whose associated modules are supposedly undamaged? Another issue that needs explanation is the finding that certain combinations of deficits frequently occur together (e.g. combined impairment of animals and foods), while others only seldom or never occur (e.g. combined impairment of animals and artefacts). On the theoretical side, Rogers and Plaut argue that the evolutionary claims made by DSA (i.e. that these modules are adaptations that evolved to recognize natural entities) are essentially post-hoc and do not provide any further evidence for the theory: '… taking the domain-specific knowledge hypothesis at face value, speculation about which semantic domains are innate is necessarily post-hoc; and it is difficult to seriously conclude that such activity provides independent motivation for the theory. Post-hoc evolutionary arguments have been made, with varying degrees of success, to support a host of differing claims about which semantic distinctions are innately given, and which are learned … In the absence of converging empirical evidence to support them, such claims amount to little more than restatements of the data' (Rogers & Plaut, 2002, 162).

4.3.1. Neural correlates of the Domain Specific Account

Perhaps, the previous difficulties are in part due to the fact that research into the causes of category-specific deficits is still a young and maturing field of research. It is therefore quite natural that most hypotheses and explanations are still quite coarse at this stage, and further empirical research is needed to refine the major theoretical accounts. This does not preclude, with what is known today, that the Domain Specific Account is a plausible candidate in the current debate on the organization of semantic knowledge in the brain. However, its correctness has no bearing on the plausibility of the *individual* claims made by the previous theories (e.g. SFT), but only shows that these cannot be the direct *cause* of category-specific deficits. In particular, some theorists believe that it is quite possible that category-specific neural areas are embedded in neural systems that are specialized in a certain modality of knowledge. It could therefore well be that neural areas specialized in living things fall within the perceptual modality, while the areas dedicated to nonliving things are embedded within the functional modality. This entails that SFT's claim that perceptual information is most important for living things remains more or less intact, while it is the domain specific organization that is the direct cause of the category-specific deficits (Mahon & Caramazza, 2003).

4.3.1.1. Category-specific specialization at early levels of processing

Note how the central tenets of DSA fit in with the evolutionary framework presented in this dissertation. The picture emerging from this account is that, under evolutionary pressures, specific neural mechanisms have become specialized in conceptual information about living things. It should be noted that this does not answer the question whether and which mechanisms exist to process complex stimuli like natural environments, which consist of a wide range of elements and spatial configurations. Probably, processing these relies on different (specialized) cognitive devices. For example, there are specific brain areas known to be involved in topographical knowledge and orientation (e.g. the parahippocampal brain area), which can be activated by landmarks (Epstein & Kanwisher, 1998). Perhaps the capacity to read the landscape (legibility) relies on these areas (Kaplan, 1987, 1988). However, we have also discussed that people display an affective predilection for more discrete contents belonging to such environments (animals and plant life) and this finding can be more suitably accommodated by the previously-described views. For example, having an inborn predisposition to easily acquire and retain specific knowledge about natural entities (e.g. which snake is poisonous; when a certain tree will bare fruit; which fruit is edible; and so on) probably was highly adaptive for our human ancestors. However, such a faculty is mainly situated at the cognitive, conceptual level, and requires quite a bit of inference. According to habitat theory, individuals had a clear survival advantage when they could quickly and accurately assess whether certain survival relevant stimuli were visually present in the scene. Importantly, such automatic and rapid assessments would be greatly facilitated if there was already category-specific specialization at the level of (early) visual processing. Caramazza and Shelton (1998; see also Mahon & Caramazza, 2003) provide evidence that is consistent with this hypothesis by referring to the existence of category-specific deficits at the level of object-recognition. For example, they refer to case studies whose semantic memory and structural description system – which stores information about an object's form – are impaired for biological categories (Mahon & Caramazza, 2003; for an overview see Capitani et al., 2003, p. 221). In particular, such subjects are unable to make correct decisions about the reality of an object (e.g. they have difficulties in distinguishing between real and unreal animals). A possible interpretation of such deficits is that there exist neural circuits at the level of visual processing, which are specialized in processing and recognizing visual information about biological entities.

We have already referred to research that demonstrates that 'natural' stimuli can be processed very rapidly (see section 2.5 of this chapter). There is some evidence that the rapid categorization of natural and man-made objects depends on the presence of a set of typical low-level formal features. This conclusion can be drawn from a series of experiments performed by Levin et al. (2001). In this study subjects either had to search for targets belonging to the category of natural objects (animals) among artefact distractors, or for artefact targets among natural distractors. The researchers made several experiments in which it was inquired which typical (perceptual) features influenced the search. In the first experiment, subjects just had to search for natural targets among artefact distractors, and vice versa. The search was found to be surprisingly fast: 'The average target-present slope for detecting an artefact among animals was 5.5 msec/item … whereas the target-present slope for animals among artefacts was 16 msec/item…' (Levin et al., 2001, 681). In the second experiment, it was inquired whether the search for targets among distractors was driven by the complete structural code of the objects. In order to determine this, the natural and artefact images were jumbled. Specifically, the orientation and the location of the parts of the objects were changed. Analyses of the search speeds indicates that jumbling only minimally slowed down the search: 'The mean slope for artefact target trials was 12.3 msec/item … and the slope for animal target trials was 17.1 msec/item…' (683). This points out that the search was not profoundly influenced by complete structural descriptions. In the subsequent experiments, Levin et al. (2001) inquired whether more simple visual features influenced the rapidity of the search process. For this, the degree of rectilinearity of the stimuli was computed, and it was inquired whether it correlated with the respective search slopes. It was found that rectilinearity and curvilinearity could predict the search slopes of both artefacts and animals, respectively. The researchers therefore conclude '… that processing systems may be segregated by category in late vision and … different early visual systems may connect differentially to these later areas … [I]t is possible that curvilinear and rectilinear contours are processed by systems that are independent at some point. We might, therefore, expect at some point to observe a patient who has difficulty integrating rectilinear contours to contrast with patients who seem to have a curvilinearity deficit' (Levin et al., 2001, 695). However, it should be noted that not *all* variance could be explained by these simple perceptual features. For example, the search for animals was also influenced by 'typicality'. This notion refers to the fact that animals often have typical constituent parts, such as heads and legs, and the search was also influenced by such features.

If curvature is in some way one of the constraints for quickly categorizing an object as 'natural', then perhaps there are cases of subjects whose deficit for processing natural kinds is rooted in a deficit for processing curves. To our knowledge, the only existent research on this topic has been conducted for a typical class of natural objects, namely faces. In particular, Kosslyn et al. (1995) make report of the subject GA, who suffers from prosopagnosia (face-blindness), which is a deficit for recognizing and coding faces. Among others, the researchers performed a test on GA with two-dimensional geometric stimuli, where he had to decide whether or not there was an X mark on the pattern. Importantly, it was found that GA performed much worse in terms of response times when the stimuli were curved, than when they were straight-edged. Kosslyn et al. (1995) assume that this finding supports the hypothesis that GA's deficit in recognizing and coding faces is rooted in a deficit for encoding curvature: '… it may not be an accident that a person who has trouble encoding curvature also has difficulty encoding faces. … faces are distinguished in part by subtle variations in curvature (this may be most intuitively obvious when one looks at members of an unfamiliar race), and G.A. may be overloaded by such stimuli' (57).

A closely similar conclusion can be drawn from research by Laeng and Caviness (2001). They performed experiments on the prosopagnosic subject RP with the same 2D shapes that were used by Kosslyn et al. (1995) on the subject GA. Yet, in contrast to GA, RP did not show any deficit for these stimuli. However, the authors note that face-recognition requires analyzing *three-dimensional* curved surfaces, and they therefore inquired RP's ability to code curved surface information. In the experiment the following classes of objects were used: faces, cubes, and curved amoeba-like forms or 'blobs'. Pairs of objects, belonging to these classes, were presented, and RP had to judge whether it were two different objects, or the same objects, which were slightly rotated. For the set of cubes RP's performance was within the normal range. However, for both the face-rotation task and the amoeba-rotation task – which involved curved surface information – RP showed an abnormal performance when compared to control subjects. According to Laeng and Caviness this difficulty in processing curved surface information could be at the root of RP's face-blindness: '… we propose that prosopagnosia can be the result of a perceptually based impairment in the representation of smooth surface' (570). It is quite probable that not only face recognition relies on these mechanisms for analyzing and decoding curvature, but also other neural systems, especially those specialized in recognizing biological entities.

4.3.1.2. The Domain Specific Account and emotion

The previous research tentatively indicates that there could be particular form primitives that mark the difference between natural objects and artefacts in early vision. There are also indications that stimuli, belonging to the class of living things activate areas in the brain that are commonly associated with emotional responses, such as the amygdala. Within the context of research on the amygdala, most often natural stimuli are employed that have a negative affective valence for most people, such as spiders, snakes or depictions of fearful faces. However, some research indicates that more positive emotions are also associated with activations in the amygdala (Zald, 2003). Perhaps this brain area will show activation when confronted with specific classes of natural contents, or with stimuli that are related to the latter. Our lengthy review of the field of environmental aesthetics shows that this could probably apply to such elements as flowers, trees, plants, savannas. (It should however be noted that entities such as flowers are sometimes used as 'neutral' pictures to assess the emotional impact of entities like spiders and snakes.)

Tentative insight into the neural correlates of the relation between living things and emotion can be drawn from a neurological study by Martin and Weisberg

(2003). In this experiment 12 subjects participated in an fMRI study, while watching computer generated stimuli depicting different kinds of movement of simple geometric shapes (e.g. triangles, squares, circles). The shapes could be moving as biological entities (e.g. dancing, fishing, playing), as inanimate objects (e.g. bowling, pinball, conveyor belt), or they could move in a random fashion. Brain imaging revealed that different brain areas were selectively activated by the stimuli. In particular, it was found that exposure to biological and mechanical movement correlated with activation in brain areas that were also found to be involved in processing living kinds and tools, respectively: '… the regions showing differential activity were highly similar to those previously linked to viewing faces, human figures, and naming animals (lateral region of the fusiform gyrus, STS [Superior Temporal Sulcus]) and those linked to naming tools (medial fusiform gyrus, middle temporal gyrus)' (Martin & Weisberg, 2003). Moreover, it was found that, as opposed to mechanical movement, biological movement was accompanied by activations in the amygdala (figure 26). Note how this pattern of activation is consistent with the fact that Brousseau and Buchanan (2004) found that the emotional valence attributed to a wide range of pictures of biological entities, was higher than for nonbiological objects. Perhaps this reflects the evolutionary association of biological entities (plant life, animals) with affective states, which acted as a guide for escaping or explorative behaviour.

It can be tentatively proposed that the brain areas activated by the animate stimuli in the Martin and Weisberg study are part of a domain-specific core system that is dedicated to processing information pertaining to animacy. Martin and Caramazza (2003) conclude from this experiment that '… higher-order concepts such as "animacy" may be represented in a network of regions composed of areas that store knowledge of what animate objects look like (lateral fusiform gyrus), how they move (STS), coupled with areas for representing and modulating affect (amygdala and ventromedial frontal cortex)' (Martin & Caramazza, 2003, 207). The case study of Adam (Farah & Rabinowitz, 2003) further suggests that this domain-specific system could in some sense have an inborn aspect.

4.3.2. Etnobiological evidence consistent with the Domain Specific Account

The central claim of the Domain Specific Account, namely that specific neural areas have become specialized in processing certain typical natural contents, is consistent with research into human folkbiologies. The notion 'folkbiology' refers to the nonscientific and intuitive way in which people classify natural objects and reason about the natural world (e.g. plants, animals). Some research indicates that the contents of folkbiologies have certain universal characteristics, which favours an explanation in terms of innate domain-specific learning mechanisms or 'cognitive modules'. Thinking about plants and animals is in some way 'special', as opposed to thinking about, say, artefacts. The fact that knowledge about the biological domain could have an inborn component is in line with our treatment of the possible genetic aspects of our affective relation with certain typical natural contents, discussed in the first sections of this chapter. It is therefore relevant to briefly discuss this field of research.

A first line of evidence for these claims about folkbiology comes from cross-cultural studies, which indicate that people employ similar taxonomies to structure the natural world. For example, Atran (1995) discusses research that compared the folkbiological taxonomies of students of the University of Michigan and Maya Indians (Itza) from Guatemala, with scientific taxonomies. It was found that the taxonomies of both groups correlated quite well with the scientific ones, and mutually compared well. This is suggestive of a universally shared framework for thinking and reasoning about natural entities. Essential to the structure of this shared folkbiology is that plants and animals are privileged to be partitioned in species-like groups. Biologists describe these as '… populations of interbreeding individuals adapted to an ecological niche' (Atran, 2002, unpaged). According to Atran (2002; see also Atran, 1995) (generic) species belong to higher-order groups and also divide into lower-level groups. Again, the resulting taxonomic structure is not arbitrary or a matter of convenience:

- folk kingdom (e.g. plant, animal)
- life form (e.g. tree, bird)
- generic species (e.g. oak, robin)
- folk specific (e.g. white oak, mountain robin)

These ranks of folkbiological taxonomies have a universal character, while the folk-biological groups or 'taxa' (e.g. bird, robin) that belong to them do not have this property. Importantly, this shared taxonomic structure is a framework that allows people to coherently organize the living world around them, and reason about it: 'Pigeon-holing generic species into a hierarchy of mutually exclusive taxa allows incorporation of new species and biological properties into an inductively coherent system that can be extended to any habitat, facilitating adaptation to many habitats' (Atran et al., 2004, unpaged).

A second line of evidence for the existence of an inborn folkbiology comes from the observation that the taxonomic types of folkbiologies are consistently and cross-culturally ascribed 'essences'. The notion 'essence' refers to the underlying causal nature of natural objects. Essences are responsible for the behaviour, appearance and ecological preference of natural objects. For instance, most people will agree that transforming a guinea pig, by giving it long ears and a short furry tail, will not turn it into a rabbit. On the other hand, they will probably acknowledge that by applying changes to a certain artefact (e.g. making a bird-feeder from a plastic bottle) it will become a genuinely new object (Keil, 1986). Importantly, essentialism is found to be a ground for making inductions about various kinds of natural objects. This feature can be explained by an experimental study described in Atran (2002). In this experiment, Maya Yukatek children and adults had to infer whether an 'adopted' adult animal would resemble its adoptive parent (e.g. a cow) or its birth-parent (e.g. a pig). Generally, it was found that both children and adults tended to attribute the animal those behavioural and physical features that were typical of the birth parent (e.g. a pig does 'oink' and has a curly tail). The experiment thereby suggests that members of the same species share an innate essence that is responsible for its behavioural and physical traits. This essence forms the basis for making inductions, even if species are reared in different conditions. (It needs no explanation that being able to make correct inductions about the natural world on the basis of essences would have provided important evolutionary advantages for an organism whose subsistence crucially depended on contact with the natural world.)

Both findings (a shared folktaxonomy and essentialism) suggest that thinking and reasoning about the natural world – and biological entities in particular – are constrained by certain rules, which seem to have a universal and inborn character. This view implies that folkbiological thinking does not undergo major shifts during an individual's development. Instead, the general picture is that there is some inborn learning mechanism present for biological things, and the details of this framework are gradually filled in and refined through experience. It should, however, be noted that a contrasting alternative to this view has been proposed. In particular, Carey (e.g. Carey, 1988; Carey, 1985) argues that there occurs a major conceptual shift around the age of ten, when an autonomous folkbiology develops. Before that age, however, a child's understanding of biological kinds is based on a folkpsychological framework.

Of course, Carey's view has not remained undisputed neither. For example, Atran (2002; see also Coley, 2000) notes that her account makes it difficult to understand how people seem to come to a quite similar folkbiology, despite the fact that it is the result of a radical conceptual change grounded in totally different cultural and learning contexts. Furthermore, in an answer to the claim that folkbiology arises from folkpsychology, Atran states that '[h]uman-centered reasoning patterns might reflect lack of knowledge about non-human living things rather than a radically different construal of the biological world' (Atran, 2002, unpaged). In particular, Atran (2002) argues that the urban North American population studied by Carey has no other option than to use folkpsychological concepts in their reasoning about biological entities, because they are only remotely familiar with the latter. However, a different pattern emerges for children that live in a more intimate relationship with nature, such as the Yukatek Maya. In an experiment (Atran, 2002) Yukatek children and adults were presented images of four familiar objects or 'bases': human, dog, peccary and bee. Next, they were taught that these objects had a certain unfamiliar substance (e.g. 'andro') inside them. Then, they were presented pictures of 'targets' (e.g. a certain tree, a mammal, the sun, and so on) and had to judge whether or not they had the same substance inside as the base. According to Carey's account, the base 'human' should be preferred as a source of projection. However, this pattern was not observed. Similar to Atran (2002), Ross et al. (2003) found that Boston-area children tended towards anthropocentrism. On the other hand, for Native American children (Menominee) projections from humans were not higher than projections from other bases. This seems to suggest that human psychology is not privileged to serve as a base for making inductions about biological entities.

5. Biophilia as a unifying framework?

Up to now, we have tried to demonstrate that humans display an affective relationship with natural entities, by relying both on cognitive and neurological research. Sometimes, such affiliations are referred to in terms of 'biophilia', which can be literally translated as the 'love for life'. The notion biophilia has been introduced by Erich Fromm, and was considered as a psychological orientation towards what is alive and vital, and is the converse of necrophilia. However, it was sociobiologist Edward O. Wilson who employed the notion in a more environmental, ecological context in his book *Biophilia* (Wilson, 1984). In the nineties of the 20th century the interest in biophilia culminated in the publication of the book *The Biophilia Hypothesis* (Kellert & Wilson, 1993). The book featured edited contributions by renowned scholars from different disciplines, shedding light on the theoretical underpinnings of the notion, and bringing together a variety of (quasi)empirical evidence lending plausibility to the hypothesis. Nowadays, despite some exceptions, attention has shifted from interest in the theoretical foundations of biophilia, to the question of how biophilia can be practically applied (e.g. in building and design (e.g. Kellert, 2005)), or how it can shed light on developmental issues (Kahn & Kellert, 2002). In the following sections we give a brief discussion of the biophilia hypothesis. We include it in this chapter because (a) this hypothesis draws heavily on the material presented in the previous sections (b) and because the notion biophilia is central to so-called 'biophilic design', which is the central theme toward which we are working in this dissertation.

5.1. Characterization of biophilia and favourable arguments

In essence, the biophilia hypothesis states that (modern) humans have (a) an emotional affiliation with life and life-like processes, and (b) this affiliation is engrained in our genetic makeup. Relying on the theories outlined in the previous sections and some other evidence, this affiliation is claimed to be the result of millennia of human evolution in a natural environment, where repeated contact with, and dependence on natural entities was crucial for hominin and *Homo* subsistence. Again, in such environments, an organism had clear evolutionary benefits when it was 'hardwired' to respond emotionally to (survival-relevant) natural stimuli. According to Wilson (1993) these emotional or 'biophilic' responses are still with us because '[i]t would be … quite extraordinary to find that all learning rules related to that [biocentric] world have been erased in a few thousand years, even in the tiny minority of peoples who have existed for more than one or two generations in wholly urban environments' (32).

Although in a literal sense, biophilia can be understood as the 'love for life', it is evident that not all life or life-like processes elicit positive reactions. Traditional examples are snakes and spiders, which are known to cause aversive or phobic reactions in humans (Mineka & Öhman, 2002) and primates (Coss, 2003). But how is this tension resolved in discussions on biophilia? A first possibility, adopted by Ulrich (1993), is to interpret biophilia as a positive emotional affiliation, and to strictly separate it from negative or 'biophobic' responses to natural entities. Yet, it should be admitted that mainly methodological considerations are at the root of Ulrich's distinction. He makes this distinction because when people posses inborn negative reactions to certain natural stimuli, then it isn't too hard to suppose that positive reactions to them – which are claimed to guide adaptive behaviours – also have a partly genetic basis: 'A general argument … is that theoretical propositions for an innate predisposition for biophilia gain plausibility and consistency if they also postulate a corresponding genetic predisposition for adaptive biophobic responses to certain natural stimuli that presumably have constituted survival-related threats throughout human evolution' (Ulrich, 1993, 75). In contrast to Ulrich's view, there is Wilson (1993) who leaves the issue of positive or negative emotions in the middle, and employs 'biophilia' in a more loose sense. He, and many others, interpret biophilia merely as an emotional affiliation, and this can include both negative and positive responses.

Another issue surrounding biophilia is discussed by Kahn (1999, see also Kahn, 1997), and involves the genetic component of biophilia. On the one hand one can adhere to a strict genetic interpretation, where the presence of a specified set of genes is a sufficient ground for biophilic responses. However, such an interpretation is open to the critique of genetic determinism. As will be pointed out below, biophilia can form the basis for an anthropocentric environmental ethics. If this view is combined with a gene-centred approach, then normative claims are deduced from factual descriptions in terms of genes (Kahn, 1999), which amounts to committing the naturalistic fallacy. Therefore, most adherents of the biophilia hypothesis advocate a more moderate viewpoint. They argue that biophilia refers to (a cluster of) biologically prepared learning rules. More specifically, biological preparedness implies that humans have an innate proclivity to quickly learn responses towards certain stimuli, and these responses are almost impossible to get unlearned or extinct (Ulrich, 1993; Cummins & Cummins, 1999): 'It is suggested that a partly genetic basis for biophilia and biophobia should be reflected in biologically prepared learning – and possibly in particular characteristics of responses to certain natural stimuli (such as very short reaction times) that may not be evident for learning and response characteristics with respect to modern and urban stimuli …. [P]repared learning theory holds that evolution has predisposed humans and many animal species to easily and quickly learn, and persistently retain, those associations or responses that foster survival when certain objects or situations are encountered' (Ulrich, 1993, 75-76). With its recourse to biological preparedness, conditioning, and hence, cultural and experiential parameters, retain a meaningful role in the biophilia hypothesis.

What makes the biophilia hypothesis perhaps unique is that it provides a ground for an anthropocentric environmental ethics. The core idea is quite straightforward. Because we are predisposed to show emotional affiliation with the natural world, it is in our own interest to preserve it. If not, we will become deprived of an important source of (positive) human emotion, fulfilment and happiness. However, it could be noted that not all nature causes positive emotions in humans. Why should one want to preserve or protect natural beings that cause disgust or fear, such as snakes, worms, maggots or cockroaches? Why should one be opposed to cutting and burning down tropical rainforests, if we are aesthetically more attracted to the savanna-type landscapes that result from it? With these remarks, one is confronted with the limits of biophilia as a guide for anthropocentric environmental reasoning. In fact, a biophilic environmental ethics should go hand in hand with the question which alterations of the natural world promote fitness (Kahn, 1999). For example, there may be a cognitive-evolutionary basis for modifying tropical rainforests into more savanna-type landscapes, but this does not increase survival chances of the human species, because rainforests play an important role in the global climate system. Yet, it should be noted that combining a biophilic conservation ethic with the question which interventions in the natural world promote fitness seems to presuppose a belief in the transparency of the complexity of ecological interrelations. Couldn't it be the case that certain species are *prima facie* quite irrelevant to our genetic fitness, but still play an essential role in the ecological balance of the natural environment to which they belong? It is far from sure whether, to date, we have sufficient knowledge about the natural world to establish with certainty which interventions will promote fitness, and which will not.

	Biophilic value	*Adaptive value*
Utilitarian	The material value of nature.	This value helps to get physical sustenance, security and protection. Think for example of plants as a source of food and medicine.
Naturalistic	Fascination, awe and wonder about nature, which triggers curiosity and exploration.	This value leads to increased knowledge and understanding of nature, and is beneficial for physical fitness, and outdoor skills.
Ecologistic-scientific	The systematic study of structure, function and relationships in nature.	Those who could precisely observe, analyze and study in detail the richness of life-forms had a clear survival advantage.
Aesthetic	The aesthetic impact of nature on individuals.	This value provides a guide for finding food and safety.
Symbolic	The symbolic value of nature is perhaps most prominent in language, where metaphors and symbols referring to the natural world are omnipresent.	Symbolizations and metaphors facilitate communication, thinking and mental development.
Humanistic	The deep emotional bonds that an individual can develop with (elements of) the natural world. Perhaps this 'love for nature' is most pronounced in the human relationship with domesticated animals.	Human-animal relations can function as a template for bonding, altruism and sharing – values important for social beings like humans. Bonding with companion animals is also important because these can help in finding food and can offer protection. Furthermore, by mimicking the behaviour of (semi)domesticated animals, one can get more adapted and attuned to the environmental context.
Moralistic	The '… strong feelings of affinity, ethical responsibility, and even reverence for the natural world' (Kellert, 1993, 53). Often, this goes hand in hand with attributing nature a spiritual meaning	This value can contribute to feelings of kinship, affiliation and loyalty, which in turn can promote cooperative and altruistic behaviour. Furthermore, projecting intrinsic meaning and ordering onto the cosmos can lead to more conservationist attitudes towards the natural environment and might also enhance feelings of wellbeing.
Dominionistic	The wish to master, to physically control, and to dominate the natural world.	Such stances can lead to increased knowledge and understanding of the natural world, and might improve mechanical skills and physical prowess.
Negativistic	Contact with nature is not always a pleasant experience, but can also be associated with fearful or even phobic responses.	Such behaviour motivates the individual to search for security, protection and safety.

Figure 27: Kellert's biophilic values.

5.1.1. Environmental psychology

The bulk of writing on biophilia has been dedicated to the question which evidence supports the hypothesis or is consistent with it, while only few have worked out the 'architecture' of the construct. An exception is Stephen Kellert, who argues that biophilia depends on an interplay of nine specific values (figure 27). According to Kellert, these '… represent a basic human relationship and dependence on nature indicating some measure of adaptational value in the struggle to survive and, perhaps more important, to thrive and attain individual fulfillment' (1993, 58-59). The most substantial body of evidence supporting the biophilia hypothesis comes from the studies described in the first sections of this chapter (see also Ulrich, (1993) for a good review). The widely documented preferences for nature, its restorative effects, and the (supposed) universal character of the findings, add strongly to the plausibility of both the 'genetic' and the affective claims of biophilia. However, some other arguments or 'amplifying evidence' have been proposed. For example, Peter Kahn (see Kahn (1999) for an overview) has performed different studies into the attitudes of children toward the natural environment. A first study – the 'Houston study' – counted seventy-two African-American children from an impoverished region in Houston, Texas. In a first part of this study, Kahn found that the children strongly appreciated nature. For example, they said that nature played an important part in their life, that they reflected about nature, and talked about nature-related topics (e.g. waste) with their families. In a second part, the children morally judged throwing garbage in either a local or in a geographically more remote waterway. In both conditions, children considered such acts to be morally wrong. Very similar results were obtained for the 'Brazil study', that included children from the city of Manaus, situated at the junction of the Rio Negro and the Amazon, and children from Nova Ayrao, a remote village upstream the Rio Negro, located in an unspoiled environment. The similarity of the results for diverse populations with different economic, social, and political backgrounds is in agreement with the univeralist claims of the biophilia hypothesis. Furthermore, it shows how people (i.e. children) living in impoverished regions, with less opportunities for extensive contact with nature, still value nature to an important extent.

But given these results, why should one worry about nature's destruction (Kahn, 2002)? Clearly, children seem to display positive attitudes towards nature. First, the studies have only inquired verbal behaviour, and not how the children actually behaved and acted towards nature. It could well be that the answers they generated were influenced by what they thought was social desirable (Coyle, 2001). Furthermore, Kahn (2002) notes that, while the children have insight in certain environmental problems (e.g. air pollution), it seems that the majority of them does not realize that these problems also affect them. An explanation for this is that living in degraded situations has become the norm for them, making it difficult to objectively evaluate their own situation.

The previous observation makes it clear that having an inborn affective affiliation with the natural world does not suffice to come to a clear understanding of the natural world, and of our relation with it. Interestingly, Kahn (2002) holds that a constructivist approach to education could prove helpful to come to a richer and more mature conceptual framework for thinking and reasoning about the natural world: 'The structural-developmental (constructivist) approach to education … posits that children are not passive beings who are merely programmed genetically or molded societally but that through interaction with their environment, children construct knowledge and values. Thus constructivist education allows children to explore, interact, recognize problems, attempt solutions, make mistakes, and generate more adequate solutions' (110-111). Importantly, according to Kahn, this educational approach needs to be supplemented with bringing children directly in contact with nature, and with teaching them about what the environmental situation was before the pollution.

5.1.2. Native biophilia

Perhaps one can get insight in what a fully developed ability of biophilia is from studies of native people's attitudes toward the natural world. This line of argument is presented by Nelson (1993) in his study of the Koyukon of Northern Alaska. The argument is that '… if native peoples offer us a way to understand what is most basic to our being, then the evidence from the Koyukon … speaks to pervasive affiliations with nature that run deep in our evolutionary history' (Kahn, 1999, 23). Indeed, because such native communities are dependent on natural resources and hunting for their subsistence, they are obliged to develop an intricate, detailed and fine-tuned knowledge of the living world – of plants, animals, landscape elements, weather conditions, and their interrelations. Having an inborn predisposition to be focussed or interested in these would make the acquisition of such knowledge easier and quicker, and could reduce error-making, which could be highly adaptive for an organism living in a natural context.

Nelson (1993) gives extended descriptions of the natives' deep knowledge and understanding of their local natural environment, and the different species it contains. Importantly, in such communities there is often no clear distinction between humans, nonhuman beings or nonliving entities. All of them are attributed consciousness or spirit: '… earth, mountains, rivers, lakes, ice, snow, storms, lightning, sun, moon, stars – all have spirit and consciousness. The soil underfoot is aware of those who bend to touch it or dig into it. Certain localities are alive with power, sometimes dangerous and sometimes benevolent. Winter cold has a mind of its own, which people may anger or assuage' (Nelson, 1993, 217). Although such an animistic or panpsychic worldview is philosophically coherent, it is highly speculative. Yet, one could adopt such a view also for more pragmatic considerations. If natural objects have a degree of sentience, then people will perhaps be more careful in their use of natural resources, and be sensitive to the brittle ecological balance and interrelations in their local environment. Such an attitude could be especially important for native populations, who often depend solely on natural resources for their subsistence, but whose availability is often uncertain and contingent on environmental factors (e.g. weather conditions).

Jared Diamond (1993) also describes the expert knowledge of nature of native New Guineans. In contrast to other contributors to the book *The Biophilia Hypothesis*, he is fairly critical for the concept of biophilia, and mentions some observations that seem to go against the hypothesis. First, it seems that New Guineans only show positive responses to a small group of animals - in particular to pigs, which are status symbols. Generally, they are not interested in holding any other pets. Diamond further notes that these people often do not realize that other living creatures – or even other humans – are capable of experiencing pain: '… I found men intentionally inflicting pain on captured live bats for no other reason than amusement at the reactions of the tortured animals. The men had tied twenty-six small Syconycteris blossom bats to strings. They lowered one bat after another until it touched the red-hot embers of a fire, causing the bat to writh and squeal in pain. The men raised the bat, lowered it again for another touch to the red-hot embers, repeated this process until it was dead, and then went on to the next bat, finding the whole proceedings funny' (Diamond, 1993, 263-264). But if they do not show strong biophilic responses, do New Guineans then display biophobic reactions to certain species (e.g. snakes, spiders)? Diamond notes that this is not the case, despite the fact that one third of the snake species on New Guinea is poisonous. In fact, 'biophobic' reactions are claimed to be only useful for people whose knowledge about harmful snakes is insufficient. It gives them a coarse behaviour pattern for reacting to *all* snakes. Finally, in contrast to the Alaskan natives described by Nelson (1993), New Guineans do not exhibit conservationist attitudes toward local ecologies, but hunt what they can get hold on.

While Diamond (1993) thinks that these findings underscore the emotional component of the biophilia hypothesis, he holds that it is unintelligible how such descriptions can provide evidence for the genetic component of the biophilia hypothesis. Nevertheless Kahn (1999) tries to weaken Diamond's position by the following argument (1999): '… while Diamond's credentials as an ornithologist are undisputed, he appears to have little training as an anthropologist or cross-cultural psychologist insofar as he reports only anecdotal social-scientific data. Thus some may find Diamond’s conclusions suspect, although suggestive’ (41-42). This remark, however, does not have any bearings on the fact that there is no meaningful way in which studies from native people can shed light on the genetic component of biophilia.

5.1.3. Cognitive biophilia

Edward O. Wilson notes that ‘[t]he biophilia hypothesis … hold[s] that the multiple strands of emotional response are woven into symbols composing a large part of culture’ (Wilson, 1993, 31). This is clearly visible in architectural design, where aesthetic enhancements often draw inspiration from natural forms and entities. Linguistic expressions of biophilia have been inquired by Elizabeth Lawrence (1993). In particular, she claims that animals are, and always have been, ideal ‘vehicles’ for metaphorical expressions and (linguistic) symbolizations: ‘The human need for metaphorical expression finds its greatest fulfilment through reference to the animal kingdom. No other realm affords such vivid expression of symbolic concepts. The more vehement their feelings, the more surely do people articulate them in animal terms, demonstrating the strong propensity that may be described as cognitive biophilia’ (Lawrence, 1993, 301).

In particular, in her treatment on cognitive biophilia, Lawrence discusses the semantic associations in the Judeo-Christian tradition evoked by the bee, the pig and the bat. In essence, she claims that these three categories impart to persons or objects associations of pureness, filth, and the underworld, respectively. Think for example of the notions ‘bat out of hell’ and ‘fascist pig’. Lawrence notes how Christ was attributed characteristics of the bee: ‘… in his miraculous birth Jesus resembled the bees who brought forth their young through their mouths as he sprang, allegorically, from his father’s mouth. The virtue of cleanliness was possessed in common, for bees live and reproduce through association with fragrant plants and avoid anything dirty. His immaculate conception found ideal expression in the alleged asexual reproduction of bees. The ancient belief that bees sprang from carcasses of dead oxen also emphasizes the bees’ chastity, for oxen, being castrated, posses no sexuality’ (Lawrence, 1993, 310).

It should be noted that Lawrence’s cognitive biophilia has been criticized by Kahn (1999). Kahn argues that Lawrence goes too far when stating that ‘*No other* realm affords such vivid expression of symbolic concepts [as the animal kingdom]’ (Lawrence, 1993, 301, our italic). Kahn offers the example of the notion ‘lust’. While it is true that lust is often symbolically expressed through animal concepts (‘you bring out the beast in me’, ‘he’s a real stud’ (see: Kahn, 1999, 34)), non-animal concepts are also used to evoke it. Of course, this does not invalidate biophilia as an explanatory mechanism for cultural appropriations of the natural world. It just makes it clear that biophilia is not the whole story in the process of symbolizing. In a similar way, it can be argued that biophilia does not preclude that people also love nonliving or inanimate things – such as guns, bikes or cars.

An interesting issue raised by Lawrence (1993) is the question which consequences the increasing destruction of nature will have on the human tendency to symbolize through nature. Isn't it most plausible that human language will contain increasingly less references to nature? Lawrence (1993) believes that the contrary will happen: 'Ironically, as countless life-forms disappear from the earth, many people experience a fuller consciousness of nature and acquire deeper aesthetic appreciation for the nonhuman realm' (337). According to Lawrence this will translate into a heightened propensity to use animal symbolism in art, literature and everyday language. It is worthwhile to note that this claim has recently been empirically tested, by Wolff et al. (1999). Contrary to Lawrence's speculation, the authors found that the decline of direct contact with nature during the 20th century had important negative effects on cultural expressions of nature. In particular, a study of the Oxford English Dictionary, which gives a clear picture of the evolution of word use, indicates that terms referring to 'tree' evolved from the 16th until the 19th century. Yet, from the 20th century onward, the use of such terms devolved, and their application lost precision. A similar devolution was observed for other (folk)biological concepts (e.g. bird, grass, flower), while several nonbiological terms evolved during this period (e.g. books, clothes, furniture).

5.2. Devolution of biophilia

The devolution of biological concepts and knowledge is intimately intertwined with the biological preparedness governing biophilic responses. Recall that biological preparedness implies that experience is also necessary to fully develop this capacity. The downside of this is that biophilic responding could become underdeveloped when there are not enough opportunities for contact with nature. According to Pyle (2003), this scenario has become reality for children living in modern, urban settings. Here, it is argued, direct contact with nature has been replaced by watching (nature on) television (e.g. Discovery Channel). In agreement with this, Pergams and Zaradic (2006) found that there is indeed a trend away from biophilia to 'videophilia', which the authors define as 'the new human tendency to focus on sedentary activities involving electronic media' (387). In particular, it was found that the decline in US national park visits – considered to be a sign of biophilia – can be explained by an '… increased use of video games, home movies, theatre attendance and internet combined with inflation adjusted oil prices…' (Pergams & Zaradic, 2006, 391)

Adherents of the biophilia hypothesis argue that diminished contact with nature could lead to a vicious circle, sometimes described as the 'extinction of experience' (Pyle, 2003) (figure 28). The core idea is that, when in a culture there are fewer opportunities for biophilic responding due to a decreased presence of natural elements, then this leads to an underdevelopment of the ability for biophilia. The consequence is that there will also be less interest in protecting elements that cause these responses, with the result of even fewer (biophilic) learning opportunities, a further degraded talent for biophilic responding, and increasingly less (cognitive) motives to protect nature against destruction and exploitation. Adherents of the biophilia hypothesis would claim that such an underdevelopment will deny humans access to the broad range of (positive) emotions that can emerge from the contact with natural things.

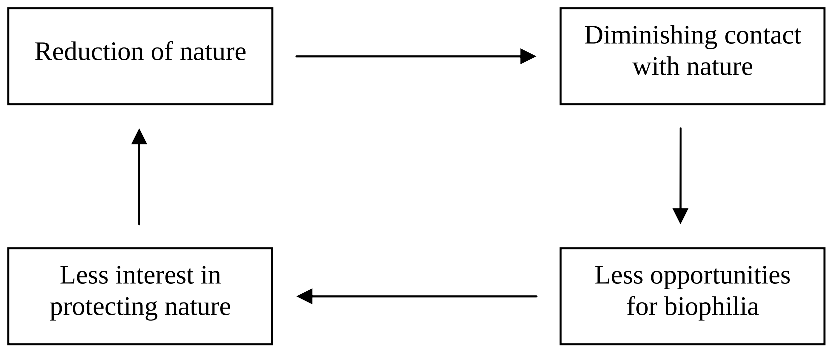


Figure 28: The vicious circle leading to a devolution of knowledge and interest in nature.

Importantly, empirical research seems to confirm some aspects of this vicious circle. Specifically, it indicates that emotional states play an important role in proenvironmental behaviour. Hartig et al. (2001; see also Kals et al., 1999), for example, found that those people that showed more interest and fascination in a piece of nature (i.e. a familiar freshwater marsh) were also engaged into more ecological behaviour. However, if the sources of such an emotional affinity are taken away – as the extinction of experience seems suggests – then a critical driving force for nature preservation could become lost.

Perhaps, it could be argued, the reported trend towards 'videophilia' (Pergams & Zaradic, 2006) can provide a solution here. Why couldn't the (emotional) interest in nature be stimulated by contact with 'virtual nature' – say, by watching nature on television or being exposed to it in virtual reality? In agreement with this, De Kort et al. (2006) found that the larger the immersion in virtual nature, the more profound its stress-reducing effects. However, Levi and Kocher (1999) caution against virtual reality nature experiences, because they often depict only spectacular nature. The downside of such experiences is that local natural environments could become devaluated. Furthermore, Levi and Kocher (1999) report that, while the experience of exceptional nature in virtual reality correlates with a willingness to preserve national parks and forests, such protective attitudes do not seem to apply to more nonspectacular and local natural areas.

5.2.1. Empirical research into devolution

Some researchers have tried to inquire the devolution of biophilic responses in a more controlled, quasi-empirical manner. Nabhan and St. Antoine (1993) inquired the impact of reduced contact with nature on the expression of biophilia by comparing the responses to nature of O'odham and Yaqui elders and their grandchildren. Both are indian populations, living in the Sonoran Desert of the US/Mexico borderlands. While the elders have been involved in hunting-gathering activities throughout a large part of their lives and, hence, have had extensive contact with the natural world, their grandchildren have an essential modern lifestyle. According to Nabhan and St. Antoine (1993) studying both groups holds genetic lineages constant, and therefore gives one a good idea of the influence of modified environmental conditions on the capacity for biophilia.

The researchers found that the expression of biophilia devolved for three areas in the children. First, basic factual knowledge pertaining to the plants and animals in the Sonoran Desert was drastically impoverished in the grandchildren. Second, in contrast to the elders, a large percentage of the childrens' experience of nature did not stem from spending time in the wild, but essentially came from television and movies. Third, while stories and myths play an important role in learning about nature in native people, O'odham and Yaqui children report that they had learned more about nature through television and books, than by stories told by their parents or grandparents (for similar findings in New Guinean youngsters: see Diamond, 1993).

From this research Kahn (1999) concludes that it '… is striking … that within one or two generations seemingly deep and pervasive affiliations of the O'odham and Yaqui with nature have been considerably extinguished' (42). Again, adherents of the biophilia hypothesis would claim that biophilia is subject to learning and experiences, and missing out on these leads to the underdevelopment of biophilic responding. However, it can be noted that the genetic component of biophilia becomes inconveniently thin if the human affiliation with nature would disappear only after two generations, and it is also quite improbable that all contact with nature has disappeared. Furthermore, it can be argued that the results of the Nabhan and St. Antoine (1993) study can have a plain *cultural* explanation. Individuals that have less contact with nature, will also have less knowledge about, and interest in it. There is no need to explain such devolution by making recourse to genetic claims (for a similar criticism, see also: Kahn, 1999).

Perhaps this devolution is in a sense a normal trend, in that nature often only provides soft fascination, and video and television hard fascination, and thereby exerts a more profound attraction on youngsters – especially when reliance on the latter domain is no longer necessary for one's subsistence. However, it could well be that their capacity for biophilia is still there, but that the young are deploying it in wholly different contexts and to new types of 'ecologies'. Consider a study by Balmford et al. (2002), which inquired the knowledge of 109 children about either British wildlife, or species of the card-trading game Pokémon. Interestingly, they found that '[f]or wildlife … identification success rose from 32% at age 4 to 53% at age 8 and then fell slightly; for Pokémon, it rose from 7% at age 4 to 78% by age 8, with children aged 8 and over typically identifying Pokémon "species" substantially better than organisms such as oak trees or badgers' (2367). Despite this devolution of wildlife species, it should be noted that Balmford et al. (2002) indicate that children have a 'tremendous capacity' at recognizing creatures: they were capable of recognizing 80% of the Pokémon creatures, from a set of 150 species. These findings are not necessarily inconsistent with biophilia. Perhaps such television or video game creatures are the only type of naturalistic contents with which children have extensive contact, with the result that they develop biophilic-like responses to these. (Note that the described expert knowledge of Pokémon species is consistent with existence of a universal folkbiology (e.g. Atran, 1995). While the structure of taxonomies has a universal character, the details of this framework are filled in by actual learning-experiences – perhaps the taxa can even be Pokémon species).

5.3. Critical notes on the biophilia hypothesis

Probably, one of the biggest challenges for biophilia has been raised by Diamond (1993), when describing New Guineans torturing bats, and having fun at it. In fact such an attitude reminds one of children blowing up frogs, or farmers brutally handling their cattle. But how could an adherent of biophilia reply to such cruelty? In fact, he or she could still claim that this accords well with an emotional affiliation with life-like processes, albeit a *negative* affiliation. Or as Kahn (1999) notes: 'Can one torture animals and say that through disaffirming that animal's life one is biophilic? Why not?' (32). But doesn't this render the notion of biophilia almost meaningless? A positive, negative, or even a more or less neutral attitude toward other natural beings can be incorporated in a biophilic framework. Indeed, Wilson (1993) notes: '… [biophilic] feelings … fall along several emotional spectra: from attraction to aversion, from awe to indifference, from peacefulness to fear-driven anxiety' (31). Because almost all possible logical attitudes towards natural entities can be explained as being consistent with the biophilia hypothesis, it becomes clear that no attitude to natural objects can disconfirm or reject the hypothesis. In fact, doesn't this imply that the description of biophilia as an emotional affiliation with natural entities is just too inclusive. Does it include all natural things, or only those that had direct evolutionary relevance? Does it include all possible emotions, with the risk of becoming trivial? However, in an attempt to address these questions, Kahn (1999) argues that Kellert and Wilson (1993) deliberately use the word 'hypothesis' '… because they want to encourage scientific investigations of biophilia across the natural and social sciences' (40). Similarly, Kahn (1999) notes that '… the biophilia hypothesis should move forward by means of both framing testable hypotheses…' (40). However, while biophilia is undoubtedly a ground for environmental ethics, it is not always clear what it can mean as a theoretical construct. An essential characteristic of a theoretical construct is that it is open to rejection, by being unable to handle or accommodate specific research data. But again, it is unclear what kind of data could lead to the rejection of biophilia – except maybe the (ridiculous) claim that people do not have an emotional affiliation with any natural element whatsoever.

In essence, biophilia is often employed as a descriptive notion that ties together some of the central issues of different research fields. Take the example of the savanna hypothesis. While this could be considered as an expression of biophilia, both the genetic and the affective claims inherent in this hypothesis can be meaningfully explained by a combination of landscape aesthetics and habitat theory. One can question whether it is fruitful to put a new concept like 'biophilia' into play here, especially since it does not add something more than the prevalent explanations. The biophilia hypothesis 'explains' such phenomena only inasmuch as it is backed up by these fields of research. It seems that biophilia is not really a theory, but an overarching or 'synthetic' concept for a body of research into (psychological) human attitudes and predispositions toward the natural world. It is in this (practical) sense that we will employ the notion in the following chapters. In particular, we will frequently use the concept 'biophilic architecture' to refer to architectural designs that are created in accordance with the findings that have been discussed in the current chapter.

6. Discussion

We have presented the reader a substantial amount of information, and it is therefore useful to recapitulate the main findings, and comment on them. First, we surveyed landscape-preference models, and the associated empirical research. It showed us that a specific set of structural landscape features are associated with aesthetic preferences. The most important features are prospect, refuge, complexity, coherence (or gross structural features), mystery (deflected vista) and legibility.

Second, we presented empirical evidence that humans display a positive affective relation with specific natural contents: especially with vegetation, vegetated settings, water-features and also with the (relative) absence of hazards. While it could be argued that our use of the term 'nature' was initially vague, these specific natural contents allow us to more clearly delineate our use of the notion. Interestingly, these natural contents and abstract structural landscape features seem to be crystallized in savanna-type landscapes. Third, it was shown that natural settings and elements have been found to induce restorative experiences in human individuals. Two types of restorative responses have been documented in the literature on landscape aesthetics, namely stress reduction and resting of directed attention. Fourth, a discussion was included about the possible neural correlates of these affective responses, based on findings from the field of cognitive neuropsychology and anthropology. In the final part of this chapter, the notion of biophilia was critically introduced as an overarching concept to summarize the body of research discussed in this chapter.

What this discussion essentially suggests is that we hold a positive affective relation with specific elements from our ancestral habitats. More specifically, typical natural objects and landscape organizations can lead to preferential reactions and higher positive affect, induce psychological and physiological stress reduction, and contribute to restoring directed attention. Due to the widespread, cross-cultural and consistent occurrence of these responses, there are strong reasons to assume that they have a (partly) genetic basis. *In se* it is unproblematic that we become to inhabit contexts that do not resonate with these inborn reactions. There is no (ontological) necessity why one should pursue contexts that are consistent with certain genetic traits, and to think so would be to commit the naturalistic fallacy. What is, on the other hand, problematic is that the literature on landscape aesthetics suggests that being unresponsive to this 'talent' (or set of talents) will have definite physiological and psychological costs, and can negatively impact aspects of our cognitive functioning and concomitant behavioural states. Therefore, from the viewpoint of human wellbeing and health, there are clear reasons to bridge the gap that is separating us increasingly from the natural world. The impact of our estrangement from nature was, among others, evident from the research by Kuo (2001). People living in an unnatural and barren architectural situation scored markedly less for certain indexes of wellbeing than people having views on nearby nature (e.g. tree group). A possible counterargument could be that the barren situation was architecturally very poor and unaesthetic, and it is therefore no wonder that it more negatively impacted wellbeing. However, instead of disconfirming the important influence of nature for human behaviour, this critique affirms one of the central points of this dissertation, namely that a visually rich and aesthetically pleasing architecture can positively influence certain aspects of human happiness.

Some shortcomings and difficulties need to be mentioned. For example, what is the specific relation between natural contents and abstract landscape configurations? And how can the informational model of the Kaplans and Ulrich's psychoevolutionary model be reconciled? Is there any overarching framework that addresses and integrates these issues? A possible inroad is proposed by Orians and Heerwagen (1992). They claim that both the Kaplans' and Ulrich's models should be considered in the light of the specific temporal order in which habitats are evaluated with regard to their habitability. In a first stage, there is an initial and immediate affective stance toward the setting, which guides the organism to further explore it, or to move on to other areas. These responses depend on the presence of some of the preferenda proposed in Ulrich's psychoevolutionary model. If the outcome of the first stage is positive, then the next stage follows, which entails gathering more information about the safety and about the availability of resources of the selected habitat – qualities which seem to depend more on cognitive evaluations. Here the predictors of the Kaplans play a more prominent role: 'Features of the environment important to this stage [are] … complexity, surprisingness, novelty, and incongruity. Other abstract features, such as "mystery" … patterns … and repeated or "rhyming" patterns … can entice exploration by providing inducements to gather information in an environment that is complex enough to be promising but not so complex as to be "unreadable" (564). Still, while this temporal account is plausible at first sight, it should be recalled that Ulrich's preferenda overlap to a large extent with the Kaplans' informational predictors. It thereby remains unclear whether a feature such as 'complexity' belongs to the first or second stage of the process of evaluating a setting. It should be mentioned that these and other theoretical difficulties remain largely unanswered by the main theorists on landscape aesthetics. Instead, it seems that their attention has shifted to the possible practical applications of the empirical findings (e.g. Ulrich & Zimring, 2004).

In the models of both the Kaplans and Ulrich, the focus was mainly on generalities in responses to landscapes, and not so much on individual and cultural differences, which do exist. In particular, Agnes Van Den Berg has performed research on the interindividual differences in nature appreciation, and found that these can be explained by the specific life-goals and needs of a person. Specifically, it seems that people who are in search for personal growth are more attracted to rough nature, whereas people in need for safety prefer well-tended nature more (e.g. Van Den Berg, 2004). Other support for the interaction between the biological and the cultural comes from Balling and Falk (1982). They hypothesized that familiarity with certain biomes interacts with inborn biological preferences, and makes that adults do not prefer savannas over other types of biomes. Today, the widespread destruction of nature shows that biological tendencies, such as the preference for vegetative life, must in some sense be overridden by nonbiological –

i.e. personal, cultural, economical – factors. These straightforward observations make it clear that there must be complex interactions between the biological and the cultural level. Still, what seems clear from the models of landscape aesthetics, and especially from Ulrich's psychoevolutionary framework, is that biophilic reactions are the initial stance towards certain landscape configurations and natural contents. It is on this level that we hope that biophilic architectural creations will 'do their work'. While it is true that in later stages of cognitive processing these responses can be inhibited by cultural or personal factors, such affective attitudes still take place initially. Furthermore, it is a challenge for architects and designers to make architectural creations that resonate with *both* the biological and cultural level of preference.

A final word is needed on the genetic claims that have been made. First, it must be noted that our discussion about possible neural correlates of biophilic responses was quite speculative, and that the debate about the specific organization of semantic memory is still ongoing, and hence controversial. Still, when this research and the other empirical findings are taken together, there are indications for a genetic basis of our preference for nature. Yet, it remains a matter of debate how strict this genetic component should be understood (see e.g. Geary & Huffman (2002) for an in-depth discussion of this issue). On a strong interpretation, the domain specific mechanisms that have been surveyed could be interpreted in terms of (a set of) cognitive modules (e.g. Pinker, 1994). However, it is equally possible to adopt a more soft approach, such as biological preparedness, where a more prominent role is attributed to experience and culture (e.g. Cummins & Cummins, 1999). Whatever the outcome of these discussions, it seems that humans have a (partly) hardwired predilection for naturalness, and there are no direct indications that such a predilection exists for, say, cars, guns or mobile phones. This biological component implies that the choice for certain aesthetic interventions in our surrounding environment cannot be trivial, random or merely a matter of tastes. On a 'biological' level (if this level could be separated from the cultural in the first place) the brain seems to have some preferences with regard to habitability, and it is these preferences that we want to give nontrivial architectural implementations.

Chapter 2

Inducing biophilic responses with nature-based architecture

1. Introduction

Ideas about nature are often integrated in architectural theory and discourse. For instance, the ideas of 'wholeness' and 'purposive unity', which are sometimes believed to be typical of living things, have taken in a prominent place in the arts, and in architecture in particular, since Plato and Aristotle (Steadman, 1979; Van Eck, 1994; Orsini, 1972; Grabow, 1995/6). More recently, metaphors referring to natural growth and evolutionary processes have found their way into modern architectural theory. For example, Frank Lloyd Wright describes the process by which a function searches a suitable form in terms of the 'organic' (Collins, 1998), and refers to the result of this process with the notion 'efflorescence' (Gilbert, 1957). Furthermore, in recent architectural discussions the notions 'zoomorphic' and 'biomorphic' are often identified with architecture consisting of irregular and curvilinear shapes (Aldersey-Williams, 2003). Biological analogies have also found their way to what is known as 'green' architecture (Toy, 1993; Wines, 2000), because like organisms, such buildings are economical and self-sufficient in their energy provision.

While biophilia, used as a synthetic concept, can undoubtedly form a part of the explanation for the architectural appropriation of nature-concepts, in this dissertation we mainly focus on the formal side of our affective relation with nature, and its implications for architecture. This focus is perhaps more urgent from the viewpoint of human wellbeing because our relation with the natural world has an eminent visual, and hence formal, component. It is therefore worrisome that it is predicted that by 2030, 60 percent of the world's population will inhabit urban environments. Whereas this evolution undoubtedly puts enormous pressures on natural ecologies, it will also lead to a further reduction of direct visual exposure to the natural world. It remains an open question of what the urban architecture will be like. However, the fast rate at which urban settings become the human habitat *par excellence* makes it questionable whether there will be enough finances, and let alone time, for important aesthetic considerations. In the following sections we will propose that urban settings can be aesthetically enhanced by including and mimicking some of the elements that were present in our ancestral habitats. In essence, it will be argued that so-called 'biophilic' design interventions (i.e.

architecture that implements findings from the previous chapter) can induce some of the biophilic responses that are associated with naturalness.

2. The value of nature-based design interventions

2.1. Creative effects of contact with natural form

It has already been noted that Wolff et al. (1999) found that decreased direct exposure to the natural world has important effects on cultural expressions of nature. In particular, a study of the Oxford English Dictionary indicates that certain folkbiological concepts (e.g. 'tree') evolved from the 16th until the 19th century, but from the 20th century onward, the use of such terms devolved, and their application lost precision. Such trend probably has nontrivial creative effects. While Elizabeth Lawrence (1993) argued that reduced exposure to the natural world would probably lead to an increase of animal symbolism in human linguistic expressions – as a sort of compensatory strategy – this research clearly indicates a reverse movement.

It is plausible that, besides such an impoverished *conceptual* and linguistic framework for natural objects, reduced contact with nature can also lead to 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 could become narrower. The reason is that natural form can be considered as a creative or compositional grammar, which can be employed for creating artwork. Peter Stebbing (1998, 2003, 2004), for example, has argued how only a limited set of organizational constituents (contrast, pattern, symmetry, proportion, unity) underlie natural shapes. These constituents form a kind of compositional vocabulary that can be used for creating artwork. Similarly, Simon Bell (1999) holds that a limited number of core patterns can be recognized in the seemingly unlimited number of natural forms (spirals, meanders, branches, explosions, packing and cracking). Stephen Kellert (1997) puts forward a similar idea: 'The aesthetics of nature can function as a kind of monumental design model. These environmental attributes suggest proven pathways of success in a multiplicity of shapes and forms. By discerning beauty and harmony in the natural world, we advance the belief and sometimes the understanding of how certain configurations of line, space, texture, light, contrast, movement, prospect, and color may be employed to produce analogous results in the human experience' (Kellert, 1997, 36).

The loss of this 'monumental design model' can now be witnessed in modern urban settings, which are increasingly governed by Euclidean geometry and stripped of ornament, patterning, detailing and colour. Architectural references to nature can help in putting an end to these non-natural form languages. By encouraging architects to integrate natural form in their work, they are motivated to study nature's shapes and compositional rules, and this can enrich their creative curriculum. At the same time, exposure to architecture that draws inspiration from natural form grammars can elicit interest and fascination, which can form the 'seed' for exploring similar creative strategies. Note, finally, that the current plea for the more 'traditional' study of natural form implies a departure from educational programs that give a dominant role to the conceptual in art and design education (Stebbing, 2003).

2.2. Epistemological effects

Besides having creative consequences, reduced contact with natural form could also subtly influence the way in which people think about the world. Irrespective of issues pertaining to the specific causes of category-specific deficits (see chapter 1, section 4), inquiries into semantic memory indicate that perceptual features are important for processing conceptual information about living things, while functional characteristics are central for knowledge about nonliving things (Crutch & Warrington, 2003; Farah & McClelland, 1991). These findings could have important implications. The presence of nonnatural things, and especially artefacts (e.g. cell phones, computers, chairs, pots, printers, and so on), 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 type of 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 scarcer or more underdeveloped.

Interestingly, the transfer of knowledge between domains is sometimes entertained to explain specific behaviour patterns. For example, Kelemen (1999) discusses research that indicates how children tend to reason 'promiscuously' about natural entities in teleological terms. One of the possible causes, she argues, is their constant exposure to artefacts, for which reasoning in terms of 'use' is most apt. Thus, here we can (tentatively) witness a transfer of functional knowledge into the biological domain. Transfers of knowledge are also clear from studies of human folkbiology. It is found that children, living in modern urban settings, reason about biological kinds (i.e. animals) in terms of human psychology, while children living in close contact with nature do not display such ways of thinking. A plausible explanation is that humans are more or less the only biological entities with which children have profound contact, hence the transfer of psychological concepts into the domain of (folk)biology. While this does not demonstrate the conflation of the domains of living things and artefacts, it nevertheless hints at the conceptual probability of such knowledge transfers.

Steven Mithen (1996) has explained knowledge transfer in terms of 'cognitive fluidity'. In essence, this concept implies that the human mind consists of a set of specialized cognitive modules, and the information belonging to these modules can be mutually shared. For example, racist attitudes and thinking could be considered as a sharing of information between the 'social' module and the module for technical knowledge. In particular, such thinking is a conflation of 'thinking about objects' and 'thinking about humans', leading to thinking about humans in terms of 'objects to be manipulated'. Mithen suggests that we have no predilection to display such cognitive behaviour, sometimes we just do so. Mithen's framework could perhaps explain why we think about the natural world in functionalist terms. In this regard we could claim that the information in the module dedicated to natural entities is insufficiently rich, and is in some sense taken over, or 'rectified', by accessing technical knowledge. There is perhaps a tendency for this to occur with a frequency above chance, because there is an essential imbalance in the 'richness' of the contents of the modules.

While functional postures are important and necessary in certain fields, the racist example shows that their transfer to other domains or contexts can prove highly 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 even shifts the balance 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 – for example, by nature education. This could help people realize that functional thinking is not always desirable when it comes down to nature. (For example, becoming aware of the fact that the short-term economic benefits that are gained through 'blind' woodcutting do not weigh up against the long-term damage that is caused by such interventions (e.g. greenhouse effect)).

While being more speculative, it is also probable that integrating naturalistic elements in architecture[5] can counteract the increasing dominance of functional semantic networks and the associated epistemological attitude. Admitted, people will not consider biomorphic architecture or design as actual nature. However, biomorphic architecture shares some essential formal features with living things, and research indicates that perceptual features are important for recognizing living

[5] In the following sections and chapter, we will also refer to such type of designs in terms of 'nature-based' or 'biomorphic' architecture. The notion 'biophilic architecture' refers to architecture that attempts to trigger biophilic responses in subjects.

things. The upshot is that 'nature-based' 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, due to the hardwired emotional affiliation with naturalness, nature-based architecture can awaken fascination for natural forms. Such an attitude could be ecologically relevant, because it is found that proenvironmental behaviour is positively influenced by emotional states toward nature (Hartig et al., 2001; Kals et al., 1999).

Note how this line of reasoning implies a departure from one of the central aesthetic principles of modernism, namely that a building's functions should be readable from its form or layout (recall Mies' credo 'form follows function'). While this view has been criticized on empirical grounds (Nasar et al., 2005), the current argument acknowledges the importance of a certain independence of the form from function for epistemological reasons. In order to provide a counterweight against functional stances, designs could be created in which the sculptural effect plays an important role, and where the function is not readily perceivable, or where it goes hand in hand with the form. There is reason to believe that this can be eminently done by drawing (architectural) inspiration from natural forms, because the latter are also processed with regard to their perceptual features. Take the example of a column with strong formal similarities with a tree. It is quite probable that this structure still will be recognized as having a function – i.e. bearing a load – and hence functional concepts will tend to get activated. On the other hand, due to its naturalistic outlook, concepts surrounding the notion 'tree' will also become active – for example: canopy, branches, stem, forest, leaves, bark, and so on. If the structure has very conspicuous biomorphic features, then the latter semantic field will perhaps gain dominance over the former.

2.3. Emotional effects

Without a doubt people can get used to less formal diversity and naturalness in the built environment, even without being aware of it. However, such impoverishment is not desirable because it can have negative effects on our physiology and psychology. Peter Kahn (2002) makes the following comparison to clarify this conclusion: 'Imagine that your favourite food item is the only source of an essential nutrient and that without it everyone suffers from low-grade asthma and increased stress. Now imagine a generation of people who grow up in a world where this food item does not exist. In such a world, it would seem likely that people would not feel deprived by the absence of this tasty food (it was never in their minds to begin with) and that they would accept low-grade asthma and increased stress as the normal human condition. Nature is like that food. A wide variety of literature, which has come under the rubric of biophilia, shows that direct positive affiliations with nature have beneficial effects for people's physical, cognitive, and emotional well-being' (Kahn, 2002, 109-110).

Indeed, 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 certain adaptive reactions (e.g. flight, approach). 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 (among others) by a mix of complexity and order (Kaplan, 1987, 1988; Ulrich, 1983). Yet, current architectural settings do not always appeal to this ordered complexity. Modern architecture mainly consists of simple volumetric forms, and thereby 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 (figure 30). Furthermore, today building is often dictated by efficiency and economic motives, barely leaving place for symbolic and stylistic references to natural contents (e.g. ornament) (Salingaros, 2003). In this regard, Pinker (2002) notes that '[i]n [modern] architecture, ornamentation, human scale, garden space, and traditional craftsmanship went out the window (or would have if the windows could have been opened), and buildings were "machines for living" made of industrial materials in boxy shapes' (410).

Figure 30: Frank O. Gehry's Weisman Art Museum (Minneapolis, Minnesota). Although this building is a complex structure, it seems to lack coherence.

Given the review of brain research presented in the previous chapter, one could even argue that the gradual removal of natural form from modern settings leads to environments that resonate with the experiences of patients with a category-specific deficit for perceptual properties of living things. Indeed, they have difficulties in processing perceptual features of living things, and by removing such elements from the built environment, their pathology is in a sense circumvented.

Remarkably, a similar link between brain pathologies and the built environment is made by Salingaros (2003, 332). He claims that there is an important '… resemblance between minimalist or disordered built environments, and the perception of a normal, visually complex environment by persons with a damaged perceptual apparatus … different types of injury to the eye and brain result in precisely the same effects offered by either minimalist or intentionally disordered design'.

Figure 31: The daily routine of driving to work sometimes has not much naturalness to offer.

In short, much of the modern built environment is fundamentally devoid of (architectural references to) the contents and structural organization that are characteristic of a good habitat: '… they *lack* the icons of habitability, or, as Ulrich has suggested, environmental preferenda…' (Parsons, 1991, 16) (figure 31). The upshot is that exposure to such environments could rapidly and automatically trigger negatively toned feelings – a conclusion that has found empirical support in studies by Korpela et al. (2002) and Hietanen and Korpela (2004). In the previous chapter we have presented evidence that the probable locus of such initial affective responses – the amygdala – is also responsible for the release of stress-related hormones. While negative affective reactions could go by largely unnoticed due to their precognitive character and due to our habituation to nonnatural environments, their long term occurrence and concomitant physiological stress responses could have important health effects. Parsons (1991) puts it as follows: 'Though such stimuli may be consciously suppressed, their effects are not … [I]t is possible that repeated low-level elevations in stress hormones (and stress-related autonomic responding) may occur, even though a full-blown stress response has been quashed from above. If so, immunocompetence and cardiovascular functioning may be compromised, albeit slightly, and over long periods deleterious health effects may emerge' (16). Consistent with this, Eleonora Gullone (2000) hypothesizes that the discrepancy between 'how we live' and 'who we are' may well be responsible for the increase in psychopathology (e.g. depression, schizophrenia), which can be witnessed in westernized societies: '… despite the very different environment in which we now live, our species' evolution continues to significantly dictate aspects of our behaviour. … cultural beliefs and practices that are inconsistent with our evolutionary constitution and physical environments that stray too far from that in which we evolved may compromise our psychological well-being. In other words, having only limited opportunities available in the modern environment to express our biophilic tendencies may impact negatively upon our psychological functioning' (Gullone, 2000, unpaged).

The core argument of this dissertation is that, by including elements of ancestral habitats in the built environment, these potential deleterious influences can be countered, resulting into more positive affects and more relaxed physiological and psychological states. In the following sections and chapters, such architectural interventions will be referred to in terms of 'nature-based' or 'biophilic' architecture. In neurological terms, we believe that biophilic architecture can activate the specific neural mechanisms that are specialized in processing information about natural entities. Because of the clear survival value of quickly recognizing and categorizing biological entities, it is probable that such representations will also activate the neural correlates of affective responding.

3. Integrating structural landscape features in architecture

It may seem awkward, but Heerwagen (2005; see also Salingaros & Masden II, 2006) notes that there is a parallel between the current argument, and the evolution of the design and layout of zoo-settings. Traditionally, animals were kept in cages. Admittedly, such structures could keep the animals alive, but it couldn't make them thrive. In fact, caged animals often display neurotic and antisocial behaviour. However, there has been a transformation from the traditional cage, to more naturalistic habitats, where mixed species coexist: '… the animals are free-ranging and the visitors are enclosed in buses or trains moving through the habitat. Animals now exist in mixed species exhibits more like their natural landscapes. And, as in nature, the animals have much greater control over their behavior. They can be on view if they want, or out of sight. They forage, play, rest, mate, and act like normal animals' (Heerwagen, 2005, unpaged). To put it crudely, we believe that the modern built environment is like the traditional cage. It answers some basic needs, such as providing shelter, but it often remains unresponsive to our inborn environmental and aesthetic preferences. This situation can be overturned by including elements that were typical of ancestral habitats in architecture.

Recall how research shows that the presence of certain structural landscape features positively influences the aesthetic appeal of (built) settings. A central question is how these qualities can be meaningfully applied to the built environment. This is a more difficult issue than applying well-defined natural contents to architecture, because structural landscape 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. For example, Heerwagen repeatedly notes that the predictors 'complexity' and 'order' are qualities that can be applied to biophilic design, but she does not explain how exactly this can be done. With the following discussion we hope to bring some clarity in these issues, and propose some practical guidelines that can be implemented by architects and designers.

3.1. Savanna

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. Interestingly, a review of an experiment for the Herman Miller Knowledge Resource Group (Herman Miller Inc., 2004) indicates that individuals performing tasks in a workstation that conveyed qualities of a savanna landscape, performed better for creative problem solving than individuals who worked in a workstation that was either plain grey or covered with geometric motifs. This finding underscores the value of using such representations, and is consistent with research on the positive effects of nature contact on cognitive functioning (e.g. Hartig et al., 2003).

While using photos is a possible method, a savanna can be mimicked architecturally by imitating some of its key structural features. Possible strategies are:

- creating wide and open spaces
- making variations in the architectural topography (e.g. balconies that overview the setting)
- integrating clusters of real or symbolic trees (e.g. columns)
- integrating a water feature (e.g. a fountain) or even a small fire
- integrating wildlife (e.g. birds)

Note how certain retail settings – such as shopping malls – often contain these elements (figure 32). 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).

Figure 32: A shopping mall often contains some typical savanna features, such as discrete trees or tree-groups, a water-element, wide and open views, topographical opportunities to overlook the setting (through balconies), and so on.

Figure 33: Detail of Frank O. Gehry's Experience Music Project (Seattle, Washington). The glistening characteristics could evoke associations of wetness and water.

Biomes such as savannas are seasonally arid, so it was essential for hominins to be sensitive to visual information that provided cues for the presence of water, such as glistening characteristics. It is not implausible that specialized pattern-recognition mechanisms have evolved to perform such tasks (Coss, 2003). In his review, Coss (2003) provides evidence that humans are perceptually attracted to glistening and reflective features. Specifically, toddlers (7-12 months) are found to display licking and mouthing behaviour for glossy surfaces, while this is more infrequent for surfaces with dull finishes (see also Coss et al., 2003). Coss (2003) further notes that '… it was not infrequent to observe toddlers on their hands and knees mouthing and sucking the center of the glossy plate as if drinking from a rain pool' (88). Glossy and sparkling surfaces are also found to evoke (semantic) associations of 'wetness' in adults (Coss, 2003). Importantly, Ulrich (1981) found that water-features play a major role in reducing stress, and inducing relaxation in subjects. If shiny, glistening patterns are a cue for the presence of water, then these can provide designers with a design strategy to attract attention and interest, to cause aesthetic reactions, and possibly to contribute to stress-reduction (figure 33).

3.2. Prospect, refuge and hazard

Due to their openness, savannas provided good prospects on the surrounding area. Furthermore, trees typical of savannas 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. Importantly, Grant Hildebrand (1999) employs the notions '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 organisations influence the prospect and refuge dimension of buildings. He notes the following about Frank Lloyd Wright's house in Taliesin (Wisconsin): 'Deep overhanging eaves, alcoves and recesses, the withdrawal of the house in the dense foliage, 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 '(28). As is evident from this quotation, feelings of prospect and refuge can be evoked by specific architectural interventions:

Strategies for evoking refuge:

- Enclosing spaces by thick walls.
- Lowering ceilings.
- Making small windowless spaces.
- Reducing lighting conditions
- Integrating the building in close and dense settings (e.g. a forest).

Strategies for evoking prospect:

- Bigger space dimensions.

- Raised ceilings.
- Thin transparent walls.
- Wide views on surrounding spaces.
- Building on an elevated site, or creating balconies.
- Increased lighting conditions.
- Tall buildings.

Figure 34: Prospectless office cubicles.

Evidently, one of the primary functions of architecture is to provide refuge, by being a shelter. Most buildings also have a prospect dimension, because they have windows or openings that allow visual access on the surrounding setting. In this sense, Hildebrand's treatment could be criticized for being quite trivial. On the other hand, these issues need perhaps be made more explicit, because modern buildings often seem to lack one or the other dimension. For example, it is not infrequent for modern offices to have no windows, or to 'imprison' the employees in 'prospectless' cubicles (figure 34). Apart from the frustration of having no meaningful prospects, such interventions also deprive workers from daylight, and the associated health benefits.

Figure 35: Le Corbusier's Villa Savoye (Poissy, France).

A further reason why a discussion of prospect and refuge is worthwhile is the observation that these features can be *augmented* in architecture. An augmentation of one of these 'vectors' can lead to a relative dominance of prospect over refuge, or vice versa. Hildebrand (1999) notes that most of Wright's buildings are refuge dominant: '… there is a paramount urge to snuggle up in spaces of peerless coziness' (39). Contrary to this, it can be noted that Le Corbusier's architectural work is mainly prospect dominant. This is, among others, clear from the large window expanses and the terraces of his Villa Savoye, which offer broad panoramic views on the surrounding site (figure 35). The variation of these two vectors can be important if it is realized in one and the same building, because it can thereby respond to an individual's changing needs and moods. Refuge-like spaces can respond to an individual's need for resting, healing, meditating, and so on. Prospect dominant spaces are utile when a person is in need of light or of sensorial stimulation. Ideally, an architect should take in account the personality and wishes of the future inhabitant, and adapt the amount of prospect and refuge of the building to these. (For example, a person performing demanding intellectual work might benefit most from a predominantly refuge-like setting that offers only sparse opportunities for prospect.) Finally, note that the aesthetic effect associated with the augmentation of prospect or refuge can be linked to the field of 'neuroaesthetics', where it is claimed that the exaggeration of certain traits is an important aesthetic principle (Ramachandran & Hirstein, 1999; see section 4.3 of this chapter).

Figure 36: Wright's Fallingwater, Pennsylvania.

It was not only adaptive for early humans to be sensitive to the prospect and refuge dimension of landscapes, but also to cues of dangers or hazards (Ulrich, 1983). Think for example of turbulent water, heights, predators, or signals of impending bad weather. Paradoxically, the recognition of such hazards seems to elicit fascination and aesthetic attraction in humans. A plausible explanation is that this recognition can imply that the hazard is controlled or handled, and that the individual is in safety. Architecturally, the aesthetic attraction of certain buildings could well derive from their hazardous or perilous character (Hildebrand, 1999). Most evident examples are buildings that are situated on an elevated site or buildings that are very tall themselves. While their attraction could be due to their prospect dimension, such buildings can also be fascinating because they evoke the danger of falling. An eminent example of 'perilous' architecture is Frank Lloyd Wright's Fallingwater (figure 36), exploiting the danger associated with heights and turbulent water: 'The balconies reach out into space, and because of prior knowledge, but also because their hovering character is recalled by the similar forms all around, there is the perceived danger of falling – and below is the ravine and the falls itself … So the prospect-claiming terraces, with refuge behind, are also perilous precipices over space and over the falling water and the rapids' (Hildebrand, 1999, 71-72).

3.3. Order and complexity

There is an evident way in which the notions 'prospect' and 'refuge' can be linked to the predictors 'complexity' and 'coherence', central to the preference matrix of the Kaplans. Only a setting that contains enough prominent landscape features (e.g. trees, rocks) can provide sufficient opportunities for refuge. On the other hand, if a setting contains too much elements then this makes it difficult to have a clear prospect over the landscape. Although complexity and coherence have primarily been applied to landscapes, there is empirical evidence that a balanced presence of both properties positively contributes to the aesthetic qualities of built settings (e.g. Herzog et al., 1982; Wohlwill, 1980; Imamoglu, 2000).

Figure 37: When complexity is defined as the number of elements that is present in a setting or an array, then there is an obvious increase in the complexity in these building façades, from the lower right to the upper left.

Philosophically, the notion 'complexity' has many semantic associations. However, in environmental psychology the notion is straightforwardly interpreted in terms of the amount of elements that a particular scene contains: 'Complexity is defined in terms of the number of different visual elements in a scene; how intricate the scene is; its richness. It thus reflects how much is going on in a particular scene, how much there is to look at…' (Kaplan & Kaplan, 1989, 53). If this definition of complexity is applied to the series of houses depicted in figure 37, then there is an obvious decrease in architectural complexity, when starting from the upper left image.

There is an upper and a lower limit to the degree of complexity which an aesthetically pleasing scene should contain. However, in environmental psychological experiments, the degree of complexity of a scene is often determined by a panel of experts, and the measure therefore remains largely quantitative. This leads to the difficulty of how an individual architect should interpret the notion 'moderate', 'high' or 'low' complexity, when he or she wishes to implement the current theories architecturally. In the next chapter a possible solution to this issue is proposed by means of a quantitative notion, namely the 'fractal dimension'. Another issue is the observation that, while complexity contributes to the aesthetic appeal of a scene, it should go hand in hand with 'coherence'. Complexity should be ordered to maximize the aesthetic appeal of a scene. But how can these qualities be successfully applied to an architectural creation? Once again, take a look at the work of Frank Lloyd Wright. Together with Louis Sullivan, Wright can be considered as one of the founding fathers of organic architecture. Although not being a necessary feature, buildings belonging to this tradition are often quite irregular and complex, both in plan and elevation. Yet, organic architects sometimes use a geometrical 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).

Still, it could be noted that repeating similar architectural elements or modules does not guarantee an ordered complexity. On the contrary, it can even lead to random structures, like in deconstructive architecture. We are therefore in need of what Ulrich (1983) calls 'gross structural features', which enhance the structuring and organization of a scene, and thereby facilitate its understanding. A possible solution is grouping these (similar) elements along the lines of some of the Gestalt Laws, or by creating patterns with them. The latter can be created by 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 38). Traditionally, patterns take in a prominent place within the organic tradition (figure 39). Throughout history, they are also found in tiling, ornaments, mosaics, stained glass windows, (oriental) carpets, and so on. Other factors that can influence the coherence or 'harmony' of a set of architectural elements are: using similar forms for distinct shapes; connecting forms piecewise; harmonizing colours (Salingaros, 1997).

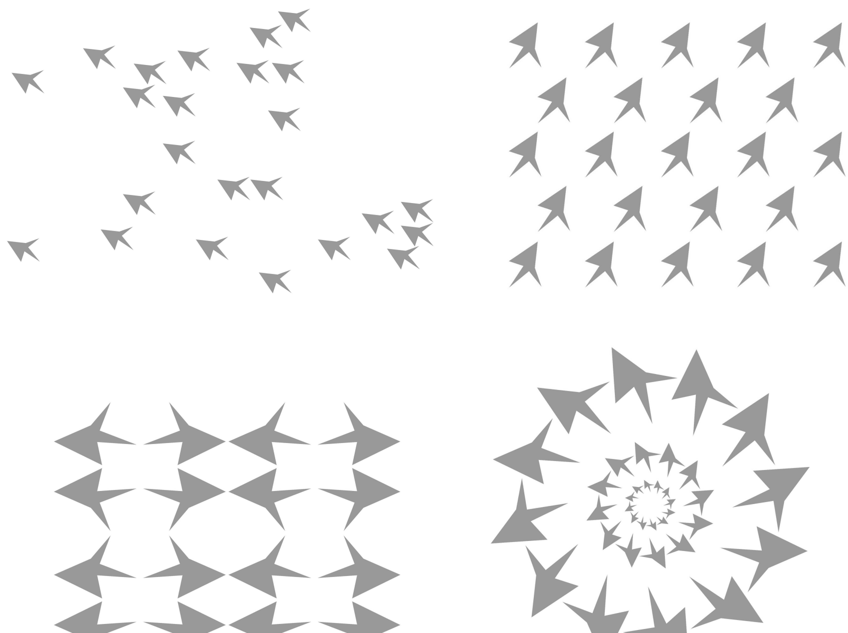


Figure 38: Patterns can be obtained by some simple mathematical transformations (Salingaros, 2003). In clockwise order: randomness, translational symmetries, rotational symmetries that are nested, reflectional symmetries.

Figure 39: Characteristic patterns of the stained-glass windows of Wright's Robie House.

Hildebrand (1999) argues that the ability to recognize complex objects promoted fitness, because it facilitated the differentiation and categorization of many natural entities: predators, conspecifics, and sources of food. This made the organism capable of extracting order from a complex world, so that the information with which it was confronted could be meaningfully understood. Although Hildebrand seems to evoke the Kaplans' preference matrix in his discussion of complexity and order, there is an essential difference in his interpretation of the notions. His understanding of 'ordered complexity' seems more akin to 'likeness tempered with difference', while the Kaplans consider complexity as a measure of the amount of information. Hildebrand illustrates his interpretation by referring to a Gothic church, whose ordered complexity lies in the fact that similar formal elements reappear throughout the building. Yet, these elements are not identical but always different; they are variations of a common theme (e.g. an arch). This also applies to the organization of traditional town- or streetscapes: 'Any street in an Italian hilltown or Cotswold village could illustrate similar repetitive characteristics … [these present] to the eye seemingly repeated elements and seemingly repeated intervals – doors, windows, dormers, gables, chimneys – whose multitudinous minor variations make each iteration as different from any other, and as alike, as individuals of the same species' (112). Perhaps these descriptions remind the reader of fractals and fractal rhythms. Indeed, similar to 'likeness tempered with difference', fractals are often characterized by the repetition of ever slightly different elements.

Hildebrand notes that the permutation of one common theme – and hence, complexity – can also be a function of movement or memory. Because the common themes can be spread throughout the building (in adjacent spaces) they can sometimes only be discerned by moving from one space to another. Sometimes these themes need even to be memorized, when they are not situated in subsequent spaces, but when they are spread throughout the architectural setting. Hildebrand thereby profoundly departs from the Kaplans' understanding of complexity. In the latter, complexity relates to the two-dimensional projection of the scene on the retina, and is not a function of time or movement. Furthermore, it should be noted that Hildebrand is an expert in the field of architecture, and that he probably has an eye for architectural similarities, spread throughout a building. However, it is questionable that someone who is architecturally untrained will notice these similarities.

3.4. Mystery and legibility

A final 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 artefacts can create a little mystery and surprise in the workplace' (Hase & Heerwagen, 2000, 30). Perhaps, the most straightforward way to apply mystery to an architectural setting is by deflected vistas. When the architectural 'trail' bends away, this can lead to curiosity of what might lie behind the bend, and thereby motivates to explorative behaviour. Mystery is also often a feature of the historical centres of traditional towns. Here the buildings have not been placed according to a strict geometric masterplan, but they have grown 'organically' around and next to existing buildings.

Interestingly, it seems that the organic tradition (associated with Wright) puts much interest in the notion of mystery. John Rattenburry notes that '[c]entral to the philosophy of organic architecture is the idea that there should be a sense of discovery of space. This discovery starts at the entrance to a building. Rather than scaling the front door of a building to a heroic level to impress the person who enters, the entrances we design are usually underplayed. This is where the element of human scale is first established. The entrance should not lose anything in quality, but just as a good novel does not reveal its plot on the first page, the space experience becomes a series of discoveries as one moves into the interior. Architecture is much more interesting if the arrangement of spaces is not too obvious, if there is a surprise and mystery around every corner. The unexpected space experience can add charm and appeal, so a space should seldom be seen in its entirety' (Rattenburry, 2000, 50).

The notion mystery can be related to the dynamical and free organization of the organic space. Such organizations entail a rejection of the classical axial ordering, which leads to a fundamental shift in the observer's experience of the organic architectural environment, sometimes denoted as 'a-perspectivism'. The latter term refers to the fact that one cannot grasp the building anymore from one fixed or absolute point, but that it can only be perceived by taking in a range of different, relative viewpoints. Or as Kuz puts it: 'The physical experience [of the building] is not a hallucination, but a reality that is hard to grasp. There is no point of photographic representation of this space; it is in a constant flux' (Kuz, 2003, 37). Goff too, expresses a similar thought: 'If we are inside the building, we only see the part we are in. The design is moving on someplace else, usually. That is why it is so difficult to photograph architecture, because it is always moving, always changing, in relation to the viewer...' (Goff, in Welch, 1996, 246-247). (Note that the presence of mystery and surprise in an architectural setting is not a quality that is exclusive to historical architecture, or to organic architecture. For example, the modern Austrian planner and architect Camillo Sitte's is well-known for his urban planning that departs from a rigid geometric organization. Instead, he advocated curved and irregular street alignments, which inevitably lead to experiences of mystery.)

Another mode of mystery is called 'enticement'. Essentially, this notion refers to the situation where a subject 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 behaviour: 'The column forest and the complex superstructure of the Great Mosque at Cordoba serve too as intervening foliage … partially obscuring from view rich information ahead in a brightly lit clearing. Exploratory intuitions urge us toward the light; our reward is the informational richness of the mihrab…' (Hildebrand, 1999, 55-56). Mystery can also be evoked when parts of a scene are blocked or when the subject is surrounded by architectural elements, from where only a slight impression of the scene lying further away can be apprehended.

While mysterious settings can be aesthetically appealing, too much irregularity or surprise can have the result that the layout of the building becomes confusing and intransparant, ultimately leading to orientation and wayfinding problems. Legibility can be enhanced by integrating signalisations and distinctive markings, by offering views on the outside, and by making the building shape more regular (Evans & McCoy, 1998). Yet, probably the role of legibility is context-dependent. For example, in very large buildings, such as hospitals, too much irregularity can have a cost, in that one can get lost. In contrast, the moderate size of most (one-family) dwellings does not allow one to get really lost, and wayfinding errors can be rectified very quickly.

4. Architectural implementations of natural contents

4.1. Integrating natural contents in the architectural context

In the following sections some further architectural design interventions will be proposed that can help in overcoming the discrepancy between the current modern living environment and our specific 'hardwired' environmental preferences. The central question is how specific natural contents, such as vegetation, can be architecturally integrated in the built environment. According to Stephen Kellert (2005), a first and obvious strategy is to offer the possibility for a 'direct experience' of nature. This direct experience can be realized according to different design interventions:

- Natural lighting and ventilation.
- Integrating plant life in the built environment.
- Providing views of the exterior (natural) environment.
- Exposure to water near or within buildings (e.g. fountains).
- Inclusion of (controlled) fires in a building.
- Integrating animals in the built environment (e.g. butterflies, fish, birds).
- Incorporating greenery on the building façade (e.g. vines, 'green roofs').

These guidelines come close to the findings of the field of 'Evidence Based Design'. This research field tries to come to specific design strategies, which are firmly rooted in (non-controversial) scientific findings from various research disciplines, such as the field of environmental psychology (e.g. Vandenberg & Van Winsum-Westra, 2006). Indeed, in the previous chapter we discussed how exposure to water-features, vegetation, and nonthreatening animals can positively influence the psychological and physiological wellbeing of subjects. These contents are found to dampen stress, lead to higher pain tolerance, and are associated with more positively toned emotional states. Mostly, Evidence Based Design is deployed in the context of hospital design, with the goal of fostering psychological and physiological correlates of wellbeing of the visitors, patients, and personnel. These are some of the central guidelines that are based on empirical findings from the field of landscape aesthetics:

- Offer the patients and visitors direct views of nature.
- Integrate potted plants and flowers in the hospital setting.
- Design green user-spaces.
- Provide pictures and images of nature, if direct contact with nature is not possible (e.g. in operation quarters (Vandenberg & Van Winsum-Westra, 2006).

Despite its solid scientific underpinning, Evidence Based Design is still not widely applied in healthcare architecture, and it is telling that some consider it as a 'once in a lifetime opportunity' (Ulrich & Zimring, 2004). Take the example of the recently finished Maggie Centre Fife in Kirkcaldy (Scotland), designed by 'star architect' Zaha Hadid. Maggie Centres are often situated near hospitals and are aimed at providing psychological sustenance and support for cancer patients, their families, friends and carers. According to Hadid (in Brown, 2006, unpaged), the new Maggie Centre in Kirkcaldy will '… encourage growth and recovery'. Yet, we believe that this aim is contradicted by the sharp-edged surfaces and piercing forms of the building. In later sections, evidence will be presented which indicates that such shapes can cause subtle stress-responses in individuals. Perhaps this building can provoke fascination and agitation by its unusual forms, but it is very questionable whether, such states are appropriate for people having experienced a very stressful, and sometimes life-threatening disease.

The Austrian painter, sculptor and (architectural) designer Friedensreich Hundertwasser (1997) seems to have been particularly sensitive to integrating actual natural elements in the built environment. A key-element in his architectural philosophy is that humans are estranged from nature. According to Hundertwasser, specific architectural interventions can close the gap that separates man from nature, and they can thereby help in putting an end to the self-destruction of man, and to the degeneration of nature. A possible intervention consists of integrating natural elements into buildings, which is '… an indicative symbol of the reconciliation between man and nature' (94). One such intervention is the architectural integration of so-called 'tree-renters', which are trees that are placed in rented building-spaces, and they are allowed to grow freely from windows and building openings. According to Hundertwasser this gives harsh and ugly buildings a more friendly and lively expression. Another strategy consists of designing buildings that are almost literally natural landscapes – think for example of the 'Flat-pasture-house'. On each storey of this 'apartment building' forests and pastures are planted. Such natural interventions have a range of (ecological) benefits. They provide shade and coolness, absorb sounds, and, to a certain extent, also purify the air. While Hundertwasser mainly emphasizes the ecological value of integrating natural elements in the built environment, our review of biophilic findings (chapter 1) shows that such interventions can also have nontrivial health-effects and can cause aesthetic responses.

Implanting a building in a natural landscape does not tell us something about the architectural form *per se*, and whether the latter in some sense displays key features of our ancestral habitats. For example, Le Corbusier's modernistic Villa Savoye is situated in a natural environment, while one of its ideological counterparts – organic architecture – also emphasizes embedding built work in a natural setting. However, it is evident that both traditions adhere to quite different form typologies, and these diverge in their responsiveness to our hardwired affiliation with naturalness. A (further) hint that some aspects of organic architecture are responsive to the human tendency for biophilia comes from the fact that this tradition is often interested in using natural construction materials: '... building materials come rather directly from the natural world, whether animal, vegetable or mineral' (Robinson, 1993, 10). For example, James Hubbell's chapel at Sea Ranch (California), is mainly composed out of wood, glass, stone and copper (Woodbridge, 1992). Similarly, Imre Makovecz, and other adherents of the Hungarian organic tradition, proficiently use natural materials in their work (Nagy, 1992; Gerle, 1985).

4.2. Literally imitating natural contents

While the integration of actual nature in built settings can prove very relevant from the perspective of biophilia, in this dissertation we are mainly interested in what Kellert (2005) coins the 'indirect' experience of nature. Essentially, this mode of experience concerns the question of how *architectural* references can be made to nature; i.e. which interventions can be made to the architectural *form*, as to make it look more natural. One of the central claims of this dissertation is that such 'architectural' natural forms will be accompanied by the same affective states that are evoked by real natural contents. A similar line of thought is expressed by Orians and Heerwagen (1992): '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 … tree canopies appear symbolically in many aspects of design, including sloped ceilings, trellises, awnings, porches, and building overhangs, particularly those with pillars. We predict that the presence of these "symbolic trees" is associated with positive response to built environments' (572).

While the positive impact of symbolic representations of nature could be *prima facie* plausible, it is problematic that it is often taken for granted in the literature on biophilic design. In fact, we believe that there is no research that has directly inquired this issue. Nevertheless, some indirect arguments can be presented that support the conclusion. First, it is evident that domain specific-mechanisms 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. More specifically, they will also be activated by elements that share some coarse geometrical features with the proper input of the domain specific systems. This is one of the reasons why a symbolic representation of a face, like a smiley-figure (☺), the front of a car, and even a rock formation (figure 45), can be perceived as having face-like features (Sperber & Hirschfeld, 2004; Pinker, 1997). Similarly, it is probable that the domain-specific 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. Due to the importance of quickly displaying adaptive behaviour to natural stimuli (e.g. exploration, escape, fighting) it is probable that at the early stages of processing already some affective processing or priming will take place, before any conscious recognition of the imitated natural elements occurs (Ulrich, 1983; see chapter 1).

Figure 45: The cognitive module specialized in detecting and recognizing faces, analyzes face-like representations, even if it does not involve a real face, such as this rock formation.

Further reasons for why imitations of nature can be accompanied by the emotional states that are characteristic of actual nature are more empirical in nature. First, it can be pointed out that research into environmental preferences often uses *simulations* of nature (e.g. photos, posters, videos and even paintings). The results that are obtained with these stimuli lie close to the responses associated with real nature. 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. An exception to such realism is mentioned in Taylor et al. (2003), in which a simplified or schematized representation of a savanna-type landscape is found to reduce stress more than a realistic picture of a forest setting (see chapter 3, section 4.3). Second, symbolic representations of nature (e.g. ornament) have been used throughout the history of art for aesthetic enhancements, which suggests that these can trigger biophilic responses. Third, recent research indicates that preferences for natural settings can (for a part) be statistically predicted by underlying geometrical characteristics, which lends plausibility to the claim that abstractions from nature can cause the associated emotive effects (Hägerhäll et al., 2004; see also chapter 3, section 3). Fourth, there is evidence that other (survival-relevant) stimuli retain their emotional content, despite profound simplification in shape. For example, exposure to simple configurations of line segments and dots, depicting a face-like pattern, are accompanied by the same kind of emotional and physiological responses, as when the subject is exposed to real faces (Aiken, 1998a). This, again, lends credibility to the claim that biophilic responses can be induced by symbolic nature-based art or architecture. Fifth, and closely related to the previous point, is the finding that in other organisms, formal abstractions of certain traits of survival-relevant stimuli lead to similar, or even stronger emotional responses, than the original (natural) stimulus (see section 4.4.1 of this chapter).

But if it is plausible that the integration of natural form in architecture can evoke the associated affective responses, then how should such integrations be conceived? A first option is to almost literally copy these elements in architectural design. As was already noted, there is an age-old tradition to copy nature – and especially floral and vegetal patterns – in traditional ornament (figure 46). Admittedly, it is possible that such imitations will not be very successful, since the associated emotional states could quickly be followed and suppressed by higher-order or cultural beliefs. This is consistent with Ulrich's psychoevolutionary framework, where initial rapid affective reactions towards typical preferenda are followed by slower and culturally-coloured responses. In fact, it is quite probable that, today, the architectural community will consider such architectural imitations as kitsch. However, it should also be noted that there is often a discrepancy between what is found appealing by experts and laypersons (e.g. Devlin & Nasar, 1989). Furthermore, the primary goal of this thesis 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. In this regard, we agree with Pinker (2002) who notes that '… if [people] … want to hang a painting of a red barn or a weeping clown above their couch, it's none of our damn business' (416).

Figure 46: Classical ornament or decoration often implies an almost literal imitation of natural elements.

This argument for including ornament in architectural design seems to be orthogonal to the minimalist form-typologies that are characteristic of modern building. As is clear from Adolf Loos' polemical essay *Ornament und Verbrechen* (1999) the use of ornament has sometimes been surrounded by quite some controversy. Specifically, Loos considers ornament as a sign of cultural and intellectual degeneracy, with negative effects on human wellbeing. Instead, he defended an aesthetic purism that banned the use of ornamentation. The above argument is completely opposite to this view. Because ornament often displays naturalistic features, it is tentatively argued that it can contribute to better human functioning (see also, Salingaros (2003) for a similar approach). Such a view cannot be considered as intellectually backward, but finds its origin in recent empirical findings from environmental psychology. It seems that the reproach of 'backwardness' applies most to Loos' own rhetoric. His predilection for aesthetic purism in architecture presupposes an outdated insight into the workings of human psychology, which we earlier referred to in terms of the 'blank slate' (Pinker, 2002).

4.3. Schematic imitations of natural contents

It would be intellectually unfair to reduce all ornament to literal imitations of nature. Sometimes ornament also displays 'schematic' imitations of natural elements. These are no longer exact copies, but artistic interpretations that still contain some essential visual similarities with regard to the original natural object (again think of a smiley as a schematization of an actual human face). As will be discussed below, such symbolic or schematic architectural appropriations are not only present in the local structure of the architectural environment, like in ornament, but they are sometimes also characteristic of larger architectural elements (e.g. columns), or even the whole architectural structure.

Apart from the aesthetic significance that can be conveyed through their 'naturalness', schematic representations of natural elements can also be artistically evocative because of their 'supernormal' character (for a further discussion of this topic, see section 4.4.1 of this chapter). While supernormal stimuli are found to play an important role in human and animal behaviour, Ramachandran and Hirstein (1999) have argued 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 rewarded for discriminating the rectangle, will respond more frequently to the rectangle. However, when the original rectangle is elongated, then the rat will respond even stronger to this new and 'exaggerated' rectangle than to the rectangle that it was taught to discriminate. The authors argue that a similar principle is often employed by artists: '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' (17).

Perhaps the most straightforward way in which this principle has been implemented in art is through caricatures or cartoons. For example, in the cartoon of Lance Armstrong, the cyclist's chin is made out of proportion, and his thighs, calves and butt are grossly exaggerated. In a sense, these amplifications capture the essence of a cyclist's body, and will probably lead to pleasant reactions and even aesthetic responses in the viewer. According to Ramachandran and Hirstein (1999), such amplifications are not only bound to occur along the dimension of form, but can also involve amplifications of textures, colour, motion, illumination, and so on. It is clear that, in the present discussion, we are mainly interested in the amplification of the architectural form.

4.3.1. Architectural implementations of vegetative elements

Ornament is often a very local feature of an architectural work. In this section we therefore turn to larger architectural elements that show some conspicuous schematic similarities with vegetative life. Such references seem to be as old as architecture itself. For example, in Egyptian architecture, the palm capital can be interpreted as a symbolic representation of a palm tree. In later periods, the Roman architect Vitruvius made the link between trees and the classical orders. In essence, he argued that the orders have evolved from a primitive hut, where the roof was held up by round tree trunks (Crow, 1999). Due to the evolution of architecture, the trees have been gradually replaced by their stone counterparts, and became stylized and ornamented. Thus, the orders are symbolic representations of tree trunks. The connection with trees is also often made in the context of Gothic architecture. As figure 48a shows, there is a very striking visual resemblance with tree structures. The columns can be considered as symbolic tree trunks, and the vaults can be interpreted as trees whose branching canopies are interlaced. (See also figures 49-51 for other examples of symbolic architectural trees.)

Figure 48: Schematic architectural trees. Interior of the Sagrada Familia.

Figure 50: Symbolic architectural trees. Central mosque in Rome, by Paolo Portoghesi.

In the late 18th century, the Scottisch geologist James Hall pushed the link with trees beyond the analogical, and 'experimentally' demonstrated the sylvan or timber origins of the Gothic by tying together pliant willow branches. Portoghesi (2000) describes Hall's system as follows: 'A row of equidistant poles of more or less the same height is fixed in the ground … But to each of these "Gothic poles", a surround of pliant willow rods is applied and fixed. When the opposite willow rods are brought together and tied, the resulting form is something like a groined vault, strong enough to carry a thatched roof, say. Small variations in the joining of the willow rods provide the models for varieties in arching and vaulting. Hall assumes the complexity to have been progressive: so the pointed arch, the clustered column, the branching roof, "the three leading characteristics of Gothic architecture," have been accounted for' (Portoghesi, 2000, 281-283). Around the turn of the 19th century, Art Nouveau implied an important turn to the natural world as a source of artistic, and hence, architectural inspiration. However, in contrast to the previous examples, its application often had a two dimensional aspect; the biomorphic motifs (flowers, plants, curves) often appeared in stained glass, in tiling, and not directly in the three-dimensional architectural structure (figure 52b). A recent design proposal where references to these elements have been integrated more three-dimensionally is Greg Lynn's Ark of the World Museum, to be situated in the mountains of Costa Rica. The form of the building complex is based on indigenous fauna and flora. The observation platform of the building is covered by a tensile fabric roof that has a flowering form. Moreover, at the entrance of the site, there is a 'garden' with columns filled with water, and these have the appearance of tree-like structures.

Figure 52: Flowering and vegetative elements in architecture. (b) Horta's Tassel House, Brussels.

4.3.1.1. Trees as structural supports

In the following sections we will discuss in more detail some examples of architecture that have strong resemblances with vegetative elements and animals, but that are not necessarily literal imitations. Perhaps the most well-known examples of so-called 'biomorphic' architecture have been created by Catalan architect Antoní Gaudí. It must be admitted that his work could also be discussed in the section about curved architecture. For example, the façade of the Casa Mila (Barcelona) has an intensely undulating surface. Curves recur throughout the whole building: from the mouldings on the ceilings, to the softly curved roof terrace, with its anthropomorphic and spiralling chimneys.

One of the main reasons why we discuss Gaudí in the context of schematic representations of natural objects is because his Sagrada Familia contains some striking examples of schematized nature. In particular, the interior columns of the Sagrada Familia are remarkably similar to tree structures (figure 48b). One can clearly differentiate a 'stem', which bifurcates into further 'branches' and 'subbranches'. The canopy of these tree-like structures consists of 'flowering' forms, which further strengthens the impression of symbolic vegetation. According to the central hypothesis of this dissertation, such symbolic trees will be associated with positive affective responses.

What is important to know is that these 'trees' cannot merely be understood as a poetic or sculptural expression of the architect. In fact, there is an important underlying reason for Gaudí's interest in biomorphic forms. In essence, his work should be understood in the context of the Gothic Revival during the 19th century in Catalonia, which implied a romantic turn towards nature in the arts. In many cases, this came down to the mere imitation of the old (Gothic) models. Sweeney and Sert (1960) argue that, for Gaudí, the revival was '… a springboard to a fresh interpretation of Gothic principles in new materials, aided by what science had opened up to the nineteenth-century architect' (66). In fact, Gaudí's architectural organicism is for a large part rooted in his desire to resolve a structural problem in Gothic church and cathedral building. This is the problem of the lateral thrusts originating from the vaulting. In Gothic architecture, these forces are cancelled out by constructing lateral supports, such as buttresses.

Figure 53: The tilting of these columns is not solely an aesthetic decision, but follows the direction of the forces exerted by the load (Gaudí, Parc Guëll).

Gaudí considered buttresses as a 'lazy' solution. The invention he came up with consisted of constructing *tilted columns*, which followed '… the directions of the force of loads and stresses …' (Sweeney & Sert, 1960, 66 & 74). Gaudí determined the inclination of the columns by *wire models*, tied to the ceiling of his atelier. To these models, weights were attached, which were proportionate to the loads that that part of the building had to bear. As a result of gravity, the curves of the wires corresponded to the logical lines of loads and stresses of the building represented in the model. When the structure of a building followed these optimal curves, no additional supports were needed (figure 53). What follows from this is that the structural shape of (some) of Gaudí's creations was not an imitation of the *outward* appearance of natural structures, but grew out of the *(natural) forces* acting beneath the surface. Among others, Gaudí used this method for the crypt of the Colonia Guëll and for the Sagrada Familia. This also implies that the shape of the trees inside the Sagrada Familia is not merely an aesthetic decision, but is also determined by structural considerations.

According to Sweeney and Sert (1960) Gaudí's interest in the intrinsic forces governing three dimensional structures forms a breaking point with the Modernista or Art Nouveau movement, with which Gaudí is sometimes associated. They note that '… much of the Art Nouveau was essentially decoration, it was surface treatment … Nature, however, for Gaudí was not merely foliage, or tendrils to spread over a bare wall, or the surface movements of flowing water to scarfe a human figure. It was essentially those natural forces beneath such surface expressions' (136). It is well-known that vegetal symbols take in a prominent place in Art Nouveau. However, as this explanation suggests, these elements have no structural work to do, but were put there to reach a certain aesthetic effect. In contrast, the symbolic trees in the Sagrada Familia are crucial for holding up the structure. Still, it would be one-sided and incomplete to suggest that Gaudí was not interested in aesthetic issues altogether. There is also a definite aesthetic factor that explains Gaudí's use of biomorphic forms. Essentially, the Spanish architect wished to imbue his works with 'life' or 'expressivity' (Martinell, 1975). He realized these qualities through the following techniques:

Figure 54: Different strategies for introducing expressiveness in architecture. (b) Mosaics on the benches in the Guëll Park.

- Through *textural variation*: using a wide range of materials, such as stone, glass, ceramic, wood, and so on.
- By *colour in architecture*: using coloured ceramic tiles, broken tiles or glass, or even the natural colour of materials (e.g. stone) (figure 54b).
- By *playing with the light* that impinges on architectural surfaces. This can create a large variety of forms and shadows. These effects can be tapped to increase or influence the expressive power of buildings. This effect can be enhanced by integrating curved surfaces in the architectural work.

- By *using sculpture* (this has been eminently applied to the Sagrada Familia).
- By creating *geometrical rhythms and patterns*. In early work of Gaudí these patterns were quite geometric (e.g. rectangles, triangles), but later they became increasingly more dynamic and free (e.g. spirals, helical forms) (figure 54a).

4.3.1.2. Poetical engineering: Santiago Calatrava

According to Alexander Von Moos, the work of the modern Spanish architect Santiago Calatrava '… relates to the morphologies of plant and animal life – on land, in the depth of the sea, or in imagination' (Von Moos in Tischhauser & Von Moos, 1998, 338). The oeuvre of Santiago Calatrava is often considered as highly 'syncretic' (Van Der Ree, 2000; Tzonis, 1999; Jodidio, 2001). This means that the architect brings different research areas and traditions together in the architectural form. In particular, Calatrava integrates the fields of architecture, plastic arts and science (i.e. building and construction techniques).

Calatrava should be considered as a (modern) heir of Gaudí because his architecture can, to a large extent, also be characterized in terms of lateral thrusts and forces. The tilted, biomorphic forms are not always the result of aesthetic decisions, but also come forth from structural considerations. In this regard, Von Moos (in Tischhauser & Von Moos, 1998, 337) discusses how Calatrava's addition to the St.-John Divine evokes the structural logic of the Sagrada Familia, and hence can be interpreted as a modern instance of 'Gothicism': 'The proposed section of the transept [of the church] is a tribute to the Sagrada Familia. It re-interprets the structural logic applied by Gaudí to this building, a logic whereby the "composite" Gothic system with its distinction of vertical members, vaults, and flying buttresses is gradually substituted in the stages of the project's evolution by an "homogenous" system, wherein all the members perform all the structural roles of the "heterogenous" Gothic system at once … bringing the loads and thrusts of the vaults directly down to the ground' (337). Something similar applies to Calatrava's Stadelhofen train station (Zurich). Here, the tilted columns and forms are not merely there for reaching an aesthetic effect, but are necessary for holding up the architectural structure (Jodidio, 2001).

Note that this emphasis on structural forces is a point of interest that Calatrava shares with German architect Frei Otto. Otto has studied the structural efficiency and economy of the shapes of natural objects and entities, with the goal of obtaining lightweight and minimal architectural structures. He is most known for his tent structures based on the structural behaviour of soap films: 'A soap film always contracts to the smallest surface possible. It then takes up the form of the "minimal surface", which is clearly defined mathematically. Liquid membranes are under the same tension everywhere. They are prestressed, flexurally non-rigid and plane load-bearing constructions that are nevertheless tension loaded. The same is true of tents. The forms produced in the experiments [with soap films] – appropriately enlarged – can provide extremely precise models for the shape of tent constructions' (Otto & Rasch, 2001, 58). It is worthwhile to note that Otto's search for the ideal shape of load bearing structures has also resulted in branching or tree-like structures. Such structures require only relatively little material and are capable of evenly spreading the forces, which are exerted by the load, through their constituent parts.

Figure 56: Allusions to vegetative elements in Calatrava's architecture. (a) Orient Station (Lisbon).

Like with Gaudí's work, the shape and structure of Calatrava's creations cannot be solely reduced to structural or engineering issues alone. Instead, his work is also informed by aesthetic decisions, which often have a profound biomorphic character. For example, Pieter Van Der Ree (2000) notes that Calatrava's '[o]rganic construction forms, such as trees, skeletons and moving structures … are an important source of inspiration for his work' (83). Of particular relevance for the present discussion is that several building elements resemble vegetative structures. They are not strict imitations of these elements, but 'schematic' or 'stripped down' versions that seem to capture some essential features of these elements, like their stem and canopy. Notable examples of such 'vegetative architecture' are both Calatrava's Orient Station (Lisbon) (figure 56a) and his BCE Place (Toronto) which have been interpreted as '… "forests" of structural "trees"' (Tzonis, 1999, 82). Another clear reference to vegetation and to flowers in particular, is Calatrava's floating pavilion for the Luzern Lake. This cupola is made up of twenty-four 'petals' and these can close and open like in a flower. A similar principle is at work in the

Kuwait Pavilion in Seville. Here, the structure refers to the interlacing leaves of the branches of a palm tree (Tzonis, 1999).

4.3.2. Symbolic animal architecture

As Aldersey-Williams (2003) correctly notes, the literal integration of animal form in architecture can sometimes lead to funny or even ridiculous results. More sophisticated instances of 'animal' architecture have been designed by the American architect Eugene Tsui. Tsui is a former student of Bruce Goff, and his work is therefore an extension of the line of organic architecture that has its origin in the work of Louis Sullivan and Frank Lloyd Wright. Tsui's work seems to stretch the expressivity and form freedom that is inherent to organic architecture very far, which results in 'animal-like' or 'zoomorphic' architecture. Consider for example Tsui's design for the Apple Computer Headquarters (figure 57b), which will probably evoke associations of a fish in the reader. As a short sidestep, it is interesting to note that the theme of aquatic animals has also found expression in works by Frank O. Gehry, in Ushida-Findlay's Grafton New Hall, and in Michael Sorkin's Beached Houses designs. Tsui's design for the Arctic Gas Pipeline Research Centre (figure 57a) again is strikingly similar to a bird that is about to fly off. This work is reminiscent of Calatrava's bird-like Quadracci pavilion near the Milwaukee Art museum (figure 59).

Figure 57: Zoomorphic designs by Eugene Tsui. (a) Arctic Gas Pipeline Research Centre. (b) Apple Computer Headquarters.

Note that the previous link with Calatrava's work is not too far-fetched, and even goes beyond formal similarities. While the work of both architects has a distinct formal signature, Tsui also aims for structural efficiency in his architecture. This can be illustrated by the Tsui house in Berkeley (California) (figure 60). The curved continuity of the elliptical shape of the house is based on the skeleton of the Cholla cactus, and it is claimed to have an important structural efficiency that is mostly absent in traditional minimalist architecture. The specific form of the dwelling has the advantage that the load is spread evenly over the total structure, thereby avoiding point loads. It enhances the internal strength of the structure, and also reduces the amount of surface that is needed to hold up a structure (Tsui, 1999).

Figure 59: Quadracci Pavilion of the Milwaukee Art Museum, which strongly resembles a bird (Santiago Calatrava).

In contrast to Calatrava, Tsui's interest in structural efficiency seems to originate more from ecological considerations than from structural-engineering matters. The logic underlying Tsui's architectural philosophy is that natural structures show an important efficiency and economy in their material make-up and energy-use. By mimicking the efficiency of natural forms, a contribution can be made to an ecologically responsible way of building. Again, consider the Tsui House (figure 60). Beneath the surface of the top of the house, black air tubes have been placed. During daytime, the sun heats up these tubes, while at night, they give off residual warmth to the inside walls, thereby avoiding additional heating and energy waste. Such interventions could become increasingly relevant and urgent, given the growing scarcity of natural fuels and the need for 'green' energy resources. Tsui argues that this ecological heating system is an instance of so-called 'evolutionary architecture' because it is based on the thermal system of two dinosaurs, namely the dimetrodon and the stegosaurus: 'In both these ancient reptiles, the plate structures [on their back] were surrounded by a densely packed configuration of blood vessels. The sun heated up these plates and helped to regulate the body temperature of the reptiles' (Tsui, 1999, 218).


Figure 60: The zoomorphic Tsui House, designed by Eugene Tsui.

The shape of the Tsui House is thus motivated by the imitation of some of nature's *methods*, rather than by its outside forms. Yet, it is noteworthy that Tsui's interest in biomorphic forms is, to a certain extent, also rooted in his worldview. More specifically, 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 also tries to adapt the design of his work to these views, and this leads 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…' (Tsui, 1999, 5). Note that the deliberate expression of the current world-view in architectural form is a theme that has also been extensively discussed by Charles Jencks in the context of fractal architecture (see chapter 3, for a more lengthy discussion of this topic, and its associated difficulties).

4.4. Architectural integration of low level features of natural contents

The previous examples of 'biophilic architecture' still referred symbolically to nature. The natural form had undergone quite some abstraction, but it still shared some conspicuous perceptual similarities with actual natural elements. For example, in Calatrava's Quadracci Pavilion there is still an evident resemblance with a bird's wings. But perhaps it is possible to leave representational content almost completely behind, while the architectural form retains some of its naturalness by integrating certain form-primitives that are characteristic of natural elements. Although there exist proposals on the form-primitives underlying the perception of many artefacts, such as 'geons' (figure 61) (Pinker, 1997), we are left in the dark with regard to natural contents. For example Pinker (1997) notes that '[g]eons are not good for everything. Many natural objects, such as mountains and trees, have complicated fractal shapes, but geons turn them into pyramids and lollipops. And though geons can be built into a passable generic human face, like a snowman or Mr. Potato Head, it is almost impossible to build a model of a *particular* face…' (272).

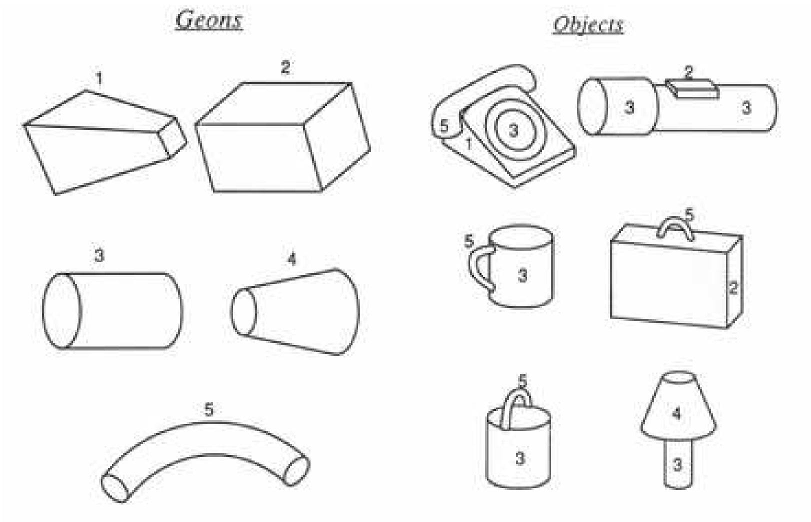


Figure 61: Geons are perceptual form primitives that can be assembled into different kind of objects.

A possible inroad to this issue is the observation that natural elements, such as vegetation or animals, are not made up of straight, angular shapes, or Euclidean volumes, but have curvilinear contours and surfaces. In biophilic design, some scholars have intuited that these shapes can evoke naturalness and the associated affective responses. Heerwagen (2003) notes that '… there is some indication that people respond positively to organic shapes and curvilinear spaces in buildings, landscapes, and artifacts' (unpaged). Similarly, Kellert (2005) notes that '[p]eople prefer the textures, curvilinear forms, rounded and spherical surfaces, movements, and plasticity typically encountered in nature to the rigid, straight-line, abstract, and contrived geometries of artificially fabricated and designed forms and materials' (159). However, both Heerwagen and Kellert present no research supporting their claims. In environmental psychology, perhaps the only empirically supported link between curved forms and positive affect is the finding that people prefer spatial layouts where the line of sight bends away (i.e. deflected vista). While this can be a useful intervention for an architectural plan, it is not directly clear how it can be deployed in, say, the design of a façade. In the following sections we will try to bring some clarity in these issues, and we will therefore discuss some empirical research into the relation between curves or curved surfaces and visual perception.

4.4.1. Preference and curvature

Let us first review some empirical research into the relation between positive affect and curved forms and surfaces. Perhaps a preliminary indication of the aesthetic value of curvy lines and surfaces can be drawn from studies of ornament. Here, the perennial presence of curved shapes (spirals, scrolls, meanders) (Wilson, 2001) could be claimed to be an important indication for the aesthetic value that people attach to such patterns (Wilson, 2001). A similar argument is pronounced by Kellert (2005): '… symbolic designs of nature [like curved shapes] occur throughout human history and across all cultures, though perhaps less so in modern, urban society. The ubiquity of these environmental simulations reflects a universal yearning often incorporated into building interiors and sometimes into exterior landscapes' (155).

Yet, Kellert's claim remains largely intuitive, and it alone cannot form any evidence for a positive affiliation with curved forms. For more systematic empirical research into the affective valence of lines, we have to turn to the field of ethology, which studies and explains behaviour from an evolutionary perspective. Research within this domain reveals that particular linear configurations can evoke different affective states in subjects. In particular, Nancy Aiken (1998b) has argued that certain linear patterns can act as a 'releaser' of affective responses, and notes how these are often used in artwork. The notion 'releaser' is central to so-called 'releaser-response packages'. These are units of innate reflexive behaviour, consisting of three important parts: a (1) stimulus or 'releaser' that can trigger an (2) appropriate neural mechanism, which leads to a particular (3) adaptively appropriate behaviour. Perhaps the most well-known example of such mechanism is the finding that herring gull chicks will peck (= appropriate behaviour) at a red spot (= releaser) on their parents' bill to make them regurgitate food. Importantly, when the releaser is 'exaggerated' – i.e. when it is replaced by a red pencil, with three white stripes at the end – then it becomes even more effective in inducing this appropriate behaviour (figure 62). The red pencil is therefore called a 'super-normal' stimulus (Tinbergen & Perdeck, 1950). Note how this principle was also mentioned earlier, in the context of Ramachandran and Hirstein's (1999) aesthetic principles.

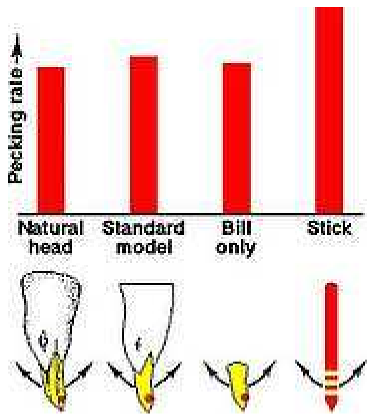


Figure 62: Graph of the different visual releasers used in the Tinbergen and Perdeck (1950) experiment. The strongest response is associated with a geometrical simplification of a gull's beak.

According to Aiken (1998b), some typical linear configurations are releasers of specific affective reactions in humans. This is clear from early studies of Lundholm (1921) and Poffenberger and Barrows (1924), where subjects had to associate different types of lines with various affective adjectives (e.g. 'sad', 'quiet', 'furious', 'harsh', and so on). These experiments revealed that angled and curved lines were releasers of different categories of feeling tones. This conclusion is supported by a more recent experiment by Johanna Üher (1991). She presented 1100 Central European subjects 24 pairs of adjectives, which had to be matched with either angled lines ('zigzags') or curved lines ('wavy lines'). In each pair, one adjective reflected antagonistic characteristics (e.g. 'aggressive', 'hostile', 'harsh', 'irritated', and so on) while the other reflected affiliative characteristics ('peaceful', 'friendly', 'gentle', 'balanced', and so on). It was found that angled lines were predominantly associated with antagonistic characteristics, while curved lines were matched with affiliative characteristics.

The antagonistic character of angled lines is also evident from an experiment by Richard Coss (2003). Coss compared the effect of pointed and rounded contours on the physiological state of ten men. It was found that the angled forms engendered a significantly greater amount of pupillary dilation than the curves. This indicates that angled shapes elicit more arousal, are more provocative, and are more attention-grabbing than rounded forms. The latter are experienced as less arousing and attractive, but will probably give rise to more 'harmonious' and 'peaceful' emotions. Coss (2003; see also Aiken, 1998b) argues that the arousing properties of angles could be due to the danger associated with piercing forms. This danger can be traced back to the piercing characteristics of canines and horns, and to the thorny plants and seeds that are abundant in African savannas. Within the field of architecture, the use of pointed sharp shapes can be used to grab attention or to elicit excitement.

In agreement with the previous research, Bar and Neta (2006) have inquired subjective liking reactions towards stimuli with either sharp-angled contours or curved contours. Fourteen subjects were involved in this experiment and – beside control pictures – two types of stimuli were used. First, there was a set of 140 pairs of real (neutral) objects that conveyed the same semantic meaning and were similar in appearance, but differed only in the presence or absence of curvature. A second set of stimuli were 140 nonrepresentational images that looked the same for all visual features, except for their contour, which was either curved or angled. Overall, it was found that subjects preferred the real objects with curved contours (mean liking: 67.2%) more than objects with sharp-angled contours (mean liking: 50.6%). A similar trend was observable for non-representational curved (mean liking: 37.9%) and sharp-angled (mean liking: 24.8%) patterns. This experiment suggests that the presence of low-level features, such as curvature or angles, can influence the affective valence of objects and images. By using nonrepresentative forms, the authors have tried to minimize the influence of personal preferences, trends and fashion on the aesthetic judgements. Consistent with these outcomes is the finding by Leder and Carbon (2005) that people find curved interiors of cars more attractive than non-curved interiors. The reason for this, they argue, is that '… softer, curved shapes are more often associated with cuteness, beauty and approach, while sharp, straight designs are presumable more related to technical, analytical and cold reactions' (604).

4.4.2. Curvature and naturalness

Curves seem to be a conspicuous feature of the hotel room depicted in figure 65. In agreement with the previously discussed studies, the 'soft' interior is inviting and seems to evoke feelings of 'peacefulness', 'rest', 'security' and 'warmth'. If one wants to create more stimulating and arousing settings, the curves can be made more volatile, or sharp-angled forms can be introduced. Evidently, the research underpinning these claims needs further replication. Another issue is the possible explanation for these findings – whence the positive affective valence associated with curved forms? Bar and Neta's (2006) explanation is similar to Coss' (2003): 'We propose that disliking of the sharp-angled neutral objects in our experiment stemmed from a … feeling of threat, and that this feeling was triggered by the sharpness of the angles per se …This result supports our hypothesis that preferences can be driven by a threatening impression conveyed by contour, and furthermore that such preferences are influenced by the sharp angles themselves, rather than by the mere straightness of the contour. Therefore, simple physical elements in a stimulus can directly mediate relatively high-level judgments of preference' (647). It should be noted that such an explanation is consistent with the evolutionary framework that is the backbone of this dissertation. Because of the danger of getting wounded by piercing objects, and hence, running the risk of experiencing life-threatening infections, there might have been an evolutionary pressure to innately display negative emotional responses to such forms (e.g. Hamilton, 1995; Coss, 2003). Note that, in its most extreme form, the fear of piercing forms can lead to 'trypanophobia', more popularly known as 'needle phobia'.

Figure 65: The soft curved interior of a room in the Hotel Puerta America, Madrid.

In view of the previous explanation, it is perhaps the absence of (disliked) sharp angles that explains why subjects prefer curves over sharp forms. However, it should be noted that subjects preferred the curved objects *over* the control objects. This suggests that such an explanation falls short, and also indicates that the presence of the curves *in se* has a genuine aesthetic effect. Another explanation could be that curved forms are preferred because in current product-design and architecture, increasingly more curves and curved surfaces are used, leading to a greater familiarity with such forms. Yet, some might claim that this begs the question as to why curves are fashionable in the first place. A biophilist could still argue that this reflects an inborn predilection for natural-like forms and patterns.

Let us take a closer look at this biophilic argument. In the introductory paragraph of this section we already suggested that the preference for curved forms might be rooted in the fact that they evoke associations of naturalness. Also, this conclusion accords well with the proposed framework of this dissertation. But what is the evidence supporting this claim? First, the link with curves and naturalness is supported by common sense. For example, architecture and art with curved forms is often referred to in terms that are semantically related to natural entities: think for example of the notions 'zoomorphic', 'organicism' or 'biomorphism'. Moving beyond these intuitions, there is also some (empirical) research that establishes a link between naturalness and curves. For example, measurements of animal contour reveal that these have a high degree of curvature, as opposed to the rectilinearity of a lot of nonnatural objects (Levin et al., 2001). Furthermore, research indicates that people consider curves more natural-like (Levin et al., 2001). Another indication for the close link between natural entities and curves comes from the series of experiments conducted by Levin et al. (2001; see chapter 1, section 4.3.1.1), which showed that curvilinearity is one of the factors that drives the search for animals. Furthermore, some speculate that the aesthetic attraction of curved ornament can be drawn back to the fact that such patterns evoke natural objects. Bell (1999) notes: 'Spirals occur in nature, meanders in rivers – do these signify life forces when used as decoration …? We will never know for certain, but it is significant, in our quest for patterns, that so many natural ones have a strong attraction to us' (37). But given these observations, how exactly can the preference for curved forms then be explained? One could argue that, due to the evolutionary relevance of animal-life, and because of the importance of showing quick adaptive reactions to these, it could well be that at the early level of processing curvature, already some (positive) affective states are primed (Ulrich, 1983). An initial preferential reaction to curves could motivate to further being attentive to this stimulus, and could motivate to inquire whether it could be of interest – say, as a potential source of food.

The preferential reactions towards curved information could also be rooted in the fact that processing such patterns is essential for recognizing faces, and hence, for identifying kin. This conclusion can be drawn from research into prosopagnosia, which was mentioned in the previous chapter. There, we discussed that some theories advance a deficit for curves or curved surfaces as the underlying cause for face-blindness. Because of the importance of human faces for social interaction and emotional expression, exposure to facial form primitives could therefore already prime affective states. Peter Stebbing (1999) also explains the aesthetic attraction of curved forms by referrring to face-like features. In particular, Stebbing concentrates on the aesthetic appeal of the so-called 'asymmetrical curve', which consists of a short straight line connected to a longer curve. In fact, this pattern is the contour of a woman's face, viewed from the perspective of a baby that is held in its mother's arms. Because babies often look at their mother's face, they are imprinted with her cheek curve. Due to feelings of love, comfort, care and security, this pattern is loaded with a positive emotional association. In adult life, the cheek curve acts as a biological releaser that elicits positive emotional states and aesthetic attraction.

What seems to be clear at the moment is that curves evoke more 'harmonious' feelings, and are associated with preferential reactions. However, the proliferation of different explanations suggests that we remain in the dark about what could be the possible cause of these affective responses. In a very coarse sense, it can be claimed that these responses are due to the fact that we affiliate positively with nature and because curves symbolize nature. However, a major objection to this explanation is that not all curved biological entities are associated with positive affective states (e.g. snakes), which makes it implausible that initial positive reactions to curved patterns are adaptive for an organism. Furthermore, it should be noted that the correlation of curves with preference, and of curves with naturalness does not necessarily imply that naturalness is the cause of the preference for curves. It could equally be that curves are higher in information content, and thereby respond to our need for moderately complex information (Salingaros, 2003). Another possibility is the plain fact that curved forms are preferred because their softness makes them pleasant to touch.

4.4.3. Biophobic features

Although biophilic architecture is mainly involved with the question which architectural elements can *positively* influence human functioning, it is worthwhile to briefly explore some elemental 'biophobic' patterns and features, which can provoke awe, fascination, and even stress or agitation (figure 66). For example, Richard Coss (2003) notes that humans might have evolved an inborn perceptual sensitivity for leopard spots and reptile scales, in order to quickly and succesfully recognize these predators and display adaptive behaviour (e.g. flight). Such sensitivity could explain the ubiquity of such patterns in design, architecture and fashion. Consider for example Gaudí's Casa Batlló, where the characteristic roof is visually similar to the skin of a reptile, or is sometimes even compared with a dragon's back (Van Der Ree, 2000) (figure 67a). Something similar applies to Gregory Burgess' Uluru-Kata Tjuta Cultural Centre (Ulura-Kata Tjuta National Park, Austrialia), which '… draws its symbolism from snakes important in the mythology of the Anangu people' (Aldersey-Williams, 2003, 73). Coss (2003) further notes that traditional carpets and mosaics could well tap our inborn recognition mechanisms for snakes, because they often display patterns that are closely similar to tessellated snake skins.

Figure 66: The spider-like artwork near Guggenheim could well evoke aversive or 'biophobic' responses.

In the previous sections we have already briefly touched upon the meaning and function of biological releasers. Perhaps the most well-known visual releasers are 'eye spots', which can elicit fear in humans and other species (Eibl-Eibesfeldt, 1989), because such patterns are associated with ambushing predators and aggressive conspecifics (Coss, 2003, 115). Butterflies, for example, sometimes have eye-spots on their wings, and this scares off potential predators. Aiken (1998b) argues that this type of releasers is often deployed in art, and she notes that it can trigger emotions stemming from defensive reactions. For instance, she describes that the threatening character of Picasso's Les Demoiselles d'Avignon can to a large part be drawn back to the mask-like faces of the ladies, and their 'great, staring eyes'. Peter Stebbing (1999) mentions that eye spots are present in the visual expressions of numerous cultures, albeit sometimes under a slightly modified form (e.g. spirals). The protective or 'apotropaic' function of such patterns can be further illustrated by the observation that hanging large banners with schematic frowning eyes near products significantly reduces shoplifting in stores (Coss, 2003).

In the field of architecture, numerous buildings have eye-like features. Well-known examples are Calatrava's planetarium in the City of Science (Valencia). This construction is a sphere-like structure, around which an 'eye-lid' has been built. The reflection of the building in the nearby water gives it the appearance of a (human) eye. Similar eye-forms are present in the nearby opera building, and in the lower part of the Montjuic communication tower (Barcelona). Other instances of architecture with 'eyes' are the balcony railings of Gaudí's Casa Battló, which look like the eye sockets of human skulls, staring at the passer-by (Feuerstein, 2002). Eye-like patterns are also prominent in some works of (organic) architect Imre Mackovecz, as he himself admits: '… all my buildings have faces. All projects have faces, they have a front and a back. At the front they have faces, that is important. And so when I build a tower, it has a face as well, it has eyes, and looks in a particular direction' (Mackovecz cited in Feuerstein, 2002, 101). Eye-like schemata are clearly present in Mackovecz's Hungarian Pavilion at the Expo in Seville (1992), and in his church in Siófok (Hungary) (figure 68).

Figure 67: Biophobic features in architecture. (a) The 'reptile skin' of Gaudí's Casa Battló, Barcelona.

Figure 68: The 'eyes' of the new Evangelical Church at Siófok by Imre Makovecz.

4.4.4. Curves in architecture

4.4.4.1. Hundertwasser: biophilic intuitions

In the sections that follow, we will review some examples of architecture and architectural styles that are characterized by one of the proposed low-level visual primitives of natural objects, namely curvature. Interestingly, a rejection of the straight line, and hence, an emphasis on the importance of curved forms, is a central theme in Hundertwasser's design philosophy (Hundertwasser, 1997). More specficially, he has expressed fierce opposition to the straight line that dominates much of modern(ist) architecture. His resistance to this feature can be traced back to the fact that he considers nature as the *locus* of growth and development, of differentiation and creative power. Due to its one-sided, reproductive and repetitive character, the straight line is the antithesis of this dynamism, and hence of nature. Because we are dependent on, and an integral part of nature, the use of the straight line is a sign of our estrangement from nature, and hence, from ourselves. The use of the straight line is, according to Hundertwasser, not merely an undesirable feature, but even leads to physical and psychological disease. In this regard he notes: 'The network of straight lines is the symbol and the symptom of the self-destruction of our society' (Hundertwasser, 1997, 37). Or: 'The nervous system of the eyes sees an accute danger in the uncountable number of straight lines. Man is becoming mentally ill and doesn't know why' (Hundertwasser, 1997, 38).

Figure 70: Breaking through the straight line in the Hundertwasser Haus.

Hundertwasser tries to counter the straight line in architecture by introducing curved forms and surfaces in his built work. He '[m]ake[s] the windows dance, the deadly straight skyline swing, and make[s] footpaths irregularly uneven according to harmonic criteria' (Hundertwasser, 1997, 74). This strategy is clear in the Hundertwasser House, in Vienna (figure 70). The façade is partitioned in different multicoloured sections by curvy, irregular lines. In the interior, the floors are uneven and tilted. Rectilinearity can also be broken through by letting the forces of nature act in on the built constructions. In particular, the sterile and monochrome surfaces of modern building 'boxes' can be 'attacked' by erosion, weathering, mould and overgrowth: 'To protect functional architecture from the moral downfall, one should create a breeding ground on the clean and smooth concrete walls, so that mould can grow on it' (Hundertwasser, 1997, 48).

The reason why we extensively discuss Hundertwasser is that he seems to have developed an intuitive account of the importance of nature and of natural form in the human living environment. In agreement with our argument developed in the previous sections, he considers the curved line as a (symbolic) reference to nature, and also believes that such type of forms has beneficial effects on human functioning. In contrast to our approach, Hundertwasser's views are not supported by empirical evidence but seem to have a more visceral origin.

4.4.4.2. Curved architecture as expression

Free-form architecture seems to be a central characteristic of the organic tradition that has its roots in the work of Louis Sullivan (Roche, 1993) and Frank Lloyd Wright (see e.g. Wright, 1992, 1970, 1987). In many cases, the free form of organic architecture comes down to a rejection of the straight angle or line, and is expressed by a keen use of curved surfaces: 'Geometry from sources other than our orthogonal relationship to gravity is a salient aspect of organic architecture' (Robinson, 1993, 12). One of the factors that contributes to this free form language is the specific 'organic' design principle that is at the root of organic architecture. This principle is often denoted as 'designing from within' (e.g. Prince, 2001), and it implies that the architectural form is not the outcome of a set of stylistic regulations and conventions, but grows from the particular and local conditions of the building, and from the specific requirements involved in the design process[6] (see also: Blundell Jones, 1999, 2000, 2003; Häring, 1978; Pearson, 2001; Davies, 1982; Scheurer, 1991; Zevi 1950, 1991). A useful metaphor is to consider these conditions and requirements as 'forces' working in on the architectural form: they '… hollow out shapes that fit their meaning. This is why these interior forms are shaped as they are, worked out of the flat surface' (Steiner, 1999, 69). Similarly, Blundell Jones (1985) argues that the organic architect is '… helping to bring together the forces that give it [the building] form' (24). This responsiveness to local conditions and requirements could explain why organic buildings often vary in form and outlook and helps to explain why they are characterized by remarkable forms and free spatial organizations. Yet, another important determinant of this form freedom is that the 'form-shaping' requirements do not logically determine the architectural work, as is the case in Hannes Meyer's quantitative functionalism (Meyer, 1999). Instead, they are architecturally synthesized by the architect's creative imagination or design intuition, which leaves place for individuality and free expression. As can be observed in the illustrations (figure 71), there is quite some variation in the form freedom of the works of different organic architects. Some of the designs only hesitantly display curves, while others are profoundly biomorphic.

[6] It must be admitted that most buildings are always a (partial) response to different internal requirements, and consequently, their form can be considered as 'originating from within'. For example, every regular family dwelling is adapted to the material and physiological needs of its inhabitants. Yet, as is clear from such dwellings, they are not necessarily characterized by curved or irregular forms.

Figure 71: Hans Scharoun's Berlin Philharmonic Hall.

Organic architecture seems to share its interest in curved three-dimensional forms with (the strand of) expressionist architecture that emerged during the first decades of the 20th century. This artistic movement was directly influenced by the individuality and expressive architecture of such architects as Antoni Gaudí and Frank Lloyd Wright. Expressionist architecture sought to express and provoke emotion in the individual through a profound form freedom and distortion of form (figure 73b). One of the culmination points of the (architectural) expressionist tradition is Erich Mendelsohn's Einstein Tower (Potsdam), with its characteristic curved surfaces (figure 73a). While this turn to curved, naturalistic forms seems to suggest a family resemblance between expressionist architecture and Art Nouveau, some crucial differences can be brought to light. In Art Nouveau the recourse to nature mainly resulted in an interest for floral or vegetal patterns, which were mostly applied locally to the architectural work (i.e. as ornament). In contrast, in expressionist architecture, biomorphism is often a characteristic of the whole building, and is much more inspired on the mineral and crystalline world, than on vegetal entities.

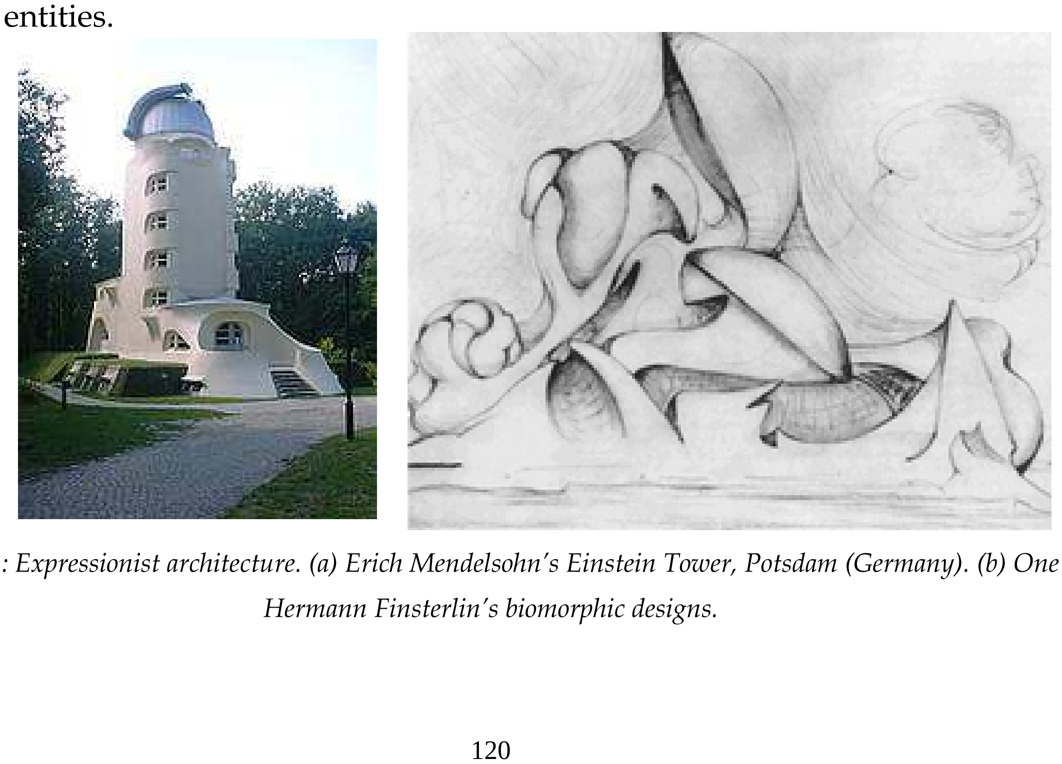


Figure 73: Expressionist architecture. (a) Erich Mendelsohn's Einstein Tower, Potsdam (Germany). (b) One of Hermann Finsterlin's biomorphic designs.

4.4.4.3. Blob architecture

While a strict interpretation would consider expressionist architecture as a historical movement, one can also adhere to a more moderate view, in which expressionism is viewed as an attitude where emotion is expressed through specific free-form architectural interventions, often displaying curved forms. Such a view reveals an incessant trail of expressionist architecture throughout modernity, including works of Hans Scharoun, Jorn Utzon, Eero Saarinen, Frank Gehry, Santiago Calatrava, and even Le Corbusier (figure 74). Part and parcel of this trail is the important trend toward curved or biomorphic forms in architecture and design, emerging in the mid-nineties of the 20th century. Specifically, such biomorphic architecture is often characterized by amoeba-like shapes and is popularly denoted as 'blob-architecture' or 'blobitecture' (Waters, 2003).

Figure 74: Curved expressionist architecture. (a) Upper left: Saarinen's JFK Airport, New York. (b) Upper right: Le Corbusier's Notre Dame du Haut at Ronchamp. (c) Middle: Jorn Utzon Opera House in Sidney. (d) Below: Gehry's Guggenheim Museum in Bilbao, Spain.

Blob architecture is most often the result of so-called 'generative' design-methods. Essential to such methods is that the computer is no longer exclusively an instrument for drawing or calculating, but instead it becomes an active player in the creative, form-shaping process (e.g. Lynn, 1999; Burry, 2001). A typical generative method consists of creating architectural or design work with genetic algorithms, which are computational models of Darwinist evolution[7]. When using such methods, the design-concept first has to be translated into a genetic code (Frazer, 1998). Next, using a computer program, this code is developed and mutated in a simulated environment until a set of architectural models is obtained. The codes of the most successful models within the environment are selected, and used in a new evolutionary cycle. This process is repeated until a certain developmental stage is reached. Genetic algorithms are the formative principles at the root of the work of, among others, John Frazer (Frazer, 1995a-b; Frazer et al., 1995; Frazer & Rastogi, 1998; Frazer & Janssen, 2003) and Italian architect Celestino Soddu (e.g. Soddu, 1998, 1999, 2003). It should however be noted that, while Soddu and Frazer are interested in biomorphic forms, their work does not have the typical amoebae-like shapes of blobitecture. Another typical generative method, which is often used to create blob architecture, consists of translating some type of information into force fields, which are released on a predetermined geometric structure, and which subsequently deform it. Or as Zellner (1999) puts it: '... forms are no longer defined by the simple parameters of scale, volume and dimension; multivalent and shifting external or invisible forces and inclinations can also affect forms' (14-15).

Blob architects often make use of software environments that support the creation and manipulation of nonstandard three-dimensional geometrical forms. When generative design strategies are deployed in such environments, this often results in exotic shapes, with very profound biomorphic features. Or as Neil Spiller (2001) puts it: '… [such architectural] projects consist of a peeling back of colourful,

[7] A simple genetic algorithm (see e.g. Flake, 1999; Mitchell, 1996) can be considered as a computational method performing transformations on a population of randomly chosen solutions for a specified problem. These solutions are interpreted as 'chromosomes', and can be coded in terms of 'bits' – for example: 0011101110. When applying a genetic algorithm, a first task is to specify a *fitness function*. This function calculates the degree of fitness of a member of the population to resolve the initial problem. Next, those individuals that seem most fit are selected for reproduction. When individuals are selected, they are able to reproduce and breed offspring. A first method consists of mating a large number of individuals or bit-strings. A simple case of this procedure is called '*crossover*'. First, two individuals ('*parents*') are randomly chosen out of the selected population. Next, a crossover point is determined on each parent-string. The genetic information to the left of the crossover point of the first string is 'glued' to the information at the right-hand side of the crossover point of the second string. The same process is repeated by swapping and merging the other sides of the same parent-strings. Out of this process two '*children*' arise. The next method for reproduction is *mutation*. This happens by randomly choosing an individual, and locally changing its genetic composition: for example, '111110111' becomes '111110110'. Usually, the percentage of mutations is held very low, because it can be detrimental for valuable genetic information.

stretched skins and rubbery ripples. These glisten in the sunlight, almost sweaty, often voluptuous, sometimes shroud-like … These [architectural] sheets look as if they cover boils, blemishes, abnormalities and swellings, which are smoothed into sculpted mouldings … [S]paces appear to have been created by a mad but aesthetically aware seamstress or a drunken candle-maker armed with a blowtorch' (105).

Despite the fact that many architects and designers are keenly interested in this type of forms, a lot of generative work remains stuck in the design phase. A few exceptions are Future Systems' Selfridges (Birmingham), the Kunsthaus in Graz (figure 75), and Nox' Maison Folie (Lille). Note that these are all larger urban projects or buildings, and not individual dwellings. This is probably due to an interplay of different factors. First, it is quite clear that a straight wall is still easier to manufacture than a curved surface, and the latter is probably also the least expensive. Furthermore, such forms imply a radical departure from what most people understand as a building. Blob architecture is not only profoundly biomorphic, but also leaves behind issues such as proportion, part whole-relations, discrete spatial boundaries and units, and so on. Interestingly, some research groups have made this unrecognizability into the core of their design philosophy. This especially applies to the design practice OCEAN North, which intends to separate the specific geometric and material structure of their design from a definite meaning. This separation leads to incomprehension and ambiguity with regard to the functional role and meaning of their work. However, by actively interacting with the design, the subject can discover a whole new range of interpretations and possible uses (Hensel & Sotamaa, 2002; Hensel, 2003).

Figure 75: A built example of blob architecture: Kunsthaus, Graz (Cook & Fourmier).

The following discussion of blob architecture is relevant for our argument for three important reasons. First, such architectural designs have a profound biomorphic character, and are therefore relevant to a discussion of biophilic architecture, which holds that curves and curved surfaces are (in a sense) 'good' for human functioning. Except maybe for some drawings by expressionist Finsterlin, the biomorphism associated with this type of design is unseen in the history of architecture. Second, the issue is relevant because a critical treatment of blob architecture will reveal that instances of biophilic architecture should be embedded in a larger context, including social, cultural, historical, personal and ecological considerations. Third, the appendix of this dissertation consists of a discussion of designs and proto-architecture that are created with methods that are conceptually similar to the strategies used to create instances of blob architecture. Finally, it must be noted that it is not the scope of this discussion to give an exhaustive review of the broad field of blob architecture. We therefore limit ourselves to a discussion of the work of only a few, representative architects/designers. We are necessarily obliged to leave undiscussed the work of, among others, dECOi (e.g. dECOi, 1999a-b-c; Goulthorpe, 1998, 1999, 2000), Kolatan MacDonald (e.g. Kolatan & MacDonald, 2000, 2001), Hernan Diaz Alonso, Ammar Eloueini (e.g. Eloueini, 1998a-b, 2001), and many others (see figures 76-79).

Figure 79: biomorphic work by Hernan Diaz Alonso.

4.4.4.3.a. Ideology of blobs

The American architect, designer and philosopher Greg Lynn can be considered as one of the founding fathers of computer generated biomorphic architecture. He is not only renowned for his design work, but has also made significant contributions to the philosophical and ideological discourse surrounding blob architecture. Let us briefly discuss some of the ideas that are at the root of his specific design propositions. Lynn observes that in architectural theory often two diverging interpretations of the notion 'complexity' are used. On the one hand, there is the idea of complexity as drawing together disparate elements, without realizing totality or wholeness. An architectural expression of this interpretation is deconstructive architecture, which is characterized by contradiction and heterogeneity. A second and contrasting interpretation is inspired by the complexity sciences. Here, a complex structure is understood as a multiplicity of simple interacting systems that give rise to a complex, emergent whole. According to Lynn, this notion finds expression in regionalism, which strives toward a unified architectural language.

Lynn (1998; see also Lynn, 1999) attempts to develop an alternative notion of architectural complexity, which implies an integration of the two previous viewpoints. In essence, he considers complex organisations as 'assemblages' that are organized like a unity, but have an internal multiplicity that cannot be reduced to this whole: '… one approach to a theory of complexity might be to develop a notion of the composite or the assemblage which is understood as neither multiple nor single, neither internally contradictory nor unified. Complexity involves the fusion of multiple and different systems into an assemblage which behaves as a singularity while remaining irreducible to any single simple organization. Such a state of organization would have to be distinguished from the merely contradictory or complicated as it is organized as a singularity, yet it would be distinguished from the wholistic by its internal multiplicity' (161-162).

But which type of geometry can be associated with this 'multiplicity within unity'? Or as Lynn (1998) frames it: '… what is the implicit spatial model with which one can measure a complex relationship that is not reducible to either the contradiction of the many or the wholistic unity of one' (162). Lynn proposes that 'isomorphic polysurfaces' can express and incorporate these properties. More popularly, such geometric elements are called 'meta-balls' or 'blob-models'. In particular, meta-balls are biomorphic primitives, whose forms are determined by the relations they hold with other meta-balls. This is because meta-balls are surrounded by a kind of 'halo', which consists of two parts. The first and interior part of the halo defines a zone where a meta-ball can fuse with other meta-balls into one continuous whole. The second and exterior volume determines an area where the surface of the meta-ball can be deformed by other meta-balls. The degree of inflection or deformation depends on the gravitational characteristics of the original meta-ball. Thus, when meta-balls approach each other, this can either result in a deformation of the meta-balls, or even in the fusion of the two entities. But how do the properties of these structures exactly relate to Lynn's notion of complex organisations? The answer is that meta-balls are singular surfaces, and, hence, are characterized by an essential unity. However, meta-balls can also be related to multiplicity because their singular shape is the result of a complex interaction of a multiplicity of disparate elements.

Lynn (1998) argues that the principle of multiplicity within unity is architecturally expressed in Reiser and Umemoto's carapace for the West Side in New York, and in Shoei Yoh's Uchino Community Center. In each case these structures are characterized by a biomorphic surface that integrates a multitude of architectural programs. This multiplicity does not disappear under the surface, but finds a translation in the local inflections on the surface – these can be understood as formal expressions of the different programs and services situated below it. Or, as Reiser and Umemoto put it: 'Our project utilises a system of differential repetition and thus has the capacity to produce a field that embodies variable scales and organisations in the same structure. These potentials thus enable the local to be created within a *global* system'. (2000, 89). Lynn himself has implemented his design philosophy in the Embryologic Housing Project, which essentially consists of a range of biomorphic single-family dwellings. The Embryologic Houses should be considered as a 'species', based on a pre-specified and shared geometric scheme. Importantly, within the limits of this geometric scheme there is place for some variation. Specifically, despite having a strong family resemblance with other members of the species, the individual houses vary in outlook, and each have a unique shape. A large part of this variation and originality depends on contingent factors, such as the life-style of the inhabitants, site, climate, construction methods, materials, spatial effects, functional needs, aesthetic preferences, and so on (Lynn, 2000).

4.4.4.3.b. Time as form shaping factor: Nox

In the Netherlands there seems to be a keen interest in blob architecture. One of today's leading generative design practices is the Rotterdam-based studio Nox. Nox is founded and headed by architect and designer Lars Spuybroek. A central element in Nox' architectural philosophy is the notion of 'time'. More specifically, Spuybroek pleads for design strategies in which the architectural form is the resultant of a set of dynamical and temporal processes. This contrasts with the traditional relation between time and form, where temporal processes are considered to be accidents of a substantial and timeless form. Spuybroek wants to turn this relationship upside down, and aims to make 'time' into the creative substance of form: '… now, finally we can see time creating form, form emerging from processes …' (1998, unpaged).

But how exactly can temporal processes influence architecture? Spuybroek believes that this can happen by establishing an interactive relationship between the subject and the architectural setting, which allows them to mutually influence and determine each other through different interactive media (Nio & Spuybroek, 1994). The philosophical framework underlying this view is borrowed from Merleau Ponty's phenomenological thought, where the world and subject are viewed as entities that constitute and structure each other. When applied to architecture, this assumption entails that the subject can be no longer the passive receptor of the architectural work. Instead, the individual's temporal activities within the architectural setting become constitutive for the characteristics of the architectural design (Spuybroek, 2000a). In turn, temporal changes in the architectural environment influence the presence and modality of the subjects' behaviour.

Figure 81: Nox' Freshwater pavilion on Neeltje Jans.

An example of such interactive architecture is the freshwater pavilion freshH2O eXPO on the Dutch artificial island Neeltje Jans (Zeeland) (Spuybroek, 1997; figure 81). A first source of interaction is the 'fluid', biomorphic interior of the building, where walls, floors, and ceiling merge into one continuous whole. The undulating interior forces the visitor to adapt his/her movements to the specific topography of the building, and thereby influences the form of his/her behaviour. In turn, due to these specific movements, sensors that have been placed throughout the building become activated, which leads to displays of light, sounds and images. Note how a similar conception is at the root of the architectural installation Son-O-House, near Eindhoven. This biomorphic design is the result of digital modelling different types of movements that people perform in houses. In this construct, twenty-three sensors capture the movements of the visitors, and these influence the generative process that produces sounds.

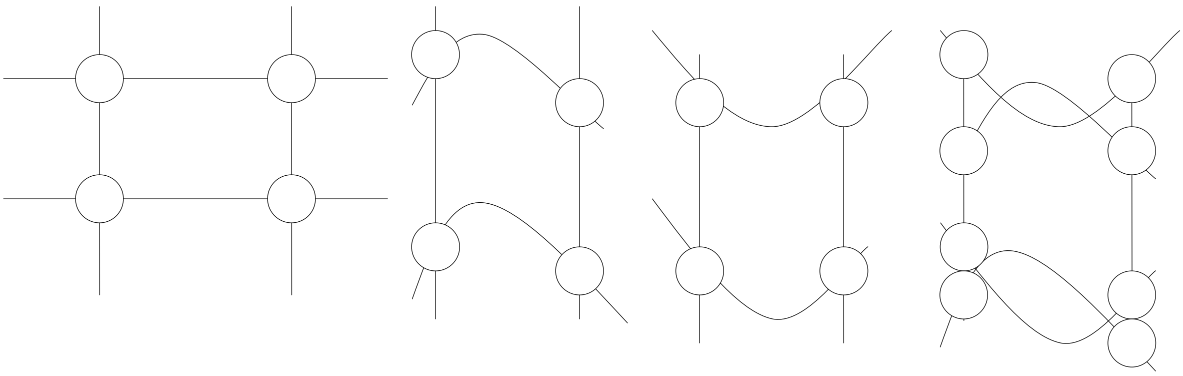


Figure 82: Schematic representation of the strings and springs method. In the Off The Road 5speed project, the original linear diagram (1st scheme) is deformed in two directions (2nd and 3rd scheme). When these diagrams are superimposed, this results in profoundly nonlinear pattern (4th scheme).

A second way in which temporal processes influence the form of Nox' designs should be situated in the specific generative processes that are deployed (Spuybroek, 1999). This is clear from a generative method that has been frequently used by Nox, namely the 'strings and springs' method. This design method makes use of an animation model, that consists of several *strings*, which are mutually connected by (invisible) *springs*. An essential property of such structures is their flexible or 'rubber' character. The degree of flexibility depends on the nature of the springs, which can be stiff, or wobbly. Importantly, these dynamical diagrams can be linked to temporality because they are capable of absorbing potential *movements* or *activities* on the architectural site. This happens by transforming the latter into forces that act upon the flexible strings and springs model, and subsequently cause changes to its form. Thus, by modelling temporal processes, a 'liquid' and flexible architectural whole emerges, which cannot be reduced to a preconceived program or scheme.

Spuybroek has used this method, among others, for the project *Off the Road 5speed*. This is a housing project, on an area near the A58 in Rotterdam (Spuybroek, 2000b). On a model of this area a flexible grid was placed, consisting of a large number of strings and springs. Following this, so-called 'radial forces' acted upon the grid. These forces corresponded to the movements of the passing cars, and deformed the structure in two different directions – to and fro (figure 82). From this procedure, an interference pattern emerged, along which box-like houses were placed. In a following stage, a strings and springs model was associated with each individual housing unit, with the goal of elaborating the schematic shape. This time, radial forces corresponding to three types of domestic activities[8] modified the form, which resulted in dwellings with an overall biomorphic shape. Again, temporal processes literally *in-formed* the appearance of the architectural designs.

Finally, it should be noted that not all of Nox' biomorphic architecture originates from the relation between time and architecture. For a recent series of generative designs Spuybroek has mainly found inspiration in the structural behaviour of materials. For example, some of his more recent designs are the result of applying Frei Otto's 'wool-thread technique', (see Otto & Rasch, 2001), which consists of dipping flexible wool threads in a liquid (e.g. water, varnish). This procedure makes that the threads merge at some points, and form holes on other points. In a following stage, these complex shapes are brought into a three-dimensional modelling environment, where they are further manipulated, and eventually translated into a specific design proposal (Spuybroek, 2002). What is interesting

[8] These three types of radial forces, corresponding to different domestic activities, are: '1. the large radial force … : parking your car, making music, sitting together, having a party, playing in the garden, etc; 2. the middle sized radial force … : cooking, making love, barbecuing, washing, etc; 3. the small radial force … : reading a book, going to the toilet, sewing, working on the computer, etc.' (Spuybroek, 2000b, 58).

about such creations is that their form follows the ideal play of forces. Such designs thereby follow the line of research that was initiated by Antoni Gaudí.

4.4.4.3.c. Adaptive architecture and building bodies: Oosterhuis and Associates

While temporal processes influence the form of the work of Nox, the dynamics of the strings and springs method is always put to an end at a certain moment, which still results in timeless and static architecture. Marcos Novak (1995, 1998) notes how this shows that there is an essential gap between architecture and time. While the process of designing and building is temporal, the final architectonic result is almost always quasi-timeless. Architecture is only trivially temporal, in that architectural elements are sensitive to wearing and patina.

Yet, some recent examples of blob architecture have been proposed that are also capable of continuously updating their overall form. Such adaptive architecture has been the main field of interest and research of the Dutch architect Kas Oosterhuis. Borrowing from information theory, Oosterhuis (1998, 2003) considers life as a force that directs the information flow in the universe. In fact, because Oosterhuis believes that architecture is an attractor of this stream of information, it should be considered as a specific life form too, which explains his speaking of buildings in terms of 'hyper*bodies*' and 'building *bodies*': 'When we make a film of, for example, a house and speed it up a thousand times … the house is acting like a living body. It absorbs all kinds of material, including a liquid stream of humans, pulsating in and out … Who could tell the difference from biological life, seen at the speed we are living at? Since we are captured in our arbitrary speed of life we are unable to experience the consistency of other life forms which are living at a completely different pace' (1998, 103).

Moreover, Oosterhuis holds that there is a universal tendency to increase the information content of the universe. Architecture participates in this process: it is attracting increasingly more information because it is imbedded in large networks and influenced by interactive and participative processes. Importantly, buildings should no longer be passive receptors of this information stream by being static. Instead, buildings can amplify their information content by responding to the information flow through transforming their overall shape. The building thereby becomes more and more like an organism that adapts its behaviour and form to new kinds of information. An example of such adaptive architectural behaviour is Oosterhuis' design for the interior of a space module (Oosterhuis, 1999a). The formal adaptations of this structure are realized by a space-frame, inserted between the inner and outer 'skin' of the module. This space-frame consists of large number of computer-driven pneumatic bars, whose length can be adapted, according to the specific needs and wishes of the users of the structure. Such adaptive behaviour is also characteristic of the pavilions in the project trans_PORTS 2001 (Oosterhuis, 1999b, 2003). These structures are situated in different ports, and virtually connected with each other. Their overall form can be altered according to the local conditions in the associated ports, and in response to incoming information from the Real-Time Evolution Game, played on the Internet. As in the previous example, formal adaptations are realized by a space-frame, consisting of pneumatic bars.

In Oosterhuis' work, the link with naturalness is not only clear from the use of curved surfaces and volumes, but also because his work can display biological-like movement. It is therefore quite probably that such creations will activate the neural areas that have been shown to be involved in processing animacy or biological movement. At this point, it might be relevant to note that some of Santiago Calatrava's work is also characterized by movement and transformation (Tzonis, 1999). According to Tzonis, movement is expressed in the architect's works in two important ways. On the one hand, the components of his design sometimes suggest implicit movement. Clear examples are the TGV-railway station Lyon-Satolas, or the roof of the opera-building in Tenerife. Although both structures are static, they nevertheless express a remarkable figurative movement and dynamic. On the other hand, Calatrava has also created designs whose components are able to make actual movements. Think for example of the Kuwait Pavilion, or the floating construction on the Luzern lake, whose 'petals' can open and close like in a flower. Similarly, the two 'wings' of the Quadrucci Pavilion can 'flap' like the wings of a bird.

4.4.4.3.d. Critical comments on blob architecture

The previous review of blob architecture needs further discussion and clarification, and must be related to the framework presented in this dissertation. First, there is the relation of blob architecture with naturalness, and the question of how this relation should be estimated. While such type of architecture is often associated with naturalness, or concepts surrounding it (e.g. 'organic', 'biomorphic', 'zoomorphic'), this link should not be overestimated. Whereas it is true that Greg Lynn has designed some work with formal references to flowers and trees (e.g. Ark of the World), he seems to be the exception confirming the rule. In general, blob architects do not necessarily pursue designs that have important resemblances with natural entities. Their main interest lies in developing a new stylistic language, a new typology of forms that implies a departure from the straightness that is characteristic of modern architecture and building. More importantly, we believe that there is a contradiction at the core of blob architecture in its current form, which further weakens the supposed link with naturalness. Although blobitecture implies a movement away from straight lines and surfaces, it mostly remains quite minimalist, because it consists of only a few global curvy surfaces. This especially holds true when the works are viewed in a *normal* architectural experience, and not in some abstract computer-supported design space. Such designs seem to share the minimalism and featurelessness of modern building, albeit without the sharp and straight edges of the latter. As will become clear in the following chapter, natural structures are mostly much richer in form.

A second issue that needs to be brought under attention is the sense of isolation that speaks from instances of blob architecture. A first indication of this comes from the observation that the designers of such work are mostly not interested in the environment in which their designs could be integrated. This is clear from the fact that they often remain silent about the future environmental context of their finished designs. Sometimes, this translates into illustrations where designs are displayed in isolation, where the building 'floats' in virtual space without being related to any landscape or setting. The impression of isolation is further strengthened by the observation that the remarkable shapes of blobitecture are factually difficult to integrate within urban or natural settings. Smooth, polished blobs often show no significant textural, material differentiation or use of colour. It is therefore unclear whether and how they can be successfully integrated in the landscape, since the latter often has a richer materiality. Moreover, it is difficult to see how these forms can be related to historical or cultural contexts. Their definite 'novelty' and 'otherness' seem to result in an a-historicism, which is somewhat surprising in view of the interest of several generative designers in the concept of 'time'. It seems that blob architecture is interested in the surrounding context, only inasmuch as it can offer parameters that can deform certain geometrical primitives.

It could be argued that, although blob architecture is not keenly interested in contextual factors, it nevertheless puts importance in the wishes and needs of the future inhabitant or user. Indeed, Tom Verebes of Ocean pleads for a design practice, where objects are literally 'in-formed' by the individual's needs and wishes: 'Modernism is now in transition towards the relations of environmental and user specificity. … A growing belief is emerging that diverges from the modernist notion of production – a system of production predicated on responses to input related specifically to the subjects criteria. Our new century promises a revision of the generic products of modernism. What we seek to gain is the potential to manufacture lifestyle products, architecture, films, TV, clothes, cars, computers, video games, etc., to the specific requirements of an individual' (2002, 192-193).

But how should this interest in the individual be evaluated? First, only a limited number of generative designers pays attention to this factor. Also, a thorough inquiry and analysis of the wishes and needs of the (future) inhabitants seems largely absent in such proposals. The individual remains an abstraction, and is not viewed as a real person, with bodily, psychological and spiritual needs. Furthermore, only little attention goes to the 'space within', the space for living. In most cases, it is not, or only roughly worked out, or barely displayed at all. Still, it could be admitted that the only goal of such 'blob' proposals is to illustrate the conceptual possibility of the formal adaptation to personal requirements. It could well be that each and every individual design will ultimately take these personal requirements into account. However, the actual presentation of proposals that are claimed to be responsive to human needs makes it clear that blob architects already have a good idea of what the future building should look like, before any significant briefing of the individual inhabitants or users has been carried through. Such generative proposals are each based on a preconceived scheme, and the variations corresponding to personality traits can only be minor because they occur *within* this aprioristic scheme. The question whether an individual really wants to live in this type of building in the first place remains largely unanswered.

What is clear from this is that blob architecture is not profoundly interested in dialoguing with what lies beyond itself. Instead, the importance of external or contextual elements lies in the fact that they can 'drive' the generative process. Although generative design proposals are responsive to personality-related concerns to a certain extent, the generative process and the resulting design-object seem to have priority over subject-related matters. This means that the design proposal can be considered as a self-containing and self-referential object. One of the primary goals seems to be developing an interesting aesthetic object or sculptural expression. This conclusion is strengthened by the observation that the structural supports of the plastic surfaces are tectonically not always in evidence, which, again, indicates that generative designers are not primarily choosing an architectural solution, but prefer a sculptural effect. This also explains the fact that this kind of design is only rarely constructed.

5. Biophilic architecture and contextual embedding

The previous criticisms do not imply that form experiments with blob architecture are to be viewed as wrong or immoral. In fact, maybe they should be understood as useful and necessary, because they explore the possibilities and limits of computer aided design and the resulting morphologies. If, however, generative designers are genuinely interested in integration, they should make their designs transcend self-reference and self-containment, and engage into a meaningful dialogue with what lies beyond them. Importantly, this issue of isolation is not only relevant for the discussion of blob architecture, but should be broadened to our treatment of possible biophilic interventions. Biophilic architecture implies that the building enters into a dialogue with a specific set of human inborn preferences to the natural world, and to natural forms in particular. With this, it already goes further than a lot of blob architecture. However, adherents of biophilic design should become aware that their work also has to relate to, or become embedded in a social, historical, ecological and individual context. 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 in this dissertation, attention is paid to a basic (biological) level of wellbeing, while other factors that also contribute to it, become totally neglected. It is not the scope of this dissertation to come to an exhaustive description of all possible factors, but merely to point out that an exclusive focus on biophilic interventions is not an automatic guarantee for a higher level of wellbeing.

Consider the level of the individual. A person can have a strong need for a retreat in his dwelling, where he or she can find a place to meditate, to think about major life-issues. It is probable that certain biophilic interventions, such as open-plan architecture inspired by savanna-type landscapes, could hamper such experiences. This could even become a source of stress for the inhabitant, and it is not implausible that it could largely cancel out the stress reduction associated with savanna-type settings. Furthermore, due to a complex interplay of cultural, personal and historical factors, people also have certain expectations of what a building should look like – they have a certain 'prototype' of the building in mind (Purcell, 1987). For example, the prototypical idea of a church could be that it has a central tower or spire. When there is a discrepancy between an actual building and its prototype, then this can lead to negatively toned evaluations. Probably, this means that biophilic architecture will have to retain a certain conservationism to lead to the desired effects. It is quite plausible that blob architecture in its *current* form will not fit into this picture. Some could claim that this line of thought weakens the arguments for biophilic architecture. We believe the contrary, and are convinced that a careful consideration of these factors can have the result that the biophilic responses to architecture can be maximized, because other interfering factors are controlled for.

Ecological matters are perhaps one of the most important factors to influence our future quality of life, and should therefore take in a prominent place on the political (and public) agenda. We have already tentatively argued how the visual outlook of biophilic architecture can lead to increasing perceptual attention to natural form, which is a factor that can contribute to conservationist and protective attitudes toward the natural world. However, it would be utopian to think that this alone can solve major environmental issues. Importantly, building and architecture have an important share in energy consumption and waste. This underscores the need for biophilic architecture to turn to alternative energy sources, recycling, efficient isolation, environmentally friendly building materials, and so on. Indeed, it would be unthinkable that nature-based architecture is interested in the short-term or immediate impact of architecture on wellbeing, while it remains apathetic for ecological issues, which are relevant for the wellbeing of our future selves, and future generations. It would be contradictory if an architecture that finds inspiration in nature, and that tries to tap its beneficial effects, ultimately contributes to the destruction of nature.

Up to now we have discussed biophilic architecture in isolation from contextual factors. Probably, the desired biophilic responses associated with such isolated architecture would be maximal in experimental settings, where the context is largely eliminated (e.g. an individual could become less stressed, or have a positive aesthetic experience). In the previous sections we have presented different formal strategies to facilitate possible biophilic responses, ranging from the implementation of curves to integrating refuges in a dwelling. However, the critical discussion in the current section shows that such interventions should go hand in hand with a consideration of the possible factors that interfere with short-term and long-term human happiness. Indeed, one can question what the value of nature-based architecture would be if it made an individual socially isolated, and hence, unhappy. What remains of biophilic responses if the building is made up of harmful substances? What of biophilic building if it disturbingly clashes with the local cultural context? In sum, these critical questions reveal that building according to biophilic principles cannot be a reductionist undertaking. Instead, biophilic building should also take into account the other different aspects that are relevant to architecture, and that have an impact on human happiness.

6. Discussion

In the first sections of this chapter we presented the core argument of this dissertation. Nature-based architecture is worth pursuing because it can (probably) positively influence us on a creative, epistemological, and – foremost – on an emotional level. We have shown that there are different ways in which biophilic interventions can be realized architecturally. First, it was proposed how and which specific structural landscape organizations can be implemented in architecture. In fact, empirical research has already established the validity of inserting such features into the built environment (Herzog, 1989). Admittedly, the subsequent parts of this chapter were more visionary. In essence, we tentatively proposed that imitating the forms of natural objects (and even some 'natural' form primitives) in architectural design, could be associated with biophilic responses. Evidently, one of the shortcomings of this discussion is that it remained largely theoretical and speculative. An interesting experiment would be to see if people (for example) show an initial positive affective reaction, and perhaps stress reduction, towards imitations of natural elements, such as symbolic trees.

While biophilic responses can function as a guideline for inserting particular shapes and organizations in architecture, our inborn predisposition to emotionally affiliate with nature can also form part of the explanation why humans have always considered nature as a source of artistic and architectural inspiration. If we are aesthetically attracted to natural entities, then it is no wonder that we also tend to depict nature in a wide range of aesthetic expressions. Nevertheless, it would be naïve to reduce all references to nature in art solely to biophilia, or to think that we are necessarily determined to create only biophilic art. For example, in order to explain why the acanthus is most prominent in Classical architecture, reference must also be made to local contextual or cultural factors. If not, it would be difficult to understand why other forms of architecture in other historical periods do not adopt the acanthus as ornamental vegetation. Moreover, the observation that not all architecture of all times contains references to nature is a clear indication that certain factors can interact with the tendency to affiliate with natural form. Indeed, the latter can even be overridden to a certain extent by parameters that are more primordial and more basic than aesthetic considerations.

Perhaps one of the major factors that could hinder a more widespread integration of biophilic design interventions is economic in nature. Indeed, still today, a lot of more work - and hence, financial resources – come in to play when creating a decorated façade, as opposed to a blank and straight surface. Perhaps our argument for biophilic interventions seems to apply best for more public architectural projects (e.g. governmental buildings, hospitals, schools), where there is more funding available, than for individual housings. Findings from the previous chapter indicate that biophilic interventions in working environments can enhance the workers' mood, concentration, and so on, which could make them more productive. (In the long run, these benefits will probably outweigh the higher construction costs of nature-based architecture). Also in commercial districts, it could be valuable to include biophilic design interventions. In such contexts, such design could not only lead to a pleasurable architectural experience, but the aesthetic component could also attract more people to the area, with the accompanying economic benefits. Still, it must be noted that in commercial contexts already efforts are made to apply findings from the field of environmental psychology, especially in the case of interior design (e.g. Brengman, 2002). The specific economic situation of individuals will make it sometimes difficult to come to architectural biophilic interventions in the context of single-family dwellings. Indeed, these are already very costly, and such interventions would only make the financial pressure on households even greater. It can however be noted that many people already decorate their own dwellings with features that come close to biophilic interventions, and often integrate greenery in their direct living environment.

Chapter 3

Introducing naturalness by implementing fractal geometry in architectural design

1. Introduction

In the previous chapter we already gave attention to a geometric feature (curvature), which seemed to be typical of many natural entities, and especially of animal life. However, from our review of environmental psychology, it can be concluded that research on biophilic responses has found the most convincing results for vegetative elements, such as trees, flowers, plants and the like. Interestingly, these elements are characterized by a typical sort of geometry, namely 'fractal geometry'. Some adherents of biophilic design (e.g. Augustin & Wise, 2005; Heerwagen, 2003) therefore suggest that the integration of fractal-like patterning in the built environment can lead to biophilic responses, because it mimics some core geometric features of natural objects. A similar line of thought is at the heart of this chapter. Whereas in discussions on biophilic design, the evidence supporting such claims often remains implicit or intuitive, we aim to come to a more well-founded treatment of this issue. In the following pages we will carefully argue that there are indeed some theoretical and empirical reasons to believe that fractals can cause biophilic responses[9].

2. What is a fractal?

An often cited quote by the mathematician Benoit Mandelbrot is that '[c]louds are not spheres, mountains are not cones, coastlines are not circles, and bark is not smooth, nor does lightning travel in a straight line' (Mandelbrot in Bovill, 1996, 4). Indeed, the *décor* of human evolution was not a world of cubes, spheres or polygons,

[9] Note that this separate discussion of fractal architecture presupposes that there are some crucial differences between fractal and biomorphic design. On the one hand, note that not all biomorphic architecture is fractal in nature – think for example of recent computer generated design, which consists of only one level of architectural detail. On the other hand, it could well be argued that most fractal architecture is biomorphic, in that it has an essential structural/formal property of many natural forms, namely the recurrence of detail on different scales. However, as will become clear from the following discussion, the notion 'fractal architecture' is not without controversy, and is sometimes used to refer to architecture that has no visible fractal characteristics at all. Furthermore, three-dimensional fractals, such as the Menger sponge, have a rectilinear character. Therefore, referring to such structures as biomorphic could become confusing.

but an environment full of roughness, intricate detail and formal richness. Therefore, if it is plausible that the human mind is in some sense adapted to the elements of its ancestral habitats, then it is also probable that it will show sensitivity to the typical geometrical characteristics of natural settings. Yet, we increasingly come to inhabit a world of simple Euclidean volumes, and this discrepancy between current and ancestral habitats could well have subtle, but important, health implications. This already (preliminary) suggests the value of applying this type of geometrical feature to the field of architecture.

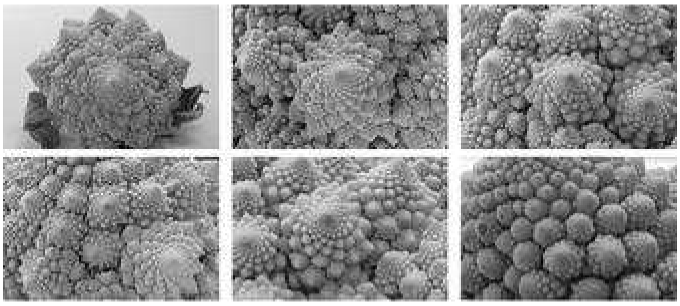


Figure 87: Zooming in on a romanesco cauliflower reveals increasingly smaller, but similar details.

From the seventies of the 20th century onwards, a systematic mathematical description and exploration of nature's geometry emerged. What is important is that it was found that this type of forms could be easily modelled and mimicked with a set of (relatively) simple mathematical transformations. The mathematical objects that were obtained with these transformations were coined 'fractals', which is a term that has the word 'fractus' as its root, which means 'broken' or 'fractured'. One of the defining features of a fractal is that its 'roughness' recurs on different scales of magnitude; a fractal shape consists of increasingly smaller copies of itself. This property is coined 'self-similarity', and it is clearly observable in the series of photographs of the romanesco cauliflower in figure 87. When increasingly zooming in on the structure, one can clearly observe that the florets are all scaled-down versions of the entire cauliflower. While in such a 'natural' fractal self-similarity stops at a given level, this quality goes on to infinity in mathematical fractals (this is because the transformations at the root of fractals are repeated for infinite times). Although this description gives one an intuitive grasp of the notion self-similarity, it should be noted that in mathematics the concept has a more clear definition. In essence, self-similarity is used to describe three related principles: strict self-similarity, quasi self-similarity and statistical self-similarity (for a good overview of the theory surrounding fractals, see Peitgen et al., 1992).

a. *Strict self-similarity* implies that every detail of the fractal is an *exact* copy of the whole structure. This property can be easily explained with an Iterated Function System (IFS), which is a method for generating fractals by iterating a specific transformation. Consider the following transformation for generating the Sierpinski triangle. Begin with a triangle, and make three scaled-down copies of this triangle, where the scaling factor is (say) 1/2 in both the direction of the X and Y axis. Put the triangles in the specified position. In a next iteration all three triangles are subjected to the same transformation. This process is repeated to infinity. The Sierpinski Triangle is the outcome of this process and it is strictly self-similar because at each point, the substructure is exactly similar to the whole (figure 88).

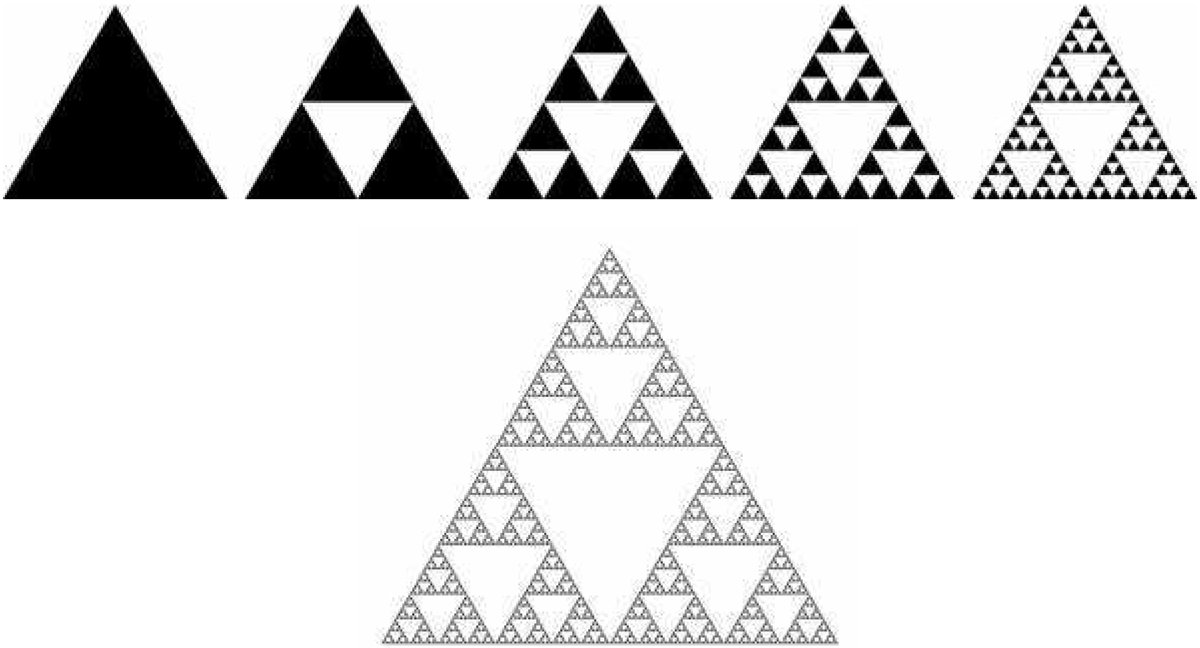


Figure 88: Generation of the Sierpinski triangle. In each subsequent iteration step, the middle third of the black triangle is left out.

b. A fractal can also be *quasi self-similar* when the substructure is recognized as being similar to the superstructure, but not in an exact mathematical way. This quality is clearly present in the Mandelbrot Set. When zooming in on this fractal, the details are more or less similar, but skewed and formally distorted versions of the larger structure (figure 89).

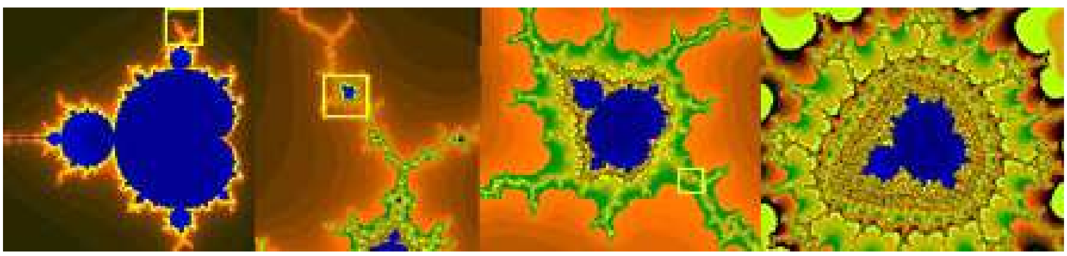


Figure 89: Zooming in on the Mandelbrot Set reveals slightly different shapes, which are still quite similar in overall form.

Quasi self-similarity is also a property of so-called 'self-affine' fractals. Consider again the IFS discussed in the previous section (a). Now, instead of scaling the copies in both directions by the same factor, reduce them by the factor 1/2 in the X direction, and by 1/3 in the Y direction (this is an 'affine' transformation). The substructure of this fractal is almost similar to the entire structure. An example of another self-affine fractal is depicted in figure 90. The quasi self-similarity of this structure is clear from the fact that the ratio of the height to the width of the (coloured) subunits is different from the ratio of the height to the width of the whole fractal.

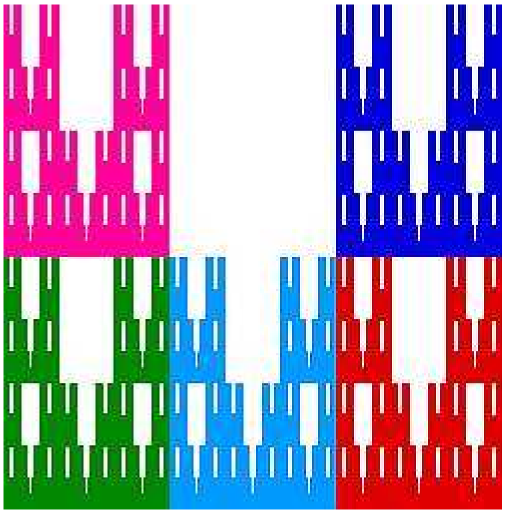


Figure 90: A self-affine fractal.

c. *Statistical self-similarity* implies that some statistical measure or trend is preserved over different scales of magnitude. Perhaps this can be understood most easily by the mountain contour depicted in figure 91. It has a clear (statistical) upward tendency, and this trend is preserved (with some variation) over different magnifications.

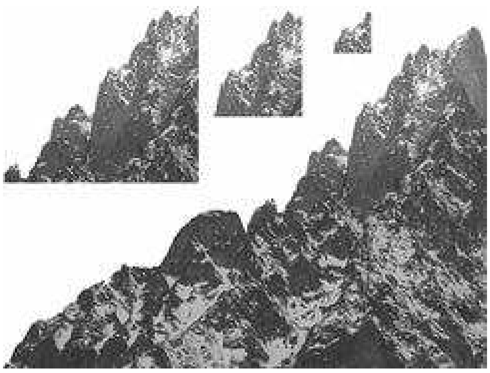


Figure 91: Statistical self-similarity.

In fractal geometry the concept of dimension plays a crucial role. In Euclidean geometry, lines have a dimension of 1, while geometrical objects, such as squares and triangles, have a dimension of 2, and volumes in space are 3-dimensional. In contrast, the dimension of a fractal – coined the 'fractal dimension' – is not an integer value. For fractals in the plane, the fractal dimension lies between the first and the second dimension, resulting in 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 'wrinkled' character, and therefore occupy more space than a simple line (1st dimension), but do not fill the plane (2nd dimension).

The noninteger value of the fractal dimension can also be appreciated by considering a more mathematical approach. Take a line segment and double its length: one thereby obtains two exact copies of the original line. When the lengths of the sides of a square are doubled, then this leads to four copies of the original square. In the case of a cube, doubling the sides results in eight copies of the first cube. Finally, consider the Sierpinski triangle, and again, double the length of its sides. This gives three copies of the original triangle. When all these numbers are put in a table, then an interesting pattern emerges (figure 92). It appears that the value for the number of copies can be written down as a factor of 2 with a specific exponent. Interestingly, the value of this exponent is the value for the dimension of the object. However, in the case of the fractal, the dimension must be a noninteger, since $(2 = 2^1) < (3 = 2^x) < (4 = 2^2)$.

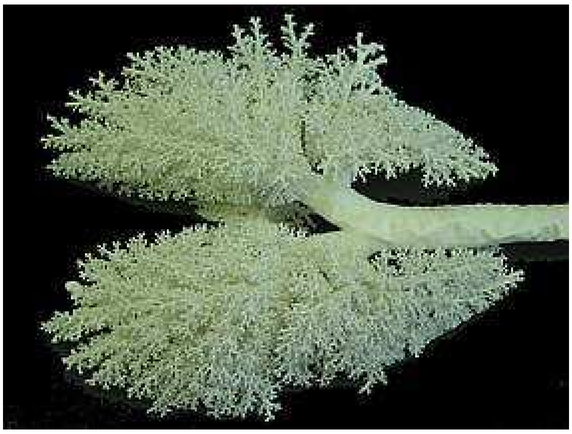
	Dimension	Number of copies
Line	1	$2 = 2^1$
Square	2	$4 = 2^2$
Cube	3	$8 = 2^3$
Sierpinski	?	$3 = 2^x$

Figure 92: Table with spatial dimensions of different geometric objects.

In essence, the fractal dimension should be interpreted as a measure of the degree in which (similar) detail recurs at different scales of magnitude (and hence, as an indication of complexity). There exist different methods to calculate the fractal dimension of a fractal pattern. One can get a very good approximation of it by using the so-called 'box-counting method'. This method consists of superimposing a grid with increasingly smaller boxes on an object, and counting the number of boxes that contains a portion of the image at each stage. For fractal objects, there will be detail from the very large to the small boxes, implying a progression of detail over many scales of magnitude (see also section 8.1 of this chapter for a more mathematical account of the box-counting method) (Peitgen et al., 1992).

3. Fractals: the geometry of nature

Mandelbrot's famous quote, cited in the previous section, suggests that the geometric qualities of natural structures are categorically different from the mathematics inherent to many of the modern architectural structures that surround us. Fractals seem to capture some essential qualities of natural objects, such as their roughness, self-similarity, their intricate detail, and so on. The close relation between fractals and natural structures can be appreciated from different perspectives. First, and perhaps most evident, is the visual observation that many natural elements are rich in fractal aspects. Evident examples are trees, mountains, lightning, clouds, coastlines, and so on. Also, some parts of human and animal bodies, such as the lungs, the arterial network and the brain, are fractal (see e.g. Kiselev et al. (2003) on the relation between the brain and fractals) (figure 93). This implies that these structures only take in a limited volume, while they can be very large in surface. A second link between fractals and nature is that natural elements can be elegantly mimicked with fractal geometry. For example, Ken Musgrave (see: www.kenmusgrave.com) has modelled landscapes and landscape features (e.g. mountains) with fractal geometry (see also Pentland, 1984). Plants and trees can be straightforwardly generated with fractal principles, such as L-systems (Prusinkiewicz & Lindenmayer, 1990). Perhaps the most well-known fractal model of vegetative elements is the Barnsley Fern (Peitgen et al., 1992), which was discovered by Michael Barnsley. As figure 94 shows, a very realistic image of a fern leave can be obtained by a simple Iterated Function System.



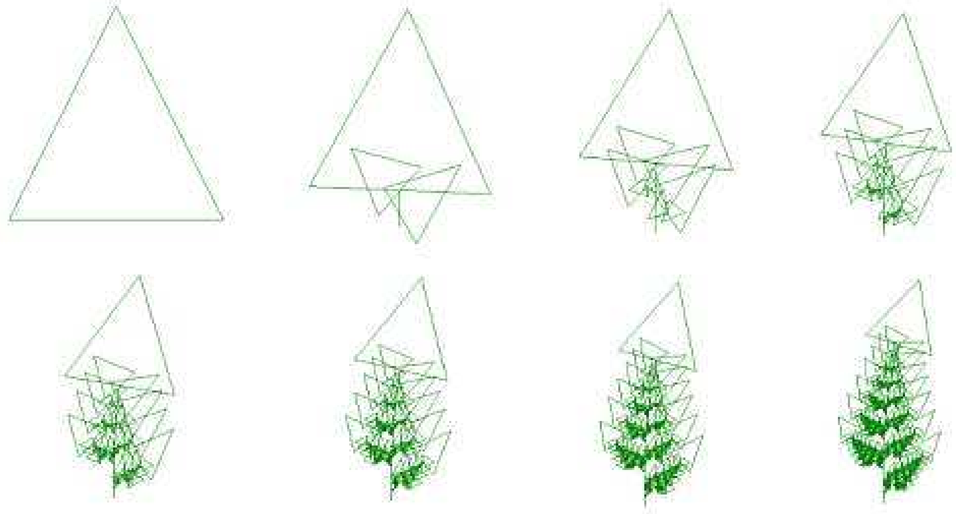


Figure 94: Naturalistic structures can be straightforwardly generated by fractal methods, such as Iterated Function Systems. This figure shows the generation of the Barnsley Fern.

A third way in which fractals and nature can be related is more psychological in nature. For instance, there is evidence that fractals evoke semantic associations of naturalness in human subjects. A study by John Geake (1992) shows that children found fractal patterns to be similar to trees, flowers, dragons, feathers, insects, elephants, planets, sea horses, leaves, root systems, star constellations, solar systems, and so on. Beside this semantic questionnaire, Geake (1992) also discusses an inquiry into the influence of exposure to fractal graphics on the perceptual sensitivity to natural form in primary school children. The notion 'perceptual sensitivity' should be understood as the '… ability to discriminate between discrete instances of highly similar natural imagery' (Geake, 1992, 4). In this experiment, the perceptual sensitivity of subjects was measured for fractal graphics and for natural scenes. In contrast to a control group, children that had intensive contact with fractal graphics in the classroom showed an increase in their perceptual sensitivity for natural environments. A possible interpretation that we have entertained for this finding is that, due to their naturalness, '… contact with fractals helps in developing the [inborn] human predisposition to perceptually differentiate among instances of natural things' (Joye, 2005, 179). This hypothesis obviously has some plausibility in the light of the research presented in the previous chapters. Nevertheless, it is equally possible that, due to the richness of detail that is characteristic of fractals, exposure to these patterns will make people more attentive to details in other visual patterns, with the result that they will score better for certain discrimination tasks.

The (psychological) relation between naturalness and fractals has also been empirically inquired by Hägerhäll et al. (2004). In the first stage of the study, 119 subjects indicated which silhouette outlines of 80 nature scenes they preferred most. In a next stage the fractal dimension of all these silhouettes was calculated. A first analysis did not reveal a statistically significant relation between fractal dimension and preference. Yet, the researchers also undertook a second analysis, in which the pictures of settings with water-features and hills were left out. The reason is that these elements have a strong influence on the visual inspection and aesthetic judgement of landscapes (e.g. Ulrich, 1981), which could distract subjects from concentrating on the silhouette outlines: '[t]he preference rating for such images would consequently be dominated by the content of the scene and have less to do with the shape of the silhouette line' (Hägerhäll et al., 2004, 251). For the remaining 52 pictures, analyses showed a relatively weak but significant correlation between mean preference and the fractal dimension of the silhouettes. Moreover, there were indications that preference increased with increasing fractal dimension until a value of 1.3, and that it decreased with higher fractal dimensions.

Two important conclusions can be drawn from this research. First, the emotional states towards vegetated/natural landscapes can (to a certain extent) be predicted by fractal characteristics, such as the fractal dimension. Perhaps the predictive power of the fractal dimension would increase if not only a fractal analysis was made of landscape contours, but of the totality of each natural scene. Second, because naturalness correlates with preference and because the fractal dimension is a predictor of preference, it can be hypothesized that the fractal dimension is the underlying factor in the relation between naturalness and preference.

4. Fractal aesthetics

In agreement with the previous remark, some environmental psychologists have intuited that fractal geometry could be at the base of the (positive) affective reactions to natural contents: '[Perhaps] … variations in both preference and the restorative value of scenes depends on their underlying geometry, with high preference and restorativeness being associated with fractal and low preference and restorativeness being associated with, for example, underlying Euclidean geometry typical of built environments' (Purcell et al., 2001, unpaged). Similarly, 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 artefacts like music' (177-178; see also Katcher & Wilkins, 1996, 123-124).

But is there any evidence supporting these hypotheses? In addition to their naturalistic character, it can be pointed out that the aesthetic value of fractals is obvious to many, and that these rich and sometimes colourful images often provoke awe and fascination in viewers. Another indication is that art is often created to elicit an aesthetic effect, and that some artists have deployed fractal principles in their work. For instance, Richard Taylor has demonstrated how Jackson Pollock's paintings have fractal characteristics (e.g. Taylor, 2002). However, it should also be noted that not all fractals are aesthetic successes. Mureika (2006) points out that many people dislike fractal art, like Pollock paintings. Also, fractals have sometimes been considered as kitsch (Ostwald, 2001) and described in terms of 'mathematical monsters' (Peitgen et al., 1992).

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 more than 90% of a group of 120 student subjects preferred fractal patterns over non-fractals. Yet, it should also be noted that Arthur Stamps (2002) has tested this conclusion more rigorously. This experiment consisted of 12 stimuli, depicting a modern city skyline. Six of the stimuli had a fractal character, while the others were not fractal. Sixty four subjects indicated the degree to which they found the scenes aesthetically pleasant. Analyses revealed that the scenes without fractal structure (mean preference: 4.69) were slightly preferred over fractal scenes (mean preference: 4.51). Stamps' conclusion is inconsistent with the hypothesis that fractal structures are aesthetically more pleasing than non-fractals. Nevertheless, it should be noted that the fractal stimuli were generated according to fractal rhythms (for a discussion of fractal rhythms, see section 8.5.1 of this chapter). It can therefore be argued that an essential characteristic of fractals – visible detail on different scales of magnitude – was difficult to perceive in this study, and that the resulting conclusion is premature, or at least, applies only to fractal rhythms. Nevertheless, Stamps' method is consistent with the fact that Taylor (2006) argues that contour is perhaps most important in the experience of architectural environments. Hägerhäll et al. (2004) have also focussed on (landscape) silhouettes, for methodological and theoretical reasons (e.g. in free-viewing situations, people tend to focus on information-rich regions, such as contours).

4.1. Fractal dimension and aesthetic preference

Other studies into fractal aesthetics have found that preference is maximal for patterns with a specific range of D values (i.e. fractal dimension). One of the pioneering studies in this field has been carried out by Aks and Sprott (1996). They inquired the preference of 24 subjects for 324 chaotic computer generated patterns.

The value of the fractal dimension of the pictures ranged from 0.49 to 1.78. The experiment revealed that subjects preferred fractal patterns with a fractal dimension between 1.17 and 1.38. The average fractal dimension of the attractors that were rated as most beautiful was 1.26 ± 0.06. Note how the Aks and Sprott study is the only one (to our knowledge) that has also inquired the relation between the Lyapunov exponent and preference. This exponent is a measure for the unpredictability of the dynamical process underlying the pattern, for the sensitivity to initial conditions, and the degree of chaoticity. Overall, the mean Lyapunov exponent for preferred attractors was 0.37 ± 0.05.

Sprott (1996) makes report of three studies into the aesthetic evaluation of two-dimensional computer generated fractal patterns. In the first one, 7500 strange attractors were evaluated by seven volunteers and Sprott himself. It was found that preferred attractors had fractal dimensions between 1.1 and 1.5. From the 443 pictures that were considered as most beautiful, the average fractal dimension was 1.30 ± 0.20. In the second study, the evaluators reviewed 7500 fractal patterns that were generated by an Iterated Function System. Sprott indicates that there was a significant preference for patterns with a fractal dimension above 1. The fractal dimension of the patterns that were described as most beautiful was 1.51 ± 0.43. In the last experiment, the capacity dimension of fractal patterns was computed. The capacity dimension is sometimes called 'box-counting dimension', and its value lies reasonably close to the fractal dimension. From the IFS experiment, Sprott took the 236 cases that were rated most beautiful. Analysis revealed that the average capacity dimension for these pictures was 1.69 ± 0.16.

The study of Spehar et al. (2003; see also Taylor, 2001) into preferred fractal dimension differs from the previous experiments in that three different categories of fractal patterns were used. The first category consisted of 11 images of natural fractals (e.g. trees, mountains, lightning, cauliflower, and so on), whose fractal dimension ranged from 1.1 to 1.9. The second category was a set of 15 mathematical fractals (i.e. computer simulated coastlines), with fractal dimensions of 1.33, 1.50 and 1.66. The third category can be considered as a set of 'human' fractals because they were sections of paintings of Jackson Pollock. The study counted forty of these sections, with fractal dimensions of 1.12, 1.50, 1.66 and 1.89. A total of 220 undergraduate volunteers had to indicate which images they liked most. The results were similar for all three categories of patterns. It was found that patterns with a fractal dimension between 1.3 and 1.5 elicited highest preference. Subjects showed a low preference for patterns with a fractal dimension between 1.1 and 1.2, and between 1.6 and 1.9.

The last study which will be discussed has been carried out by Abraham et al. (2003). In this experiment, eighteen subjects had to aesthetically judge instances of a population of 168 chaotic attractors. The fractal dimension of the attractors fell within four ranges: 0.5-0.8, 0.86-1.4, 1.4-1.6 and 2.2-2.4. Subjects had to rate the aesthetic appeal of four instances of each range, giving a total of sixteen patterns to be evaluated. Analysis revealed a non-monotonous relation between aesthetic preference and fractal dimension. The highest and lowest fractal dimensions were least preferred, while the patterns with a mid-range fractal dimension were liked most. More specifically, it was found that highest preference ratings were attributed to attractors with a fractal dimension ranging from 1.4 to 1.6 and with a mean fractal dimension of 1.54. This result is consistent with the findings of the previous studies.

4.2. Further support for the special status of an intermediate fractal dimension

Although these results are to be treated with caution, there is a tendency for subjects to prefer patterns with a low to intermediate fractal dimension, ranging from 1.3 to 1.5, approximately. According to some authors this '… dimension preference is not surprising since many natural objects have dimensions in this range' (Sprott, 1996, 91). Similarly, Taylor et al. (2003) notes that coastlines and clouds have a corresponding fractal dimension. Still, it should be admitted that the number of empirical studies into this subject is still modest, and further replication is needed. Also, the above-discussed experiments cannot be placed on an equal footing. Perhaps the Aks and Sprott and Spehar et al. studies are methodologically most rigorous, because a large number of subjects and stimuli have been used. The Sprott (1996) study, on the other hand, counted a relatively small number of observers, and was not the subject of a stringent statistical analysis. (Note also that the confidence intervals associated with the preferred fractal dimension are very large).

The preference for a low to intermediate fractal dimension is consistent with the study by Hägerhäll et al. (2004) which indicated that preference seems to summit around 1.3. There are further hints for the special status of this range of values. For example Rogowitz and Voss (1990) have conducted a study in which twelve subjects had to recognize and find new shapes in fractal patterns. The researchers used two-dimensional cloud-like patterns and fractal contours as stimuli. Analyses showed that the ability to perceive namable shapes in the fractal stimuli depended on the fractal dimension. Overall, the results indicated that for both the cloud and contour-stimuli with a low fractal dimension (1.2 and 1.4) the shapes were identified best.

The potential special status of an intermediate fractal dimension is also hinted at in a study by Geake and Landini (1997), in which individual differences in the perception of fractal curves were measured. Forty subjects had to indicate the complexity of a set of fractal curves, on a scale from 0 (least complex) to 10 (most complex). The researchers found a high variance in the estimated complexity. Importantly this variance seemed to 'explode' for D values above 1.3: '… for $1 < D <$

1.3 the variance … seems to increase monotonically with D; for D > 1.3 the variance … seems to "explode", indicating that this task became generally more difficult as the stimuli became more complex, and that some threshold had been crossed at about D = 1.3' (Geake & Landini, 1997, 133).

These two experiments seem to suggest that our mind is in some way attuned to processing fractal patterns with low to intermediate D values. Note that this conclusion is consistent with research into the relation between complexity and preference. Empirical studies have demonstrated that the mind searches for an optimal arousal level, for a balance between low and high information content (Baars, 1988), between order and complexity. Graphically, this finding is reflected in an inverted U-curve. The shape of the curve shows that, when complexity increases, preference initially increases, but eventually decreases for the highest levels of complexity (see for example: Nasar, 1994; Ulrich, 1983; Hildebrand, 1999; Imamoglu, 2000).

The relation of this research with fractal aesthetics becomes more obvious by considering a study conducted by Cutting and Garvin (1987). In this experiment, eight subjects had to rate 216 (fractal) stimuli on a 1 to 10 scale for their perceived complexity. Each of the stimuli originated from a 'generator', and was developed for three recursion depths (1, 2 and 3). When all recursion depths were included, there was only a low correlation between fractal dimension and judgements of complexity. However, Cutting and Garvin found that this low correlation was due to the fact that the first recursion was not a fractal. When only the stimuli with a recursion depth of 2 were considered, then the fractal dimension was a much better predictor of complexity (r = .68). This result suggests a correlation or equivalence between the inverted U-curve, which governs the relation between preference and complexity, and the observed preference for an intermediate fractal dimension.

4.3. Restorative responses associated with an intermediate fractal dimension

If fractals can be meaningfully related to aesthetics, then is there any way in which these patterns can be linked to another biophilic response, namely stress reduction (Ulrich et al., 1991)? To answer this, it must first be noted that it has been hypothesized that restorativeness is the underlying factor for aesthetic reactions towards natural settings. Van Den Berg et al. (2003) have experimentally confirmed this hypothesis and found that '… environmental preferences are mediated by perceptions of the environment's potential to provide restoration from stress' (unpaged). How can this finding be related to the field of fractal aesthetics? Recall that fractal characteristics underlie aesthetic responses to natural settings to a certain extent, and that these responses are maximal for intermediate fractal dimension. It can therefore be tentatively inferred that this range of values will also have the highest restorative potential.

Recently, Wise and Taylor (2002; see also Taylor et al., 2003; Taylor, 2006) have carried out a preliminary study on the relation between fractal geometry and stress reduction. For this, they re-examined a study performed by Wise and Rosenberg (1986). This experiment counted twenty-four subjects, which were continuously exposed to four different patterns: a photograph of a forest setting, a simplified representation (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, subjects had to undergo three stressful mental tasks: an arithmetic task, solving logical problems and creative thinking. Between every task there was a recovery period of one minute. Physiological stress was determined by skin conductance. Research indicates that increased conductance correlates with higher levels of stress.

What were the results of the study? A plot of the skin conductance shows a clear alternation between stressful work periods and recovery. It was found that the degree of physiological stress was dependent upon the type of pattern that was presented to the subjects. 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 it was found that 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 (Taylor, 2006).

Because the researchers did not expect this outcome, they decided to determine the fractal dimension of each of the pictures. This revealed that only the forest and savanna pictures had fractal characteristics. It was found that the pattern that was most effective in stress reduction, namely the savanna picture, had a fractal dimension that fell within the range of D 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 presence of 'naturalness' alone cannot be a sufficient condition for a restorative effect. If this would be 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 D value should fall within the range 1.3 – 1.5.

Despite these remarkable results there still remain some untreated issues and open questions. First, of course, is the highly 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 like savannas most, 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. So 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. But again, 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, and not only the depicted contents. On the other hand, recall how the pictures with certain highly preferred contents (e.g. bodies of water) were left out of the Hägerhäll et al. (2004) study, because they drew attention away from the fractal contours that were the focus of the study. Perhaps, something similar applies to the savanna painting. For example, the typical shape of savanna trees could be a highly preferred feature or 'icon' in landscapes. Perhaps it is a basic 'preferendum' (Ulrich, 1983), that is irreducible to fractal characteristics.

5. Evolutionary explanation of fractal aesthetics

Let us briefly recapitulate the main findings from the previous sections, and show how they can be linked to the general evolutionary framework, forming the backbone of this dissertation. In the first chapter, it was argued that humans show consistent biophilic responses toward naturalness. In this chapter, we argued that fractal properties can capture naturalness. Although more empirical research is needed on this topic, it could potentially explain why fractal patterns can cause aesthetic reactions and stress reduction in individuals. But what could be the explanation for the preference for fractal patterns with low to intermediate D values, and for their restorative power? Because Cutting and Garvin (1987) have revealed a correlation between the fractal dimension and judgments of complexity, a possible answer is that the fractal dimension offers a quick cue of the complexity of the scene. Complexity is a predictor of habitat quality (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 best chances for survival (Wise & Taylor, 2002; Barrow, 1995; Wise, 1997). 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. predator) will be missed or ignored. On the other hand, the complexity is high enough to keep one interested, to awake further explorative behaviour, 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., 2003). 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 hard to suppose that these compute the fractal dimension in order to have a rapid cue of this habitability.

While this line of reasoning mainly takes Roger Ulrich's psychoevolutionary framework as its starting point, to our knowledge no research exists on the relation between fractals and the Attention Restoration Theory of the Kaplans (e.g. Kaplan, 1995). Because exposure to discrete instances of nature (e.g. views on a tree) can lead to the restoration of attention, it is quite plausible that there must be something in the (fractal) shape of these natural elements that facilitates such restorative states. Perhaps the most straightforward link with ART is that fractals are often intrinsically fascinating, which makes that they can be effortlessly perceived, without requiring much conscious attention. Furthermore, fractals also have 'extent'. Due their richness in detail and 'deepness' in structure, they offer the eye a lot to look at, and thereby keep the mind busy. Perhaps the link with compatibility must be situated on a more cognitive or perceptual level. Sometimes it is claimed that the human brain is optimized to process fractals, and in this sense, perception of fractals could be considered as compatible with the workings of our cognitive system. Still, it should be noted that these remarks are entirely speculative, and it is not clear how the restorative property 'being away' would fit in. (Because these issues are an interesting and unexplored research topic, they are part of a research proposal, that will be discussed in the general conclusion of this dissertation.)

6. Alternative explanations

6.1. Fractals and the peak shift effect

Some have also related the aesthetic appeal of fractals to the peak shift effect, which has been described as one of the 'aesthetic laws' deployed by artists (Ramachandran & Hirstein, 1999; see section 4.3, chapter 2). Remember how this principle states that aesthetic effects can be obtained if stimuli are grossly exaggerated – think for example of caricatures. Jonas Mureika (2005) notes that, while there seems to be a consistent preference for fractals patterns with a low to intermediate D value (e.g.

Spehar et al., 2003), artists such as Jackson Pollock have produced artwork with a much higher fractal dimension (1.7) (see e.g. Taylor et al., 2003). Mureika therefore wonders that '[i]t is a curiosity, then, that the artists would apparently tune their art to have such a high dimension when their audience would not appreciate it' (Mureika, 2005, unpaged). But what could be the reason for this discrepancy? Mureika believes that a possible explanation lies in the peak-shift effect. By exaggerating the fractal aspects, the pattern is made more attractive: 'Thus, the hypothesis introduced … is an application of the PSE [Peak Shift Effect] not in physical, representational works, but rather in abstract psychological spaces in which the fractal dimension is the perceptive key. If a pattern of moderate fractal dimension is the most aesthetically appealing, then the PSE suggests that a pattern of high fractal dimension will make the image initially more attractive' (Mureika, 2005, unpaged). Yet, we find this a strange line of reasoning. Fragments of Jackson Pollock paintings have been used in Spehar et al. (2003) with different fractal dimensions. If Mureika's hypothesis would be correct, then wouldn't those fragments with a D value of around 1.7 be preferred? But this is contradicted by the facts. One would, however, expect from an aesthetic 'law' that it is quite general in character, and that a large population of subjects would like the works to which the law has been (unconsciously) applied. Yet, Mureika (2005) notes that '… many dislike the work of Jackson Pollock' (unpaged).

While Mureika's hypothesis is question begging, the application of the peak shift effect to fractals could be an interesting perspective. Perhaps, a more plausible hypothesis would be to state that fractal patterns are super-stimuli *themselves*. In fact, they seem to capture an essential geometric quality of naturalness, and thereby can cause aesthetic effects. More specifically, they seem to be an exaggeration of the dimension of 'recursiveness'. Indeed, this recursiveness goes much deeper in fractals than in natural structures. Fractals are just like the striped pencil, which caught the geometric essence of the beak of a mother's gull. Because many natural phenomena haven't got a very low or very high fractal dimension, it can be speculated that patterns with intermediate D values can capture naturalness the best.

6.2. 1/f or 'pink' noise

Sometimes, the aesthetic appeal of fractals is explained by referring to the fractal characteristics of the brain. For example, it is sometimes argued that cells in the visual cortex are hierarchically organized in so-called 'channels', specialized in detecting a certain spatial frequency. Aesthetic experiences are claimed to occur when there is a matching between the fractal characteristics of the image and the fractal organization (or scaling relation) of the channels (Taylor et al., 2003;

Rogowitz & Voss, 1990). (Note that a similar approach is adopted by Nikos Salingaros, who claims that aesthetic experiences of fractals can occur when there is mapping between the fractal structure of the mind/brain, and the fractal character of the perceived object (see section 7.2 of this chapter for further discussion)).

More commonly, discussions on the relation between aesthetic experiences and the fractal character of the brain make reference to 'pink' or '1/f noise' (pronounced as: 'one-over-f noise'). 1/f noise is a noise signal that is most commonly found in the way the physical world changes through time. It can be found in almost all electronic components (e.g. carbon resistors, vacuum tubes, semi conducting devices); in all sorts of time standards (e.g. atomic clocks, quartz oscillators, hourglass); in ocean flows and flood levels of rivers; in the stream of cars on a highway; in music; and so on (Voss, 1988). In discussions on 1/f noise, often reference is made to two other types of noise, namely 'white' noise and 'brown' noise (figure 98). An essential characteristic of white noise is that the changes through time, which it visualizes, are wholly uncorrelated, and thus random. On the other hand, the temporal changes in brown noise are strongly correlated, which makes this kind of noise more 'ordered'. 1/f noise is considered as the 'midfield' between white and brown noise. It is not as ordered as white noise, nor is it as random as brown noise. As Bovill (1996) mentions, 1/f noise is a combination of 'order' and 'surprise'.

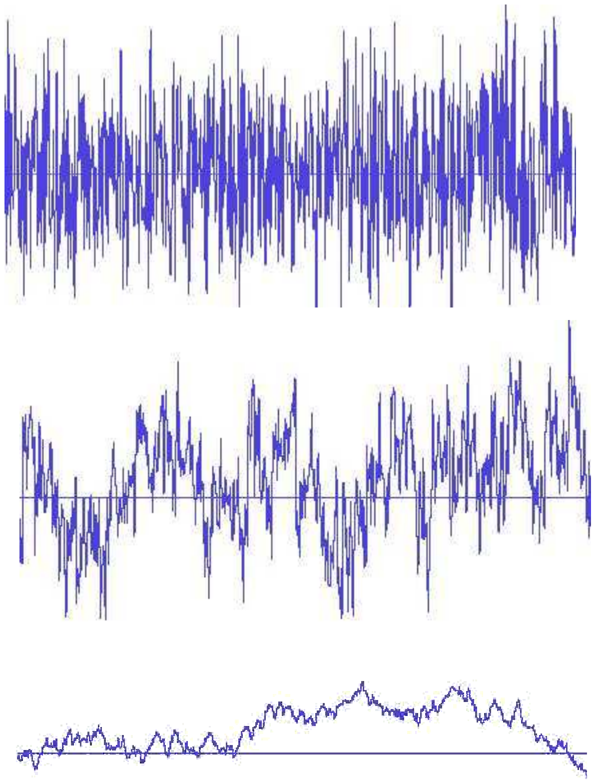


Figure 98: White (above), pink (middle) and brown (below) noise.

The concept of pink noise is a difficult one to grasp. It is therefore insightful to mention that brown, white and 1/f noise can be generated by a fairly straightforward procedure, involving a die and a graph. White noise can be obtained by throwing the die and marking the values on the graph. It is clear to see that all subsequent throws are uncorrelated, and that a random set of values is obtained. In the case of brown noise, the number of the first throw determines the 'starting position' on the graph. On subsequent throws the value should be increased with one unit if the die shows an even number, and one should go down one step if it shows an uneven number (Bovill, 1996, 105-106). The graphical representation of this process is a highly ordered pattern because all the listed values depend on the values of previous stages.

Bovill (1996, 106) also mentions a procedure to generate 1/f noise. What is needed for this procedure is a graphic layout as in the previous methods, three dice, and a scheme consisting of three columns and eight rows (figure 99). The three columns each correspond to one of the three dice. As is clear from the scheme, all the cells in the rows are attributed a binary value.

Row	Die 1	Die 2	Die 3
1	0	0	0
2	0	0	1
3	0	1	0
4	0	1	1
5	1	0	0
6	1	0	1
7	1	1	0
8	1	1	1

Figure 99: Table used for generating 1/f noise.

1/f noise can be produced by the following procedure. First, determine the starting position by throwing the three dice, adding together their values, and marking this number on the graph. To produce the second point of the sequence, consult the table, and compare the binary triples from the first row (000) with those from the second row (001). In this case, the binary values of the third column are different. Now, the procedure says that only those dice that correspond with the columns whose binary values have changed have to be thrown; thus, in this case only the third die should be thrown. Next, add this value to the values of the dice that were left untouched, and mark the sum on the graph. Repeat this procedure to determine the third point on the graph. A comparison of the binary values of the triples of the second (001) and third row (010) shows that the values in the second and third column have changed. Consequently, throw the second and third die, add the sum to the value of the first die, and mark this number on the graph. If this procedure is repeated, a sequence that comes close to 1/f noise is obtained. The numbers that are listed on the graph correlate up to a certain degree because during some stages of the procedure one or two of the numbers from the previous throws were retained, while only two or one dice were thrown, respectively. However, the correlation is not as strong as with white noise. Observe that after a number of steps, all three dice are thrown together, leading to values that are unrelated to the previous stages of the procedure.

6.2.1. Pink noise and aesthetics

Anderson and Mandell (1996) 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' (114). More specifically, the authors describe how human functioning is characterized by 1/f noise, from the microscopic level of neural functioning to the macroscopic level of human behaviour. For the present discussion, the presence of this type of noise in the human mind and brain seems essential: '… 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 behavioural states of consciousness' (Anderson & Mandell, 1996, 77). Some authors propose that due to 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 et al., 1990). For instance, Gilden et al. (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 et al., 2005).

Some authors hypothesize that the proposed fractal nature of the human mind can illuminate the creation of fractal artwork. Essentially, such type of art should be understood as an exteriorization of the fractal aspects of brain functioning (Goldberger, 1996). But 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) puts 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' (102). Similarly, Larry Short argues that, '[i]f fractal structure is built into our nervous systems … it should not be too hard to suppose that there is some resonance or feedback between our perceptual apparatus and that which is perceived' (Short, 1991, 349).

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 something about *subjective* aesthetic states? However, it can be noted that some research exists, which indicates that certain stimuli, which are easily processed by the human cognitive apparatus, can be accompanied by aesthetic reactions – a phenomenon coined 'perceptual fluency' (Reber et al., 2004). Still, this research indicates that the brain is most fluent in processing stimuli that are low in information content: '… stimuli with less information are not only more pleasing, but also easier to process, as measured, for example, by recognition speed' (Reber et al., 2004, 368-369). It is quite clear that such simplicity does not apply to the perceptual outlook of fractal patterns, and it is therefore questionable whether the phenomenon of perceptual fluency can explain aesthetic responses towards fractals. Yet, research involving a search paradigm shows that people can recognize very quickly and easily complex objects, as opposed to simple geometric forms (Li et al., 2002). Furthermore, intricate and complex fractal patterns can be generated with remarkably simple rules, and perhaps the brain uses similar simple rules to decode these forms. While these observations do not prove that the recognition of fractals is characterized by perceptual fluency, it suggests that it is premature to rule it out as an explanation for the aesthetic quality of these patterns.

If the brain is in some sense optimized to recognizing and processing fractal stimuli, then it should not be too hard to understand why such processing is accompanied by aesthetic reactions. Perhaps the aesthetic preference is maximal for patterns with a low to intermediate fractal dimension because the mind is most efficient in processing stimuli falling within this range of D values, being a reflection of the intermediate complexity of a lot of natural structures. Note how there is evidence consistent with this claim. Recall how, identifying new shapes in fractal patterns was best for patterns with a low to intermediate fractal dimension (Rogowitz & Voss, 1990). Perhaps this is due to the fact that perception is most efficient for such stimuli, with the result that more cognitive resources could go to finding forms in these stimuli. Note that also Geake and Landini (1997) found that there was a breakdown in the ease of processing fractal patterns beyond a D value of 1.3.

6.2.2. Healing properties of 1/f noise

Can theories involving 1/f noise explain the stress-reducing effect of fractal patterns? The literature on this matter seems circumstantial and quite thin. A possible inroad to this issue is the finding that, physiologically, a healthy organism is characterized by 1/f spectra. This fractal quality, which we described earlier as a mix between order and surprise, expresses the organism's possibility to adaptively respond to changing situations, or to 'variability': 'Efficient functioning is seen as a multiply determined, multidirectional process that is manifested in high levels of variability. Thus, healthy systems are generally more labile, and maintain "far-from-equilibrium" dynamics…' (Thayer & Friedman, 1997, 40).

It is probable that, in the case of stress, the system's variability and the associated fractal qualities break down (Mountantonakis et al., 2005). Behaviourally, when confronted with extreme stress – such as in the case of phobias – the organism is constrained to only a very narrow range of possible behavioural states: avoiding the phobic stimulus. In an individual with less stress, there will be more behavioural options, but these will nevertheless be more constrained than in unstressed individuals. For example, he or she will more likely stay away from places that can cause further agitation (e.g. crowded, noisy places). Physiologically, stress also seems to be accompanied by less variability. In particular, it is found that the heartbeat over time of healthy subjects is characterized by a large 'heart rate variability'. In the face of disease - and stress in particular – this variability is reduced, and this seems to be accompanied by a breakdown of the heart's fractal or 1/f characteristics (Goldberger et al., 2002).

One can speculate that, by administrating fractal patterns or qualities to stressed individuals, efficient functioning, and the associated fractal spectra, can be restored. Perhaps this is the underlying cause of the (supposed) stress-reducing character of fractal patterns. Note that, although they are very few, some inquiries into the healing and therapeutic character of 1/f noise are consistent with this hypothesis. Stuart Tentoni (1978) has directly inquired the effects of listening to pink noise on physiological correlates of stress. During a period of 6 days, 30 subjects underwent two possible treatments. On the one hand there was a baseline condition, where heart rate, systolic blood pressure, and muscle tension were recorded, without exposure to pink noise. After this baseline period, the same physiological variables were measured while subjects listened to pink noise. Consistent with the current hypothesis, mean heart rate, blood pressure and muscle tension dropped significantly with exposure to pink noise, compared to the baseline condition. This indicates a reduction of physiological stress in the face of pink noise.

Other research into the healing effects of pink noise has mainly focussed on its influence on pathology. Muzalevskaya et al. (1993) conducted different experiments in which 1/f signals were administered by a weak magnetic field to animals and humans. They found that such admissions contributed to immune responses, lengthened survival after exposure to radiation, reduced cancer growth in animals, and normalized cardiac function and EEG (Muzalevskaya et al., 1993). Takakura et al. (1987) inquired the role of 1/f spectra for pain relief. The causes of pain were: trauma, inflammations, cancer, back pain, and so on. Patients received electrical nerve stimulation, either with a 'marketed' stimulator or with a 1/f fluctuation stimulator. They had to indicate the degree of pain relief, ranging from 'complete pain relief' ('0') to 'no effect at all' ('10'). For the 60 subjects that were administered a constant one regular frequency, the average pain relief was 6.5±1.8. The effectiveness of this method was 35%, when the cases where the pain became reduced for 50% or more were considered. The average pain relief of the 91 subjects that were treated with the 1/f stimulation was 4.8±2.4, and the effectiveness rate was 70.3%. Similar results were obtained when the 1/f treatment was accompanied by classical music. Finally, the pain relief continued after treatment for a larger percentage (54%) of the 1/f group than for the group that was stimulated with a constant frequency (36%).

6.3. Critical notes

Are there any reasons for favouring our evolutionary account above the two alternative explanations for biophilic responses toward fractals? First, it has to be admitted that all accounts and explanations are speculative, and should therefore be treated with caution. Second, we have pointed out that Mureika's (2005) explanation for the aesthetic appeal of fractals is difficult to hold because contradicted by some empirical facts. We have proposed a slight modification, and it is easy to see how it can be accommodated in our evolutionary framework. In essence, fractals often imply an exaggeration of the recursiveness and self-similarity that is typical of natural elements (e.g. trees), for which humans display an inborn preference. Thus, the modules or neural mechanisms that respond positively to natural fractals could well respond even stronger to an 'artificial' fractal with more recursive depth. This makes that this account is not at variance with the evolutionary framework, but only deepens some of its aspects. Third, it can be noted that the explanation of biophilic responses towards fractals in terms of noise signals 'emitted' by the nervous system, must be situated on a different level than the proposed evolutionary framework. The former explanation refers to the workings of the nervous system, but it does not explain why the nervous system is characterized by 1/f noise in the first place. Whereas it is true that some researchers have stated that it is the result of evolution in a natural world, with similar fractal properties (Anderson & Mandell, 1996), it remains obscure how a connection with our evolutionary framework should be conceived precisely. In fact, pink noise occurs on all levels of human functioning, from human gait dynamics to neural functioning, while in our evolutionary account it is proposed that the preference for natural form has its correlate in more discrete brain mechanisms or even ‘modules’.

The previous discussion on fractal aesthetics tentatively suggests that the beneficial effects of contact with natural objects (positive affect, stress reduction) could be tapped without the presence of *actual* representations or imitations of nature (see also Cheung & Wells, 2004). Indeed, fractal structures seem to capture some essential features of naturalness, such as the recurrence of (similar) detail on different hierarchical scales. However, the ‘Euclidean’ character of the architecture of many modern environments seems orthogonal to our (hypothesized) predilection for fractal structure. As most humans intend to live good lives, it wouldn’t be a bad idea to replace some of this architecture 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.

Finally, a note should be made on the relevance of fractal architecture for education, and for art and architectural education in particular (see also Joye, 2005). First, while a solid understanding of mathematics is important for architects, the artful nature of fractal images makes them an ideal instrument to draw attention to mathematical concepts, and the underlying worldview. Second, due to the reduced contact with nature in the modern world, artists’ knowledge of shape grammars could become narrower. The introduction of fractal forms in art education can therefore considerably enrich students’ creative curriculum. In this regard it is noteworthy that Geake and Porter (1992) found that the introduction of fractals in the classroom lead students to explore new types of formal composition. Third, in educational contexts, students are often asked to stay concentrated for a long time, which can be cognitively fatiguing and stressful. Creative contact with fractal patterns could counter these effects, because these are found to lead to liking reactions and stress reduction. Finally, making students aware of the human emotional affiliation with fractal forms, could lead to more willingness to protect the (natural) elements that share this type of geometry. This claim finds support in research that shows that emotional interest in nature is associated with proenvironmental behaviour (e.g. Kals et al., 1999).

7. Appropriations of fractal geometry in architecture

In essence, the value of fractals in architecture lies in the fact that it imports some of the geometric structure that was characteristic of prehistoric human habitats into the current living environment. It should be noted that fractals have received some attention within the field of architecture for numerous reasons. In the following sections, we first review some other arguments that try to demonstrate the value of fractals in architecture. After this, an extensive discussion of how fractals have been appropriated in architecture will be presented. This will give the reader insight in the different methods that can be applied to create fractal architecture, and it will show him/her which of the applications is most in line with the current argument.

7.1. Fractal architecture is 'necessary' because it expresses the current worldview

With his books *The New Paradigm in Architecture* (2002) and *The Architecture of the Jumping Universe* (1997a) Charles Jencks has undoubtedly an important share in bringing the issue of fractal architecture under the attention of the architectural community. In the latter book Jencks gives the reader an overview of the complexity sciences, going from principles from quantum mechanics to fractal theory. He further shows how these concepts can be applied to architecture and design. Interestingly, Jencks has also formulated an argument that should demonstrate the importance and necessity of fractal architecture. Although he thereby shares a common point with the current thesis, he does not derive his conclusion from insights into human (psychological) functioning, but infers it from a more inclusive, cosmological view. Jencks' (1997a) argument starts with the observation that we live in a postmodern time where '… society lacks direction, [where] it is disintegrating into angry fragments' (7). Yet, he argues that current cosmology and science can counter this fragmentation, because they can offer us a new meta-narrative, as an alternative to the mechanistic, reductionist and materialistic worldview. Essentially, this meta-narrative shows that the world is '… fundamentally dynamic, [and] self-organizing …' (Jencks, 1997a, 29).

But how can this new worldview penetrate into human life? Jencks believes that science and religion are unable to give direction to society with this new worldview. On the other hand, he thinks that architecture can give direction by expressing a mutual culture. In particular, fractal architecture can provide an artistic interpretation of physical reality; it can refer to the complexity sciences, and thereby express the dynamic, creative and self-organizing universe (see also: Mae Wan Ho, 2001). But why is *architecture* privileged to express this new worldview? The reason, Jencks argues, is that '… when there is a change in the basic framework of thought then there has to be a shift in architecture because this, like other forms of cultural expression, is embedded in the reigning mental paradigms' (Jencks, 1997b, 7).

Perhaps the reader has noticed that Jencks' argument for fractal architecture is essentially flawed. He is correct when he claims that there is often an association between architecture and cosmological views (e.g. Von Simson (1988) describes how the Gothic cathedral is a model of the medieval universe). Yet, by claiming that there is a *necessary* link between architecture and cosmology ('… there *has to be* a shift in architecture'), he commits the naturalistic fallacy. In fact it is entirely unclear how a normative conclusion ('architecture should express the nonlinear worldview') can be drawn from a factual description of the universe ('the universe is nonlinear/fractal'). This flaw is disturbing, especially given the fact that Jencks is quite influential in the architectural community.

7.2. The sensory value of fractal architecture

In the previous chapter, already some short references were made to the writings of Nikos Salingaros. Interestingly, Salingaros has been one of the most ardent proponents of fractal architecture. In a previous life, he was a theoretical physicist, contributing to the fields of mathematical physics, relativistic field theory, and thermonuclear fusion. Yet, since the mid-nineties of the 20th century, Salingaros began publishing in urban and architectural theory. One of his central aims is to come to a scientific foundation for an architecture that follows nature's fractal composition rules.

In essence, Salingaros understands fractal architecture as an architecture that has much detail at subsequent hierarchical scales – think for example of Baroque or Gothic architecture. The core of Salingaros' argument is that fractal architecture is desirable or valuable because, in some way, its geometry is in tune or resonates with human functioning (e.g. '… we connect only to fractal structures' (in: Padron & Salingaros, 2000, unpaged)). But why is this so? In a paper (Mikiten et al., 2000), co-authored by Terry Mikiten and Hing-Sing Yu, Salingaros claims that this due to fractal nature of the human brain. In essence, the brain is '… a structured system of hierarchically-organized modules. These interacting modules communicate with one another. In turn, the modules contain within them yet other sub-modules which communicate among themselves. This pattern is repeated at several different levels of scale, culminating in what is a molecular and biochemical fractal of interacting and communicating systems' (Mikiten et al., 2000, unpaged) Importantly, the processes underlying mental activities – such as memory – are also fractal in nature: 'The brain's multilayered structure has … been suggested as providing a framework for associative memory' (Mikiten et al. 2000, unpag.). Because of its fractal character, the brain and its correlative cognitive processes are ideally suited to recognize and process stimuli that share these fractal qualities.

Probably, Salingaros speculates in Mikiten et al. (2000), the fractality of the mind is the result of human evolution in a fractal world. The natural world has important fractal qualities, and this required a nervous system that was capable of analyzing and decoding such structures. This view has important consequences for human creativity, in that it can form an explanation for the origin of creative outcomes of the human mind, which obey the same fractal rules or 'rules for structural connectivity'. The reasoning is that the mind/brain is fractal-like, and these same fractal-processes are deployed in creative acts, with the result that the mind '… seeks to shape its environment according to the same rules for structural connectivity' (Mikiten et al., 2000, unpaged).

Yet, the authors do not only offer an explanation for the occurrence of fractal-like artwork and architecture, but also claim that it is *necessary* to pursue such creations: 'We believe that environmental structures need to be fractal to satisfy the human brain' (Mikiten et al., 2000, unpaged). If this condition is fulfilled – like with fractal architecture or design – then there is a 'mapping' or 'resonance' between the structure of the world and the structure or workings of the human mind. Importantly, the degree to which this mapping is successful correlates with the experience of 'meaning' of the perceived element. Furthermore, the experience of meaning has an emotional valence, which can be either positive or negative. If the mind/brain perceives a fractal-like structure, then it can easily decode it, by which the structure becomes meaningful, and associated with positive emotions. On the other hand, if an image is non-fractal or incoherent, there is much less meaning, and a more negatively toned emotion can occur. (Note that these hypotheses come close to the concept of perceptual fluency, described in section 6.2.1 of this chapter).

As a fractal architectural theorist, Salingaros has opposed himself ardently against modern, 'non-natural' architectural styles, and does not believe that '… such types of structure are in harmony with our neurophysiological make-up' (Salingaros, 2003, 332). But couldn't it be claimed that the creative processes that generate modern architecture also find their origin in the brain's neurophysiology? For example, Zeki (1999) has argued that there is a correlation between certain instances of abstract art and line sensitive neurons in the visual cortex. Because the brain is the locus of human creativity, it entails that minimal architecture, postmodern and deconstructive architecture will inevitably resonate with certain aspects of our neural mechanisms too. The upshot of this argument is that such type of building cannot be *inherently* wrong for our cognitive apparatus. On the other hand, what is problematic is the (increasing) *dominance* of such non-natural building-styles, at the expense of settings with natural form languages (albeit natural or artificial ones). What we are suggesting is that there is indeed a wide range of factors that influences the aesthetic appreciation of an object. While we emphasize the biological component in this dissertation, this does not rule out in any sense the possibility of more culturally-coloured modes of aesthetic experience (see Bourassa (1991) for a similar approach).

8. Possible implementations of fractal geometry in architecture

The deployment of fractal-like principles in art and architecture seems to be a phenomenon of all times, and is in no way restricted to the period *after* the systematic mathematical understanding and description of fractals from the seventies of the 20th century onwards. In fact, it could be argued that the perennial and cross-cultural presence of fractal geometry in art and architecture is a sign of the human predilection for such type of geometry. Nowadays, computer generated fractal art, and the software to generate it, are widely available on the Internet. Fractal principles are also at work in more 'traditional' arts or crafts: think for example of Dalì paintings, mandalas, mosaics, floor decorations, and so on. Architecturally, the appropriation of fractal geometry seems to have its culmination point in Gothic and Hindu architecture, which will be discussed below.

In modern times, the first *deliberate* instances of fractal architecture were created shortly after the publication of Mandelbrot's *Fractals: Form, Chance and Dimension* (1977). From 1978 to 1988 there was a rise in the interest in the relation between fractals and architecture. Yet, this trend did not persist throughout the nineties, when it was sometimes considered as a kitschy trend (Ostwald, 2001). Recently, there seems to be a renewed interest in applying fractal geometry to architecture. In this regard, an important role is played by Carl Bovill's *Fractals in Architecture and Design* (1996). In this book, which will be discussed below, fractal geometry is promoted as a useful instrument for architectural design. The dissemination of ideas from nonlinear science has also taken advantage from Charles Jencks' treatment of the issue.

Today, the interest in fractal architecture is sometimes grounded in a social-psychological framework: it is argued that such type of architecture is valuable because it can contribute to human wellbeing and functioning. As the reader might notice, this dissertation essentially belongs to this strand of thought. We however, start from a more environmental psychological perspective to support our argument, while eminent fractal-architectural theorists, such as Salingaros or Taylor, take in a more mathematical or empirical approach. Despite its potential relevance for human functioning, fractal architecture takes in a minority position within architectural discussions, and not many scholar treatments of the issue exist. A possible cause is that only few architects use this type of geometry, nor do they profoundly understand which type of worldview is at the root of such structures (Ostwald, 2001). Furthermore, as will be discussed below, discussions on fractal architecture often have a rhetorical component, which can imply a reluctance to be (theoretically or architecturally) associated with it. Some scholars have fiercely criticized such approaches (e.g. Nikos Salingaros), and argue for a more well-founded and scientific interpretation of recent appropriations of fractal geometry in architecture. The current dissertation can be considered as an attempt to meet up to this critique.

8.1. Mathematical analyses of architecture – box-counting dimension

Carl Bovill (1996) extensively discusses and illustrates the relation between fractals and architecture in his didactical book *Fractal Geometry in Architecture and Design*. A reading of the book reveals that an important asset of fractal geometry is its use as an analytical instrument in an architectural context. In particular, by calculating the fractal dimension, the degree of recurrence of architectural elements can be determined for a given building. As will be seen below, this can shed light on the theoretical narratives underpinning certain types of architecture. The analyzing method that Bovill often uses is called the 'box-counting dimension', whose value closely approximates the fractal dimension.

The box-counting dimension is determined by the following straightforward method (see also figure 100). First, place a rectangular grid over a (two-dimensional) representation of the architectural object. Count the number of boxes across the bottom of the grid (B_1), and the number of boxes that contain a portion of the representation (N_1). Next, make the boxes of the grid smaller, and again count the number of them at the bottom of the grid (B_2), and the number that contains a fragment of the object (N_2). Finally, plot a log (B) versus log (N) on a log-log diagram. The slope of this (straight) line approximates the box-counting dimension. The exact formula for calculating the box-counting dimension is:

$$\frac{[\log(B_2) - \log(B_1)]}{[\log(N_2) - \log(N_1)]}$$

Bovill employs the box-counting method to calculate the fractal dimension of some Frank Lloyd Wright buildings. This calculation is interesting because Wright's organic architecture drew inspiration from nature (although it often remains unclear in what sense this inspiration should be understood). By determining the box-counting dimension of some of his architecture, it can be inquired whether the notion 'organic' has any bearings on the organization of the architectural form. More specifically, such analyses can illuminate whether there is reason to believe that some of Wright's work is 'organic' in the sense that it shares the underlying structural organization of many natural elements. Bovill's calculations confirm this hypothesis, and show that some building exteriors (e.g. Wright's Robie House) have a 'cascade of detail' from the largest to the smallest scale, similar to many natural objects.

Bovill has performed similar analyses on modernist works, such as Le Corbusier's Villa Savoye. In contrast to Wright's buildings, the fractal dimension of the Villa Savoye decreases for smaller scales, and eventually drops to 1.0. In essence, this means that there is only detail on the largest scales, while it becomes increasingly more absent on smaller scales. The results of this fractal measuring technique seem to reflect the compositional preoccupations of Wright and Le Corbusier: 'Wright's organic architecture called for materials to be used in a way that captured nature's complexity and order. Le Corbusier's purism called for materials to be used in a more industrial way, always looking for efficiency and purity of use' (Bovill, 1996, 143).

Figure 102: The Cantor Set.

It is interesting to note that Daniele Capo (2004) has applied fractal-analyzing techniques to the Classical orders. Essentially, these analyses show that the orders can have a fractal interpretation. Capo begins by drawing a vertical line through the middle of the orders, and a point is set whenever this line 'hits' some element. In a first stage the information dimension (i.e. a variation of the box-counting method) of the point-assembly is calculated. This procedure entails that increasingly smaller squares are superimposed on the point set, but that the number of points that fall within the squares are also taken in consideration. This method reveals that design elements are present up to eight scales of magnitude: '… all three of Palladio's orders maintain a certain consistency of the data up to the eighth level, indicating that the value of the dimension is demolished only when the count is based on squares with a small side that is equal to 1/256 of the height of the entire order' (Capo, 2004, unpaged). The second technique consists of counting the number of spaces between points whose length is larger than a given value *u*, when *u* is halved on consecutive iterations. This method shows that, as the value of *u* decreases, the number of spaces increases. This, again, shows that there is noticeable detail up to the smallest scales, which is an essential characteristic of fractal objects. Finally, Capo creates a control order where the succession of elements is based on the Cantor set. This fractal set is constructed by the following procedure (figure 102). Take a line, divide it in three equal parts, and leave the middle third out. Next, consider the resulting two parts, and, again, leave out the middle thirds. This process is repeated (until infinity) for all subsequent line sequences. Visual inspection of the control order based on this principle reveals that it is quite similar to the Classical orders. Furthermore, when the first two analytical methods are applied to the control order, then the results come close to those of the real orders. This suggests that the Cantor set is a good approximation of the orders, and lends credibility to a fractal interpretation of them.

Note that Capo is not the only one to propose a fractal interpretation of the orders. For example, Andrew Crompton (2002) asks why '… a Doric entablature, built up out of just a few steps and curves, manage[s] to appear so graceful and natural?' (452). A possible answer, Crompton speculates, lies in the fractal character of the contours of such entablatures. In particular, these elements can be divided into three parts – the cornice, the frieze, and the architrave – which each consist of three further constituent parts. The link with fractal geometry becomes even more intimate when Crompton notes that the Doric cornice has some remarkable similarities with the Devil's staircase. This 'borderline' fractal (Peitgen et al., 1992) is constructed as follows. Consider a square whose side length is 1. In the first step, make a column on the middle third part of the square with width 1/3 and height 1/2. In the second step, erect a column of height 1/4 over the interval 1/9 - 2/9 and one of height 3/4 over the interval 7/9 - 8/9. In the third step, make four columns of heights 1/8, 3/8, 5/8, 7/8. For k steps, 2^{k-1} columns are drawn of heights $1/2^k$, $3/2^k$,…, $(2^k – 1)/2^k$. A visual comparison of the Devil's staircase and the contour of a Doric entablature brings some remarkable similarities to light, providing support for a fractal interpretation of this architectural element.

8.2. Fractal ground plans

Fractal geometry has been implemented in architecture in different ways. In the following sections, we will describe these particular modes. The descriptions are not merely illustrative, but also have a creative component, in that they can serve as a blueprint, or as inspiration for future architecture. In the philosophical discussion at the end of this chapter it is shown how the current argument for the integration of fractal form in architecture fits in with the diverse range of fractal appropriations in architecture.

In the next few paragraphs, the fractal character of ground plans is discussed and illustrated. Such a two-dimensional application can be found in a wide range of architectural structures, ranging from the plans of fortifications, to the organization of traditional Ba-ilia villages (Zambia). The global form of the latter settlements reoccurs in the family ring, which consists of individual houses, which are, again, similar to the overall shape of the village. Interestingly, the scaling hierarchies governing this whole are a reflection of the social hierarchy in these communities

(Eglash & Odumosu, 2005). In particular, the more one moves away from the entrance of the settlement, the higher the status, with the free-standing ring of houses at the back being the chief's extended family ring.

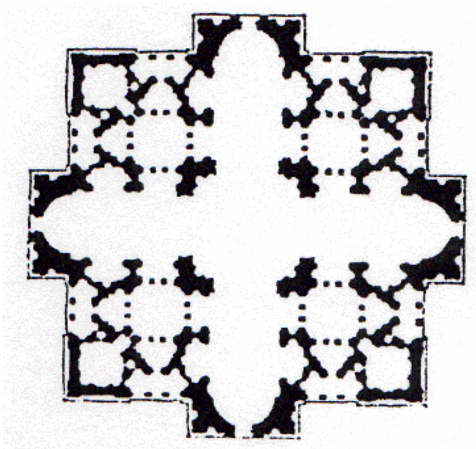


Figure 105: Fractal plan of the St.-Peter Cathedral.

As is noted by George Hersey, fractal organizations are also characteristic of the plan of Bramante's design for the St.-Peter Cathedral (Rome) (figure 105): 'Symmetrically clustered within the inside corners formed by the cross's arms are four miniature Greek crosses, that, together, make up the basic cube of the church's body. The arms of these smaller crosses consist of further miniatures. And their corners, in turn, are filled in with smaller chapels and niches. In other words, Bramante's plan … may be called fractal: it repeats like units at different scales' (Hersey (1993) cited in Sala (2002) unpaged). A recent hint to fractal geometry is also made by Greg Lynn: the outline of the body of water surrounding his Ark of the World (Costa Rica) is remarkably similar to the Mandelbrot set.

8.2.1. Frank Lloyd Wright's Palmer House

Leonard Eaton (1998) seems to be one of the first to offer a direct analysis of Wright's architecture in terms of fractal geometry. While Bovill (1996) also related Wright buildings to fractal geometry, his goal was primarily analytic: to show that fractal geometry is a useful instrument for architecture and design. Although Bovill found that Wright's buildings were more fractal than, say, Modernism, it is Eaton who sheds light on the specific architectural interventions that are at the root of this fractality.

In order to understand the fractal character of some of Wright's architecture, it is important to note that architects sometimes use a 'module' as main organizational element. In a sense, such an element can be understood as the geometrical 'building block' of the house (e.g. a circle). Mead (1991) indicates how Wright often applied this procedure to his work. Initially, the geometry governing the architecture created with the aid of such modules remained Euclidean. In later works, however, these elements were sometimes so organized that they gave the building a remarkable fractal organization in ground plan (Eaton, 1998, 31). A (supposed) culmination point of this evolution is Wright's Palmer House. Here, one geometric module – an equilateral triangle – is repeated in the ground plan (Eaton, 1998) on no less than 7 different scales: 'Consider the fractal qualities in the Palmer house. The entrance, one of the finest that Wright ever designed, is marked by a triangular lamp. As the visitor proceeds up the delicately scaled flight of steps, on his left are rows of clay blocks cut out in a complicated triangular pattern. Under foot the slabs of tinted concrete are canted slightly … The floor [of the living room] consists of slabs of concrete cast in the basic triangular module of the house … Overhead are the great triangles of the ceiling. A view of the kitchen shows a 120° angle in the brick wall and the complex triangularity of the clay block. And at the low end of the scale are the small inset triangular lights on the soffit of the cove which runs around the room … Furthermore, similar diagrams could be drawn in section; the fractal scaling of the Palmer house would then be seen to be eminently three-dimensional…'(Eaton, 1998, 32-35).

While at first sight Eaton seems to demonstrate the fractal nature of the Palmer House, his argumentation stirs up some questions. If the Palmer House is, due to a recurrence of similar geometric units on different scales, an example of fractal architecture, then wouldn't almost every instance of architecture be fractal? For example, take the house where we live in. It has a rectangular layout. In this ground plan, smaller rectangles are embedded: the individual rooms. The walls are even smaller rectangles, and they are in some places further partitioned where the chimney passes. The walls themselves are made of bricks, and in some places they have rectangular openings for windows or doors. Only in this superficial description, our house already has self-similarity up to five hierarchical scales. But surely, it can't be an instance of fractal architecture?

Despite its silliness, this argument seems to confront one with some pertinent questions about what exactly makes an instance of architecture fractal. Yet, Eaton tries to clarify more precisely why the Palmer house is fractal and notes: '… [it] presents iterations of precisely similar geometric units, not approximations of varying sizes' (Eaton, 1998, 37). With the notion 'precisely similar' Eaton seems to presuppose that a structure is fractal when it is strictly *self-same*. However, in the previous sections we described that classes of fractals exist that are not strictly self-same. Eaton also notes that, in order to consider a building as an instance of fractal architecture, '… none of the iterations … [can be] the serendipitous result of available manufactured materials; in the Palmer house the fractal quality is in every case the result of a *specific and conscious* act of design' (Eaton, 1998, 37). But what does Eaton mean with a 'specific and conscious act of design'? Does he mean that Wright deliberately aimed at self-similarity on different scales? But if deliberateness is in some sense a constraint for considering a building as fractal, then it should be explained why certain buildings are *prima facie* fractal, while their self-similarity was not deliberately pursued. But couldn't it also mean that the use of a triangular module is a conscious act? However, as previously mentioned, the different elements of my house are also the result of conscious acts – the doors and windows are put there for a definite reason. If, according to this line of thought, my house would become fractal, then this would render a lot of buildings fractal, and would make discussions on fractal architecture almost trivial.

But even if these issues are left aside, there is a further difficulty with the fractal nature of the Palmer House. When inspecting the ground plan of the house, there seems to be no overall coherence or structuring; the triangular modules are distributed in a quasi random fashion. Surely, random fractals exist, but it is confusing that Eaton does not relate the Palmer house to these. These difficulties do not imply that Wright's later work doesn't have any fractal component whatsoever. Instead, they illustrate that there is need of more carefully articulating how the fractality of the works should be interpreted. A building where the fractal character is perhaps more readily perceivable, and less random, is Wright's Town Hall in Marin County (San Francisco) (figure 108). In this structure, above each arch a window or arch is placed that is somewhat smaller than, but similar to the previous one. This gives the structure self-similarity up to five hierarchical scales. Portoghesi (2000) notes that the resulting structure comes close to the Cantor Set (figure 102).

Figure 108: Fractal organization of arcs in Wright's Town Hall in Marin County.

8.2.2. Ushida-Findlay

Although Wright often referred to his architecture with the notion 'organic', he used it in many ways, and did not exclusively employ it to refer to the architectural form. On the other hand, several works of the contemporary architectural cooperation Ushida-Findlay can be considered as 'organic' because they often make recourse to biomorphic form grammars. A well known biomorphic building is the Truss-Wall House (Tokyo). While the nonlinearity of this building can be related to the complexity sciences because it is formally similar to a strange attractor, Ushida-Findlay have also made more explicit references to fractal geometry in their work (see e.g. Ushida & Findlay, 1996).

Michael Ostwald (1998) argues that their works relate to fractal geometry in different ways. First of all, the ground plans of a number of designs is based on the golden section. This applies, among others, to the House for the Third Millenium, Kirishima Sculpture and Housing Prototype. Importantly, the fractal interpretation of these works should be nuanced because the golden section, and hence the architecture based on it, is only 'trivially' fractal. It is fractal because it is the result of an iterative process and because it fills the plane more than, say, a line. It is a trivial fractal because it typically does not have the irregularity recurring on different scales of magnitude.

According to Ostwald (1998), the ground plan and layout of some other Ushida-Findlay designs could receive a more literal fractal interpretation. Examples are the Hoshida Housing Competition and Kaizankyo. In the former design, the buildings are organized around a leaf-like pattern that is repeated on different scales. Similarly, the Kaizankyo house consists of four 'leafy' structures that are imbedded in a golden section. The scale of these structures reduces according to a certain ratio and according to their position in the spiralling structure. Fractal organizations also govern the ground plan for the urban 'Ƨ Project', which is '... a major transport interchange for Tokyo located at the intersection of a number of arterial roads and rail line' (Ostwald, 1998, 141). This urban project consists of four roads that come together, and bifurcate at their ends in different subbranches. The relation of this structure to chaos theory is hinted at by Ushida-Findlay (1996), when they note how urban structures should adapt to the chaotic traffic of individuals: '... [S]paces must be created to accomodate the innumerable encounters of freely moving persons who drift throughout the city; and the city itself must be programmed as a vessel to contain this Brownian movement' (15).

Ushida-Findlay's work is worth discussing because it is one of the few modern examples that have been claimed to implement fractal principles. Yet, some could find that the recognized links with fractal geometry are perhaps quite shallow. Indeed, as will become clear from the following sections, more convincing appropriations of fractal principles have been created. Furthermore, it can be noted that not the buildings are fractal in ground plan, but that it is their organization or placement that follows a fractal pattern. Despite these tensions, discussing Ushida-Findlay's work is still relevant, because it foreshadows some of the difficulties associated with the concept of fractal architecture. In agreement with Ostwald (1998), here we can witness a movement from the literal appropriation of fractal geometry in architecture, to a more symbolic application. When pushed to their limit, such broad interpretations of fractals in architecture sometimes have no longer any bearing on the architectural form, but instead, only serve rhetorical purposes.

8.3. Fractal tiling

An obvious disadvantage of fractal ground plans is that the fractal component is barely visible for the viewer in a normal architectural experience. In this sense, it could be claimed that it looses some of its significance, and that there is need for three-dimensional applications. A method, recently adopted by some architects, is to tessellate an architectural façade. On first sight, the link with fractal geometry seems obvious: such patterns are rich in detail, which seems to be an intuitive characteristic of fractals. This applies especially to traditional tiling and mosaics. Note how an important adherent of fractal architecture (Nikos Salingaros in Mikiten et al., 2000) has recently argued for the integration of fractals in an urban context by integrating tiling in pavements.

The architectural group Ashton Raggatt McDougall was perhaps one of the first to apply (fractal) tiling to architecture (Ashton Raggatt McDougall, 1997; Jencks, 1997a, 1997b). They covered the façade and the interior of the Storey Hall (Melbourne) by polygon tiles that are inspired by Penrose tiling (figure 111). Penrose tiling has been discovered by the British mathematical physicist Roger Penrose, and can be described as a pattern of simple tiles that can cover the plane in a non-repetitive manner. While different sorts of Penrose tiling exist, the one depicted in figure 110 is made up of two types of tiles. An important precondition for arranging such tiles is that they cannot form a parallelogram. The link of such tessellations with fractal theory can be inferred from the fact that they can be generated by Iterated Function Systems and L-systems (Ramachandrarao et al., 2000).

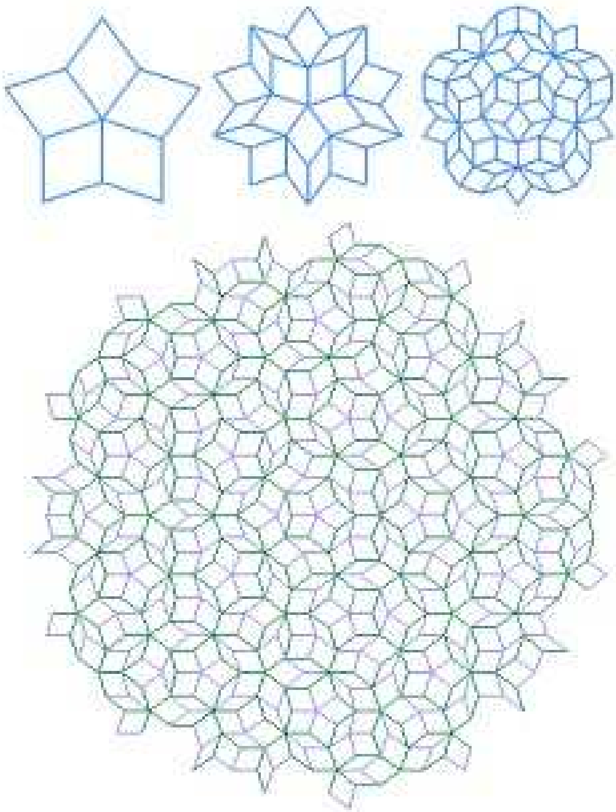


Figure 110: Penrose tiling.

Figure 111: ARM's tiled Storey Hall, Melbourne.

A 'tiling-approach' has also been adopted by the Lab Architecture Studio for the Federation Square in Melbourne and its adjacent buildings (figure 112). The main units of this 'fractally incremental system' (Lab Architecture Studio, 2007) are triangles, which are organized by five into panels, while five of such panels form the main constructional module. The connection between tiling and fractals has also been made in Daniel Libeskind's expansion for the Victoria & Albert Museum (London). The exterior walls of this design are spirally positioned around a virtual and continuously shifting axis. The surface of this geometric structure is covered by ceramic tiles, which Libeskind coins 'fractiles': '[t]he structure and cladding of the new extension are formed by the 'fractile', a new kind of tile pattern whose economy allows a multiform language to emerge out of an elementary geometric piece, interpreted in a variety of different ways' (66).

Figure 112: Lab Architecture Studio's Federation Square building with 'fractal' tiling.

It should be noted that the relation of tiled façades with fractal geometry is difficult to judge, and sometimes ambiguous. On the one hand, it can be noted that such constructs have no detail within detail, no tiles within tiles. In a sense, the patterns are no more fractal than a grid of squares is fractal. They contain many details on one scale, but zooming in on the structure would not reveal new detail on finer scales (perhaps this is most obvious in Libeskind's creation where there is only one level of detail). On the other hand, it should be noted that in the case of the Storey Hall and the Federation Square, the tiles are organized into 'higher-order' wholes, with the aid of texture, colour and lines. This gives them a profounder sense of self-similarity. Finally, some might argue that such fractal architecture is merely surface treatment: essentially, they are not architectural but decorative interventions. Indeed, leaving out the patterns would probably wipe out the (supposed) fractal character of the building altogether.

8.4. Three-dimensional fractal architecture

But do there exist instances of modern architecture, where the fractal component is eminently three-dimensional, where it pertains to the architectural form and/or structure? Such appropriations seem rare. On the Internet we came along the website 'www.fractalarchitect.com', which shows building designs that are the result of 'marrying' fractal principles and modernist forms (figure 113). In the 20th century, the Russian artist Malevich has created a series of architectural designs ('Arkhitektoiniki') of which some have a remarkable fractal component. For example, the building in figure 114a, is surrounded by smaller versions of the whole building, which are again surrounded by even smaller fragments. The relation between their number and size is claimed to obey a 1/f relation. More recently, Steven Holl Architects' Simmons Hall has been related to fractal geometry, because it is inspired on a sponge, whose openings are known to have a random fractal distribution. The relation of the building with fractal geometry can also be appreciated by comparing it with the random fractal depicted in figure 115.

Figure 113: Proposal for three-dimensional modern fractal architecture.

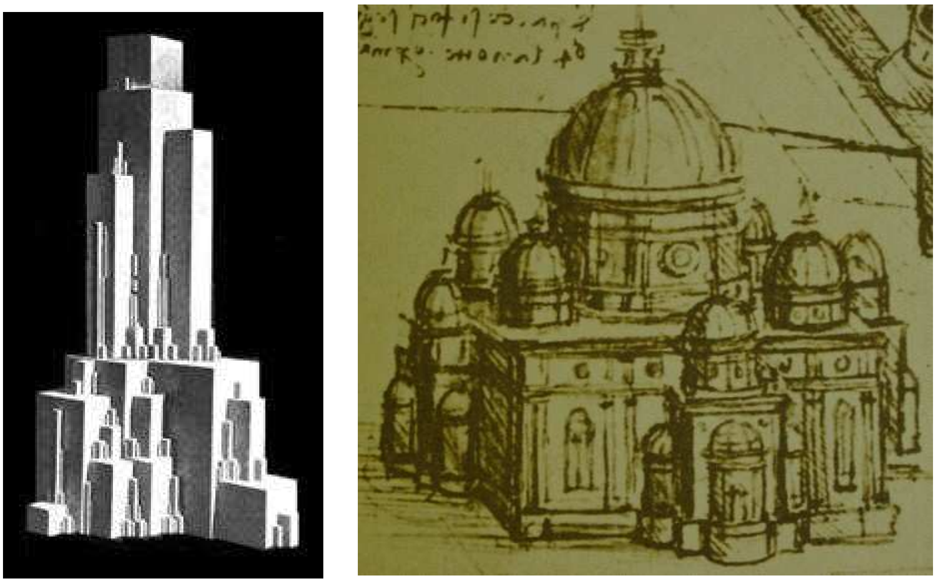


Figure 114: Three-dimensional fractal architecture. (a) Example of Malevich's Arkhitektoiniki. (b) Fractal cathedral design by Da Vinci.

For other eminent examples of three-dimensional fractal architecture, we have to go back in time. Sometimes it is noted that Da Vinci's cathedral designs are fractal, because the domes are repeated for different sizes (Sala, 2002) (figure 114b).

However, this example and the previous one, cannot meet up to the profound fractality of certain Hindu temples (figure 117) (Portoghesi, 2000; Lorenz, 2003; Sala, 2002). Importantly, the fractal character of Hindu temples is profoundly intertwined with Hindu cosmology (Trivedi, 1989). In fact, these edifices should be understood as models of the Hindu cosmos. In Hindu cosmology, each part of the cosmological whole ís the whole itself, and contains all the information about the whole. Some schools of Hindu thought adhere to the (related) view that the macrocosm is 'enclosed' 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, 245-246). Interestingly, both cosmological conceptions can be straightforwardly related to fractal self-similarity. Here also, the global structure of the patterns recurs – over and over again – in the microstructure.

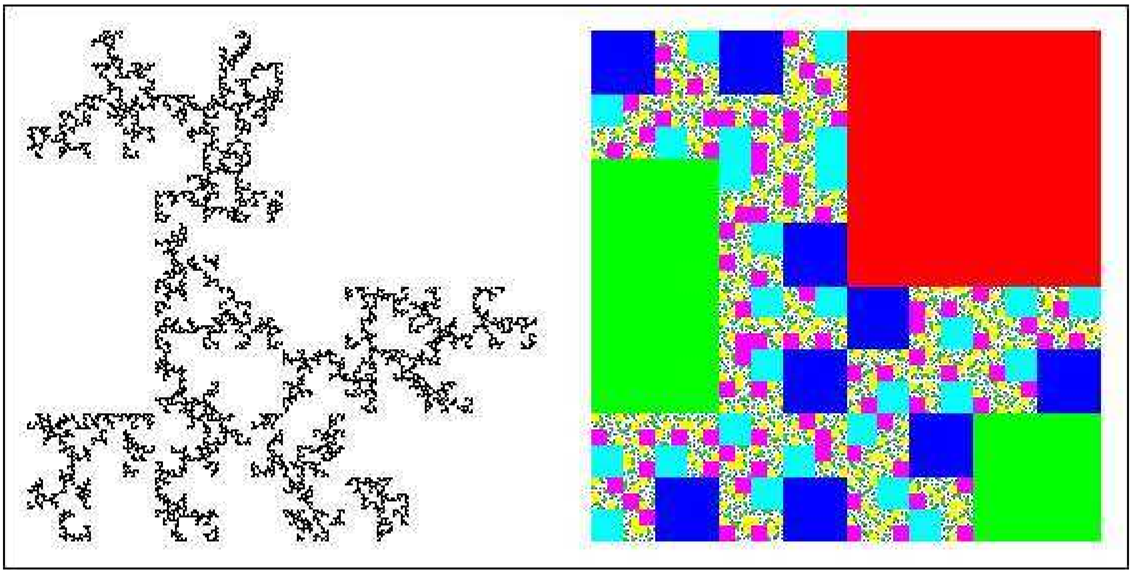


Figure 115: Random fractals.

In order to maintain a harmonious worldview, man-made objects and artistic expressions were made in accordance with the central principles governing the Hindu cosmos. The result is a profound three-dimensional fractal architecture. The fractality of Hindu temples can be traced back to a set of typical architectural interventions. A survey of these methods is not only theoretically interesting, but also offers one a set of concrete guidelines for enhancing the fractal character of architecture.

(1) Splitting or breaking up a form, and repeating it horizontally, vertically or radially.

(2) In the ground plan, iteratively replacing the (plain) sides by sides that contain interior and exterior projections or more detail. This method can also be applied in three dimensions.
(3) Three-dimensional self-similar iteration of the (central) spire of a Hindu temple (figure 118).
(4) Repeating similar shapes horizontally and/or vertically.
(5) Three-dimensional superimposition of architectural elements ('… motifs are inscribed within different kinds of motifs and several different kinds of themes and motifs are condensed and juxtaposed together into one complex and new entity' (Trivedi, 1989, 257).)

Another building style that is often related to fractals is Gothic architecture. Goldberger (1996), describes the fractal character of this building style as follows: '… fractals capture several key features of Gothic architecture: its porous 'holeyness' or carved-out appearance, its wrinkled crenelated surfaces, and its overall self-similarity … The fractal nature of the Gothic cathedral can be appreciated by viewing it (both from without and within) at progressively greater magnifications … 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. The carved-out, fenestrated nature of the buildings, particularly when supported by flying buttresses, gives them a remarkably skeletal appearance and accounts for their luminosity' (101).

Figure 117: The richness in detail, and the repetition of forms on different scales, makes that some Indian Hindu temples have an eminent fractal character.

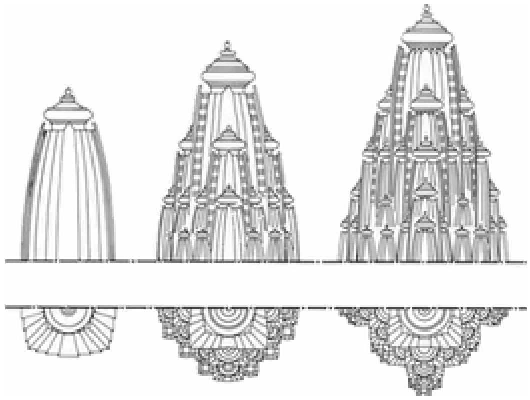


Figure 118: Three-dimensional fractal generation of a Hindu temple. The main spire is surrounded by scaled-down spires.

From the illustrations one can easily discern which specific methods have been (intuitively) deployed to give Gothic buildings their fractal outlook (e.g. figure 119). In fact, these methods are quite similar to the ones used in Hindu architecture. For example, the shape of the main portal in figure 120 recurs on a smaller scale in the two side portals. Further and smaller versions of this form can be found in the different arched windows. These are sometimes divided into constituent parts, where the stained glass, with its vibrant and colourful patterns, adds even more detail to the façade. The complexity of the façade is further increased by the mere repetition of forms. For example, the contours of the main and side portals are repeated inwardly, and often circumscribed with a wealth of figurines. The fractal component of Gothic cathedrals also speaks from the rose windows. The window depicted in figure 121, has an overall circular form, in which a flower-like shape is inscribed. Around this flower, circles of varying sizes are placed, and some of these also contain flower-like patterns. Near the ends of the large 'petals' of the rose window further circles with flower-like patterns are enclosed. Each of these is divided into two sub-petals. The fractal character of the window is even further enhanced by stained glass.

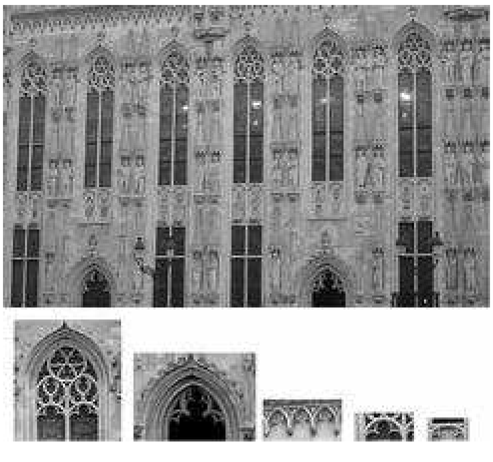


Figure 119: The fractal character of Gothic architecture (town hall, Bruges). An architectural element is repeated on different scales.

Figure 120: 'Fractal' North Entrance of the Westminster Abbey, London.

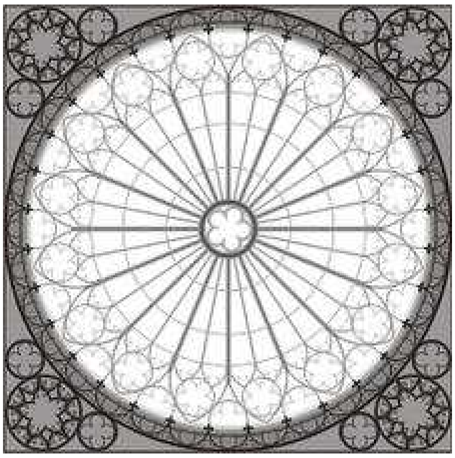


Figure 121: Drawing of the rose window of the west façade of the Strasburg Cathedral.

There is no really straightforward way in which fractals can be related to medieval cosmology, and we therefore limit this discussion to a few general remarks and speculations. For example, Kevin D. Marti (2001) traces the three-dimensional (fractal) form of these buildings back to neo-platonic concepts such as 'emanation' and 'reversion': 'The form of classic Gothic cathedrals reflects the stages of Pythagorean emanation: three-dimensional space emanates from its terminus in two-dimensional space, which in turn emanates from its terminus in the divine point or monad; and rectilinear space emanates from curvilinear space. Reversion reverses these stages' (Marti, 2001, unpaged). The relation between Gothic architecture and fractals can also be appreciated by the fact that Gothic architecture was based on a stringent proportional system. It thereby was a model of the medieval cosmos, which was governed by strict mathematical proportions or harmonies (Von Simson, 1988). Interestingly, sometimes it is noted that a consequence of these strict proportions is that the Gothic cathedral could be built back up, when only one small fragment of the building was left (Steadman, 1979). Note how this is somewhat reminiscent to fractals generated by Iterated Function Systems. By some simple transformations, based on a generator and initiator, such systems can build up an intricate and complex fractal structure.

8.5. Fractal principles as a creative instrument

The previous discussion contained already quite a bit of practical information to enhance the fractal character of built work. In this section we propose some more of these guidelines. Before embarking on this, it is relevant to note that some architectural theorists have intuitively worked out composition rules that favour fractal forms. In particular, Crompton (2002) hypothesizes that traditional composition is attractive and successful because it produces fractals. He tries to prove his case by closely examining some of the composition rules that have been proposed by John Ruskin. We give a brief overview of these, and relate them to fractals.

(1) First, Crompton (2002) mentions that Ruskin found it important that ornament is meaningful both when seen from a distance as from close by. This connects to fractals because these contain detail, ranging from the macrostructure to their microstructure.

(2) Second, Ruskin pleads for an abundance of features or an uncountable number of elements. As Crompton (2002) notes, this abundance is also a property of fractals: 'Fractals are aptly described as uncountable. If one tries, for example, counting the bumps on the Koch curve one is soon lost because it cannot be decided if a component is too small to be included or not' (457).

(3) A third composition rule is the 'law of principality', which refers to organizations that contain one focal or dominant feature, while the other features group with it in subordinate positions. (Crompton, 2002, 457). This can be related to the (architectural) fractals that are characterized by one dominant form, around which smaller iterations of the global form are organized (e.g. figure 118).

(4) Another law is Ruskin's 'law of repetition' where '… one group imitates or repeats another, not in the way of balance or symmetry, but subordinately, like a far-away and broken echo of it' (Crompton, 2002, 457). In fractals, the substructure is also often an echo or scaled geometrical variation of the whole structure.

(5) The variation or permutation of subordinate elements within fractal structures seems to evoke Ruskin's 'law of continuity': '… an … orderly succession to a number of objects more or less similar … most interesting

when it is connected with some gradual change in the aspect or character of the objects' (Crompton, 2002, 457).

(6) Finally, Ruskin believed that beautiful objects are characterized by 'delicately curved lines'. This closely fits the fact that a lot of fractals, and especially those resembling vegetation, have curved contours whose aspects are continuously changing.

8.5.1. Fractal rhythms

Besides using fractal geometry as an analytical tool, Bovill (1996) also employs it as a creative instrument. This makes that he is in a quite unique position. Although many researchers discuss the relation between fractals and architecture, almost none offer specific guidelines on how to create architecture according to fractal principles. In his treatment of the subject, Bovill mainly uses fractal rhythms as a generator of architectural organizations. A straightforward method to generate such rhythms is by midpoint displacement (figure 122). This generative strategy works as follows. Start by drawing a horizontal line of a certain length. Next, determine the midpoint of this line, and from there, draw a line of length L, perpendicular to the horizontal line. Connect the two extremes of the horizontal line with the upper endpoint of the vertical line. In the following stage, determine the two midpoints of the sloping lines and, from there, again draw two perpendicular lines. Connect the extremes of the sloping lines with the endpoints of the perpendicular lines. Repeat this procedure until a desired pattern or resolution is reached.

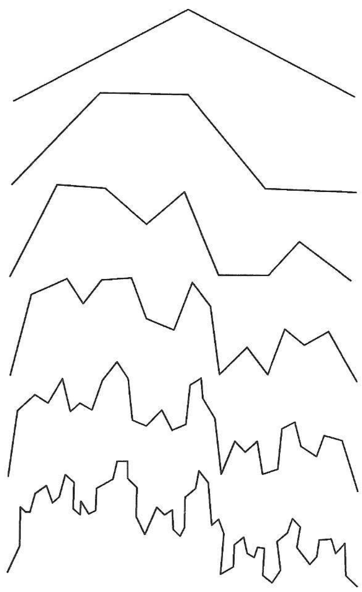


Figure 122: Midpoint displacement.

Note how different fractal rhythms can be obtained by choosing different scaling factors for the subsequent perpendicular lines. Also, randomness can be introduced in this procedure. For example, flip a coin to determine whether the perpendicular line in a certain step of the generation process goes up or down (figure 122). The procedure can be made even more complex by making the displacements dependent on a Gaussian distribution centred around zero. By randomly choosing a point on this curve, two things can happen. On the one hand, the value associated with this point can be positive or negative, which determines whether the perpendicular line goes up or down, respectively. On the other hand, the fractional value of this number can be used as the scaling factor for the perpendicular lines. Because this value varies along the curve, some of the displacements will be large, while others will be small.

Architecture is characterized by discrete elements: i.e. windows, doors, walls, and so on, have well-defined boundaries. In contrast, the fractal curves that are the result of midpoint displacement are continuous. However, they can be easily transformed into discrete step functions by superimposing a grid on the fractal rhythms. This procedure results in a specific range of values. Bovill indirectly uses these values to generate architectural organizations. In particular, he associates each of these values with one element of a sequence of eight modular sizes, whose widths are borrowed from Van Der Laan's architectonic scale. The result is that different fractal rhythms lead to different numerical sequences, which translates into a new organization of the modular sizes. This method can be used for, say, strip windows, or for the specific layout of planning grids.

The values of the step function can also receive a more direct architectural implementation. For example, take a base height of, say, 2.50 m, and subtract from this the value of a point on the step function, multiplied by 0.10 m. Although using other values, Bovill has applied this method for aesthetically enhancing a noise abatement. The underlying thought is that such a structure in front of a row of trees would look better if it had the same fractal rhythms as the contour of the tree canopies. Interestingly, Arthur Stamps (2002) has empirically verified this idea of 'contextual fit'. In this experiment, the central hypothesis is that the aesthetic appeal of a scene '… will be maximized if the fd [fractal dimension] of building in cities matches the fd of the surrounding landscapes…' (Stamps, 2002, 170). The stimuli used in this experiment were three types of landscape contours: hills (D = 1.07), volcanic islands (D = 1.23) and mountains (D = 1.11). Each of these three contours was coupled to three skylines, whose fractal dimension (1.07, 1.16 and 1.33) fell within the sampling limits of the contours. Sixty-four subjects judged the aesthetic pleasantness of all the scenes. Stamps found no support for Bovill's hypothesis that a 'fractal fit' between architectural structures and landscape elements is aesthetically more pleasing: 'The average preference for the scenes in which the fractals matched [the contours] was μ = 4.45, the average preference for the scenes in which the fractals did not match was μ = 4.34' (175).

While Bovill (1996) offers a clear overview of fractal geometry, another point of criticism is that he pays no attention to Gothic or Hindu architecture. Here, however, the fractal component is often much stronger and more straightforward than in the works of Frank Lloyd Wright. Furthermore, when fractals are promoted as a creative instrument, he gives not much attention to three-dimensional applications. Bovill mainly uses fractal rhythms and comes to two-dimensional results. An analysis of Hindu or Gothic architecture could lead to more convincing, and perhaps a broader range of design strategies. Moreover, these fractal rhythms are often not directly applied, but are mainly used to organize elements, which are not fractal themselves. This means that the relation with fractals becomes fairly shallow and derivative, and entails that the fractal component can only be appreciated by insiders.

8.5.2. Scaling factors

As was described in previous sections, Nikos Salingaros believes that successful architecture should have the same scaling properties as the human mind. Concretely, this means that a building's form should have a fractal organization by displaying architectural detail at different hierarchical scales. An essential point is that this scaling hierarchy should be visible to the user or viewer, in his/her daily experience of the building, and that it cannot be merely a feature of the plan or of the model of the building. Probably, Gothic and Hindu architecture would resonate well with the fractal characteristics of the human mind. However, this leads to the question of whether there is an optimal scaling relation between the different elements of such buildings – a scaling organization where the building's aesthetic impact is maximal. Salingaros (1998) argues that there is a definite answer to this question, and holds that the relation between subsequent elements should obey the ratio 2.7. Concretely, this means that if the largest building element is 10 m, then the subsequent (but smaller) elements should have sizes of approximately: 3.7 m, 1.3 m, 0.5 m, 0.18 m, 0.06 m, and so on.

But isn't Salingaros' (1998) choice for precisely this scaling factor an arbitrary decision? He answers that '[m]ost natural objects exhibit a hierarchy of scales, starting from their largest dimension, down by approximately factors of 2.7 to the smallest perceivable differentiation' (Salingaros, 1998, unpaged). Buildings that share this scaling factor are intuitively experienced as having natural-like qualities or 'life'. However, doesn't this come down to a mere *statement*? What is the evidence for the validity and aesthetic appeal of this scaling factor? Salingaros tries to resolve these issues and presents the following three arguments. First, he notes that

Christopher Alexander has phenomenologically established this value '… by measuring internal subdivisions in buildings, man-made artefacts, natural structures, and biological forms' (Salingaros, 1998, unpaged). The second argument is essentially heuristic. Consider a scaling factor of less than 2 on the one hand, and one of 10, on the other hand. With a scaling factor of 2, the architectural elements come to lie too close together, with the result that differentiating between subsequent scales becomes difficult. In the case of a factor 10, the scaled structures come to lie too far apart, and would be perceived as being unconnected. Salingaros, therefore assumes that a scaling factor between 2 and 5 avoids these problems. A third argument is that self-similar fractals (e.g. the Koch curve) that look most natural have similarity ratios of 1/3 or 1/2.65, which is consistent with Salingaros' scaling factor.

Salingaros' treatment is valuable because it offers one a direct instrument to determine the number of scales, and the subsequent sizes they should have, in order to make an interesting instance of fractal architecture. Yet, like in this dissertation, Salingaros' argumentation remains often quite theoretical, and empirical research that would test the predictions could make his claims only stronger. For example, it would be interesting to empirically verify whether 2.7 is the scaling factor that is characteristic of many natural objects. Moreover, it is also another issue whether the architectural implementation of this 'natural' scaling factor will be found aesthetically pleasing by the broad public. It would be illuminating to complement Salingaros' scientific arguments for its aesthetic appeal, with environmental psychological experiments.

8.6. Symbolic fractal architecture and its rhetoric component

In the examples discussed so far, the relation between fractals and the architectural form was fairly straightforward. Most buildings that were mentioned had some of the mathematical properties characteristic of fractals – albeit in ground plan or elevation. However, some authors have difficulties with such a narrow interpretation of fractal architecture. Instead, they propose that the discussion should be broadened, and also include those types of architecture that are (supposed) symbols or 'icons' of fractal theory, or of the nonlinear worldview underpinning it. According to Ostwald and Moore (1997; see also Ostwald, 2003) an example of such a fractal icon is Peter Eisenman's design for the Biocentre of the University of Frankfurt. Its organisation is based on the biological code-structure of DNA, which Eisenman considers to be fractal: 'The structure of DNA and its spiral mutation pattern is usually represented diagrammatically as a sequence of coloured blocks each paired with another block of reciprocal shape such that in combination they are a complete rectangle. As the DNA growth and mutation occurs the blocks undergo re-inscription such that they exhibit self-similarity ... Eisenman has used the mutation of the fractal form to create the overall architectonic form, in addition, to 'mesh' it with the nearby buildings and the surrounding landscape ...' (Ostwald & Moore, 1997, 406-407).

Figure 128: Correa's fractal ground plan for the IUCAA, Pune, India.

Another example of 'iconic' fractal design is Correa's commission for the IUCAA (Inter-University Center of Astronomy and Astrophysics) (Ostwald & Moore, 1997; see also Jencks, 1997a) (figure 128). In this work, a number of cosmological and scientific concepts find a symbolic translation into the architectural or design form. For example, the ground plan depicts an eight-like figure, symbolizing the mathematical concept of infinity. The ground plan also contains a clear reference to fractal theory, because it displays an approximation of the Sierpinski triangle. Another 'fractal icon' is the ESTEC building (European Space and Technology Centre), situated in the Netherlands. This complex, designed by Aldo and Hannie van Eyck can be linked to fractal geometry because its ground plan has an overall similarity with a well-known fractal icon, namely the fractal dragon (figure 129).

Figure 129: 'Iconic' fractal architecture. (a) The ESTEC, designed by Hannie and Aldo Van Eyck. (b) A 'fractal dragon'.

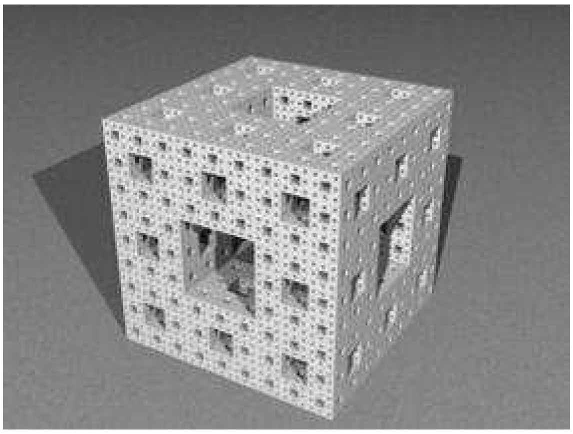
 

Figure 130: (a) Menger Sponge and (b) apartment façade.

Some difficulties need to be mentioned related to Ostwald and Moore's (1997) appeal to iconic fractal architecture. If their view is thought through, then why isn't an apartment building an icon of fractal geometry? It could be argued that it has some superficial similarities with the Menger Sponge (figure 130). A possible reply is that its architects probably did not *intend* it to be a symbol of fractal geometry. Yet, as is evident from the following quote, linking the ESTEC with fractal geometry was probably done *post hoc*: '… the [fractal] Dragon family of elements have, at some stage, either during the project, or in retrospect through the post rationalization of Lefaivre and Tzonis, been applied to the [ESTEC] project' (418-419). But why couldn't we make a similar post-rationalization, and claim that the apartment is a fractal? If admitted, it seems that post-rationalizing the iconic fractal character of certain buildings opens the door to triviality, and could make a lot of architecture into a fractal icon.

The claim that some building forms can symbolize fractal geometry, while not having a straightforward fractal form, is in fact unproblematic. Just like a note symbolizes music, the layout of a certain building can stand as a symbol for fractal geometry and its associated world-view. However, nobody would claim that the note symbol has musical characteristics. Similarly, on observation, two of the discussed fractal icons (ESTEC and Eisenman's Biocentre) do not have a significant fractal form (neither in plan, nor in elevation). Nevertheless, Ostwald and Moore (1997) claim the contrary: '… ESTEC … is fractal … in one dimension. ESTEC's fractal form may only be read in plan … Eisenman's Bio-Centrum is the only building … which attempts to produce a sectional and elevational fractal form' (418-419). From this, it becomes clear that the authors are incorrectly collapsing the view of a symbolic reference to fractals with the issue of having a fractal form.

The previous discussion wouldn't be problematic if it didn't foreshadow a rhetorical component present in discussions on fractal architecture. Perhaps the champion of such 'fractal rhetoric' is Charles Jencks (e.g. Jencks, 2002). We get the impression that he essentially misunderstands what a fractal really is, leading to a misrepresentation of fractal architecture (see also Salingaros (2004) for a polemic discussion of Jencks' treatment of fractal architecture). More specifically, Jencks interprets a fractal as a broken, fractured form, instead as a self-similar shape, containing a nesting of hierarchies. This misinterpretation is also clear from Jencks speaking of 'zigzag fractals' or 'angular fractals' (Jencks, 2002, 249). However, as Eglash (2000) notes, the presence of broken forms is not sufficient to consider a pattern as fractal: 'The latin root of "fractal" is fractus, meaning broken, but this is chosen because (in additional to the quantitative link to fractional) a rough broken edge will typically have a fractal pattern (jaggedness within jaggedness)' (unpaged).

Figure 131: Libeskind's 'fractal' Jewish Museum in Berlin.

The upshot of Jencks' misinterpretation is that none of the examples that he discusses have any significant self-similarity. Take the example of Daniel Libeskind's Jewish Museum in Berlin, which, according to Jencks (2002) is '[w]ithout doubt the most convincing fractal building finished so far…' (243) (figure 131). In fact this museum consists of a complex of container-like buildings whose metallic surface is interpolated by lines and slashes. While these zigzag patterns are certainly non-orthogonal, the shape of the building is not self-similar or self-same in any sense. From this, it can be concluded that Jencks uses the notion 'fractal' mainly as a rhetorical instrument: to create an exciting story around these designs, to give them a (supposedly) scientific foundation. This rhetorical component is further supported by the observation that, although Jencks (2002) calls certain buildings fractal, he does not clarify why this exactly is so, but just states it. The reader is left to believe Jencks because he is an authority in the field of architecture. Furthermore, the notion 'fractal' could be easily left out of Jencks' writing, without it losing its content or meaning. The notion 'fractal' seems mainly an eye-catcher, and does not significantly add anything to the content.

9. Is the issue of fractal architecture tenable?

As Ron Eglash (2000) notes, in discussions like the previous one, the metaphoric use of fractals is stretched almost to its breaking point – and sometimes beyond it, in the case of the rhetorical use of fractal concepts. Some might therefore claim that these issues could be resolved by more clearly delineating what fractal architecture precisely is, and what it certainly is not. From a common-sense point of view, it would appear that the meaning of fractal architecture is quite straightforward. A (visual) fractal is a structure, where similar details recur on a large number of scales. Therefore, fractal architecture refers to buildings where some architectural element or structure is present on subsequent scales, and where it is visible for the user or viewer. While Mandelbrot and Salingaros adopt such a view, it is not universally accepted.

In fact, some authors have extensively discussed the meaning of the term 'fractal architecture', notably John Moore and Michael Ostwald. Central issues are: what is meant by this notion? Can the notion 'fractal' be meaningfully applied to the field of architecture? These questions can, to a large extent, be traced back to the different interpretations/definitions that exist of the notion 'fractal' (see Ostwald & Moore (1996) for a discussion of this issue). For example, it is evident that a strict mathematical definition of a fractal entails that no architecture can be fractal. More specifically, such a definition implies that self-similar details stretch to infinity, and, evidently, nothing in this physical world can meet up to this requirement. A possible alternative is to adopt a more liberal interpretation, where a structure is fractal when it shows a 'deep' degree of self-similarity (say, up to 6 or 7 hierarchical scales). However, it is plausible that this will render fractal architecture trivial, because it implies that all architecture is fractal. More specifically, it can be argued that all the materials and elements used in a building have a fractal character. For example, the timber used for constructing a house originates from trees, which are essentially fractal, from the macroscopic down to the microscopic level: 'From the leaves and branches to the root systems and cellular shapes trees posses statistical self-similarity' (Ostwald & Moore, 1996, 146). Similarly, the house remains essentially 'fractal' when other building materials are used, such as metal: 'From the metal shapes that crystallise in the production stage to the alloy crystals and … those altered by welds the structure of a piece of metal will posses self-similarity at a number of scales' (Ostwald & Moore, 1996, 146). Similar arguments can be made for other building materials, such as cement, concrete, composite materials, and so on.

Figure 132: Mies Van Der Rohe's Crown Hall, Chicago.

It seems counterintuitive to consider all architecture as fractal. An evident solution to this issue is to argue that the fractal component of a building should be the result of a conscious and deliberate building or design decision: '[a]s the micro-scale of the concrete, steel and materials are not conscious parts of the form generating power of the designer they are not relevant to a stylistic definition' (Ostwald & Moore, 1996, 146). This entails that, in deliberating whether a building is fractal architecture, mainly attention should be paid to the *architectural* intentions of the architect; to the geometric organization of building elements and spaces. Yet, this solution can confront one with yet another difficulty. Ostwald and Moore (1996) discuss Mies van der Rohe's Crown Hall (figure 132) and suggest that it is a fractal building, because some structural element – the I section – is applied throughout the whole building, on different scales of magnitude. And surely, there is no doubt that the decision to use such sections is part of the 'form generating power' of the designer. Yet, it seems counterintuitive to consider the Crown Hall as an instance of fractal architecture. In fact, the modernism of Mies seems to be eminently Euclidean, and evades a meaningful description in terms of fractal geometry[10]. For example, Mandelbrot concluded that a '… Mies van der Rohe building is a scalebound throwback to Euclid, while a high period Beaux Arts building is rich in fractal aspects' (1977, 23-24). Nevertheless, if the previous line of argument is accepted, then again, this seems to render the notion of fractal architecture almost trivial (see also Moore & Ostwald (1996) for an in-depth discussion of the relation between fractals and Mies Van Der Rohe's architecture).

But how can this issue be resolved? The question of defining fractal architecture comes down to clearly delineating the notion, to narrowing it down. However, it is not clear whether this is a fruitful approach. Perhaps it is too restrictive and makes critical discussion impossible. Therefore, instead of pursuing a narrow interpretation, we consider it more constructive to come to a resolution that leaves place for the richness of possible applications of fractal geometry in architecture. This comes down to a middle position between those who stretch the notion too far

[10] An exception is perhaps Le Corbusier's Notre Dame du Haut at Ronchamp, which is characterized by curved, expressionist forms.

(e.g. Michael Ostwald and Charles Jencks), and others that use a more narrow interpretation (e.g. Benoit Mandelbrot and Nikos Salingaros). Our approach merely consists of making explicit wherein the fractal component of a certain building lies. This avoids paradoxes or inconsistencies, such as with Mies' Crown Hall. Here, there are two interpretations at work: namely the observation that (structural) components of the building - the I sections – have a fractal organization, and the fact that, phenomenologically, the building does not have an overall fractal form. However, both interpretations are not mutually exclusive. It is entirely plausible that a building's structural make-up has a fractal component (just like, say, its ground plan) without it having direct visible fractal forms for the viewer in his or her day-to-day experience of the building. A precondition for our approach is that, when fractal concepts are related to a certain component of a building (e.g. structure, ground plan, contour), then they should be applied correctly. As was discussed earlier, this does not count for the discussion of the ESTEC, or for Jencks' treatment of fractal architecture. Here, the works were claimed to have a fractal form (phenomenologically, while it was clearly observable that this was not the case.

With this we have come full circle with our critical discussion of fractal architecture. In the sections on fractal aesthetics it was tentatively argued that fractal structures emotionally appeal to us, and it was proposed how this could be elegantly accommodated in the proposed evolutionary framework. With the previous treatment of fractal architecture, it was shown how fractals have been appropriated in the field of architecture, and we can now clearly delineate how our project relates to this. The way in which fractals are promoted in this dissertation is essentially human-centred or phenomenological, meaning that we have to be able to perceive the fractal character of the building in the normal 'everyday' experience of architecture (this is a point that is also repeatedly stressed by Salingaros). In particular, one of the central themes of this thesis is the question of how the visual outlook of architecture can positively influence certain aspects of human life. So, if fractal architecture is going to play its social-psychological role in this project, an individual must be able to perceive its fractal characteristics (e.g. self-similarity, richness in detail, roughness, and so on). This perception should occur in the concrete experience of the built environment, and not in some abstract design space, such as a digital model or a plan. Or as Nikos Salingaros states it: '… flat, smooth buildings that are aligned and spaced 20 m apart may resemble a fractal line on paper, but they so far exceed the human scale as to be totally alienating. They are not fractal on the human scale, which is what is important' (Salingaros in: Padron & Salingaros, 2000, unpaged) While a strictly theoretical view can establish the fractal character of Mies' Crown Hall, its fractal component does not have any direct relevance for our human-centred or phenomenological approach. In fact, it is strange to observe that, since the systematic description of fractal geometry by Mandelbrot and colleagues, so few instances of 'phenomenological' fractal architecture have been created. (In effect, this forces researchers always to refer back to the past to make their argument, with the potential risk of being pushed in the corner of 'architectural conservatives' by the architectural community.)

10. Discussion

In this chapter it was tentatively proposed that the preferential and restorative responses towards natural elements and settings can be traced back to their underlying fractal geometry. If true, this would mean that the beneficial effects of nature could be tapped without direct contact with actual nature. Instead, it would suffice to be exposed to its typical fractal geometry. Still some reservation should be taken in account when considering this conclusion. Indeed, there is convincing evidence that fractals capture some of the essential geometric features of natural structures. Furthermore, there is also some support – both intuitively and empirically – that affective 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 inherent to fractals that is the underlying cause of these responses. Notwithstanding that this is perhaps the most obvious explanation, it could be equally speculated 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 this topic.

Whether or not biophilia is the underlying cause for our preference for fractals, the built environment seems to be the ideal place where this type of geometry can be integrated. This is not only because we spend a lot of time in built or architectural settings, but also because architecture is also essentially a mathematical undertaking, with keen interest in proportions among parts and whole. But how should a successful integration of fractals in the architectural environment be conceived? Several possibilities have been proposed. For example, Judith Heerwagen (2003) notes that images of fractal patterning can be included in buildings. Nikos Salingaros (in Mikiten et al., 2000) has argued how positive emotional responses can be elicited by pavements that display fractal forms. However, equally important seems that the façade can be given a fractal outlook, by repeating architectural details and elements on different scales of magnitude (cf. the façade of a Gothic building). In this regard Salingaros' view departs from Taylor's (2006), who thinks that there is reason to believe that it is not the façade but the silhouette outline of a building that plays a primordial role in inducing positive affective responses. He supports his claim by an inquiry by Heath et al. (2000) into the relation between the complexity of building skylines and preference. In contrast to skyline complexity, it was found that façade complexity only influenced judgments of visual complexity, and not preference, arousal or pleasure. According to Taylor (2006), the fractality of architecture should therefore be mainly situated in the contour of the building. However, it can be pointed out that the skylines of buildings are often not visible if one walks through urban areas with narrow streets, which underscores the relevance of the façade. Furthermore, it should be mentioned that, contrary to Heath et al. (2000), research indicates that the most important factor influencing visual preference for residential façades is surface complexity, while silhouette complexity had less importance (Stamps, 1999).

A further constraint on the construction of fractal architecture is the finding that people seem to prefer patterns with a low to mid-range fractal dimension. This point is stressed by Taylor (2006), who claims that architecture with a typical fractal dimension of around 1.3 will elicit maximal positive affective responses. This typical fractal dimension is relatively low, which shows that fractal architecture shouldn't have too much intricate detail. However, this immediately generates the difficulty that the perception of complexity of a building – and hence the fractal dimension – changes when an individual takes in different positions with respect to the building. In such situations it is difficult to keep D constant at 1.3, and it could therefore be more fruitful to allow some variation around this specific value. Note furthermore that it is not enough to know which fractal dimension is preferred to create an interesting and aesthetically attractive fractal building. A pile of self-similar building materials could have a fractal organization, but is very questionable whether it will be found attractive by the public. Indeed, the examples of three-dimensional fractal architecture discussed in section 8.4 all showed an ordering in their global and smaller structure, involving different kinds of symmetries (see also section 3.3 of the previous chapter for possible types of symmetries).

Our critical discussion on fractal architecture is valuable in several respects. First, it shows how fractal architecture has been understood or (intuitively) implemented, and thereby can provide artists and architects with different templates to create such work. For example, the methods deployed in Hindu temples can also be applied to more modern architecture. Second, our discussion was essentially critical and brought some of the difficulties associated with the notion of fractal architecture under attention. We believe that our contribution to this philosophical debate is worthwhile in that it offers a moderate view on the appropriation of fractals in architecture. 'Fractal architecture' is a semantically rich notion and there is no reason why certain interpretations should be excluded from the debate. On the other hand, this debate should perhaps more clearly articulate in which sense the references to fractals should be understood. A third benefit of this discussion is that it helps in clearly delineating in which sense fractal architecture should be understood in order for it to play a meaningful role for the proposed social-psychological project. It was repeatedly noted that the fractal component should be clearly perceivable to the human observer.

Conclusions

Humans have always tended to integrate formal representations of natural entities in artwork, architecture and design. Although human creativity is influenced by a wide variety of factors, the human mind also tends to recreate those elements that had a significant survival value during its evolutionary history. More specifically, we have presented evidence that the human brain consists of an integrated system specialized in processing information about natural things, and this information is expressed in different cultural/artistic creations and discourses, albeit sometimes intuitively. Perhaps the creation of such art by the brain is a way to stimulate itself.

Increasing urbanization, which can be witnessed today, certainly has a number of positive consequences. For example, in cities people come to live more close together, which could promote social contact and interaction, and the pleasure and enjoyment associated with it (Van den Berg et al., 2007). Yet, in this doctorate we also have pointed to possible downsides of growing urbanization. In particular, due to the loss of natural form in the modern human living environment (albeit actual or 'architectural' nature) the human 'talent' for nature and for connecting emotionally with it could become less drawn on. It is argued that this evolution can lead to important impoverishments on an emotive, formal and epistemological level. Importantly, our proposed solution for this problem did not imply a romantic turn to nature or to rural life, but acknowledges the reality of urban life. In essence, we proposed that the impoverishments can be countered by integrating different types of formal references to nature within architectural design. A widespread integration of such architecture can form a compensation for the loss of natural form in the human living environment. Admittedly, some modern architects have an (intuitive) grasp of the importance of natural form in architecture, and provide an alternative to architecture devoid of natural references. Yet, it is questionable whether such architecture is widespread enough as to sufficiently stimulate the neural areas that are specialized in processing natural-like forms.

But if we are in a sense genetically predisposed to affiliate with nature, and to express this affiliation artistically, why then is it that not all architecture of all times contains references to natural elements? It has been noted that such an inborn system does not imply a genetic determinism, but is in a sense 'open' in that it can be influenced by cultural or experiential parameters. It should be evident that the tendency to artistically express natural form can be inhibited by external factors. For example, the tendency to construct a richly ornamented house can be inhibited by financial factors or by assumptions of what is fashionable. Today, the absence of nature in architectural form is perhaps due to a complex set of factors, which cannot be easily untangled. Such entangling is not necessary for the current argument. What is clear that in the past, such inhibitions were not really problematic because there was a more profound contact with natural form, and hence our integrated neural 'biophilic' system received more adequate stimulation. This contrasts with the situation in modern technologically-oriented societies, where contact with natural form has been drastically reduced. From this perspective, it is valuable to encourage architects and designers to work out specific design-proposals that are in line with the previous arguments. Importantly, such designs are not intended to completely replace 'non-natural' types of architecture. No, the argument of this dissertation is essentially pluralistic and aims at the coexistence of diverse architectural styles. While some types of architectural design are mostly responsive to cultural ideas and needs, those discussed in this thesis also fulfil conditions that are guided by a shared human evolution in a natural world.

Evaluation

A central and important notion in the title of this dissertation is the word 'tentative'. With this notion we wanted to emphasize that there was a fair amount of speculation involved in our writing. However, where possible, we have tried to support our hypotheses with references to empirical research. Still, there remain some grey zones, or black boxes, and further (empirical) research is needed on these topics. Still, we believe that our approach is important in that it implies a departure from, and an alternative to, the mere intuitive or philosophical grounding of biomorphic types of architecture. Furthermore, the plausibility of our theoretical arguments underscores the value of initiating empirical research lines on the relation between biomorphic patterns and affect.

It is worthwhile to point out where the more and the less speculative points of our argumentation lie. On a global level there is a discrepancy perceivable between current modern habitats (epitomized in modern metropolises) and between what are believed to have been 'ancestral' habitats. While in habitat theory (Orians, 1980) it is claimed that the ancestral habitat *par excellence* was the savanna, we have briefly discussed that this is not the accepted view within the field of paleoanthropology. Yet this criticism does not have any repercussions for the claim that hominins and early *homo* have evolved in *natural* settings, and have therefore become sensitive to naturalness. Thus, the idea of a formal discrepancy between current and ancestral habitats seems quite uncontroversial, especially since the former contain increasingly less natural contents, and also often do not display the geometric characteristics of natural settings. This is especially the case in modern urban agglomerations, where there is a dominance of high-rise and similar building block apartments. (Perhaps this applies less to (say) the historical centres, which we are familiar with in our regions and which are characterized by ornamentation, complexity, mystery, and the like.)

This discrepancy would in fact be quite unproblematic if the human brain was an almost entirely plastic structure that had no preference for one typical kind of environment or for certain conspicuous landscape configurations. In that case, it would make no difference in which type of environment an individual would spend his life because the brain would come to like the environments with which it became most familiar. Yet, the field of evolutionary psychology argues against this view. While it admits that, to a certain extent, the formation of the brain is influenced by experience and learning, it also stresses that a certain portion of the neural tissue is genetically predisposed to perform certain evolutionarily relevant tasks. It is still a matter of debate whether these predispositions should be conceived in terms of cognitive modules, or if a more moderate approach is at its place (e.g. prepared learning). Yet, this is not the crux of our argument, and it cannot be a sufficient reason to reject our account.

What our discussion of the inborn character shows is that the choice for certain types of architecture could well not be a triviality, or *solely* a matter of tastes. In fact, the human sensitivity to particular landscape configurations and to certain specific natural contents has been established numerous times and cross-culturally within the field of environmental psychology. In contrast to urban environments, natural contents and landscape configurations are capable of inducing aesthetic preference and stress reduction, and can aid in restoring the ability to direct attention. Such elements are often not present in our living and working environment, or at least they are becoming increasingly less prominent. Such environments thereby deprive humans of a source of wellbeing and pleasure, and of an important restorative power for our psychological, physiological and cognitive functioning. This underscores the importance of integrating naturalness in our current modern habitats. This is perhaps the least controversial aspect of the proposed argument, and it has also been one of the central emphases of Evidence Based Design. Importantly, the universality of these findings indicates that they can be applied where many people gather or pass, and where there is need for psychological and cognitive restoration due to significant emotional pressure and great demands on cognitive functioning and concentration (think for example of schools, hospitals or the work floor).

One of the main arguments of this doctorate is that biophilic reactions can be evoked by architectural or design *imitations* of naturalness. Empirical research indicates that almost exact simulations of nature, and even artistic interpretations of natural settings, are capable of inducing biophilic reactions. Therefore, if it is not possible to integrate real natural contents in a setting, then it could be valuable to implement realistic representations of nature (e.g. through paintings, photographs, video-displays, screensavers, and so on). A possible counterargument is that it may well be that such representations lead to biophilic responses in an experimental setting, where they are strictly separated from a definite architectural context. However, some might argue that (say) animal wallpaper leads to unaesthetic or even ridiculous results when it is integrated in an actual living environment. But how can this seeming paradox be resolved? First of course, it is possible that the dislike of an individual for such type of representations outweighs the possible benefits of integrating them. If the overall goal is to come to a higher degree of wellbeing, it could be counterproductive to insert such biophilic interventions. Yet, it could also be that the dislike is not because of the naturalness inherent to the representation, but due to the fact that there is not a successful fit between the type of natural representation and the specific architectural setting (e.g. rustic animal wallpaper versus modernist architecture). However, it can be pointed out that a very large amount of nature representations exist (ranging from the quite kitschy, to the very stylish), which are 'in tune' with many kinds of aesthetic tastes.

What the previous remarks show is that individual variations in the appreciation of nature are indeed possible. It can be seen as a shortcoming of landscape aesthetics that its major focus is on commonalities, while individual differences are obscured, or remain largely undiscussed. Still, for architectural or urban projects that pertain to the broad public sphere (e.g. hospitals), such general findings can be very useful. Furthermore, we believe that personal tastes can be met to a certain extent, by integrating more abstract or schematized representations of naturalness in architectural design. Because these are not exact copies, there is some place left for infusing them with culturally coloured artistic interests. Yet, it must be admitted that at the same time such an approach implies a higher level of speculation. In fact, such architectural interventions seem to make use of the finding that at early levels of (visual) processing, our cognitive machinery does not seem to differentiate between what constitutes a real or unreal natural entity. In fact, there is some evidence that it is even stronger stimulated by representations that exaggerate some crucial features of the entity, or that capture its essence. While some ethological research is indicative of this, it must be noted that there is no empirical evidence *directly* testing the hypothesis. It would be interesting to see how, in a controlled setting, people respond psychologically and physiologically towards (say) ornamental representations of nature.

A more theoretical issue is the question why we need architectural schematizations of nature in the first place. If real nature can 'do the job' of provoking biophilic responses, why then bother about creating – possibly expensive – biomorphic architecture? A first answer is that this question presupposes a certain irrelevance of the outlook of the architectural form. It does not matter what a building will look like, as long as we place some vegetative elements in its surroundings. However, this argument minimizes the importance of architectural creativity and style. People genuinely care about the outlook of a building's exterior and interior, whether or not it is accompanied by trees or plants (perhaps the perennial need to ornament architecture is one indication of this). Why then not deploy typical forms and organizations in architecture, which imply a certain stylistic language, but which can also improve our functioning in certain respects? Second, it is also a matter of fact that in some modern urban areas with massive high-rise building, large-scale tree-planting is not really an option. This underscores the usefulness of architectural biophilic interventions. Finally, it can be pointed out that planting trees could indeed be useful because it is a relatively cheap intervention, and because it can significantly enhance certain 'barren' architectural settings, where the 'damage' has already been done (think for example of the uninspired box-like buildings that dominate commercial centres).

The most tentative parts of this dissertation were the claims that biophilic responses could be triggered by certain typical low-level formal features of natural elements. The first feature we discussed was curvature. While some research has established an aesthetic preference for curved objects, and while curvature is associated with naturalness, it seems premature to conclude that naturalness in a sense underlies these preferential reactions. Perhaps 'curvature' is one of the nodes that need to be filled in to categorize something as natural, but there seems so much more going on than this single quality. Furthermore, it is difficult to deduce strong conclusions from the small body of empirical research (two studies) that is available. It can be pointed out that, in many natural objects (e.g. trees), the curved information is represented in a nested hierarchy. With this, we have come to our second low-level feature, namely fractal geometry, with its characteristic self-similarity. While still tentative, here the evidence for biophilic responses seems somewhat stronger. In fact, research shows that the degree of self-similarity of scenes can predict biophilic responses to natural settings. Yet, the main body of empirical research that was evaluated consisted of inquiries into preferred fractal dimension. But this does not tell us whether subjects prefer fractals over non-fractal patterns in the first place. One of the defining characteristics of most fractals is their self-similarity. It would therefore be interesting to inquire patterns of the same complexity, of which some have (fractal) self-similarity, while others not. If the hypotheses are correct, then one would expect that fractal patterns are associated with aesthetic reactions, and possibly stress reduction, more than the other patterns. But perhaps it can 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.

Finally, it is questionable whether all the works that have been presented in the figures will be considered attractive. More specifically, the architecture based on animal form is perhaps not always convincing. Consistent with the evolutionary account, it is probably that some architectural representations of animals will lead to more negatively toned emotional states, because the represented animals posed prolonged threats during our evolutionary history. Yet, this does not rule out that they still cause strong emotional responses, albeit more negative ones. On the other hand, perhaps the integration of symbolic vegetation will lead to more positive and 'peaceful' reactions. Yet, it must be admitted that – although ornament has had a perennial presence – it has not always been appreciated equally. What this amounts to is that there is a complex interplay between different factors in the aesthetic appreciation of art or architecture. Architects are sensitive to what is culturally fashionable, and perhaps they have the best eye for coherently fusing the biological and cultural levels of appreciation into a successful architectural expression.

Future research

It is true that one of the shortcomings of the current research is that it remains largely theoretical. While an appeal has been made to different empirical research traditions, there is need for more direct experiments, especially regarding the hypothesis that certain low-level formal features of natural objects can entail biophilic responses (e.g. fractals). We will try to address these questions to a certain extent in a future research proposal. In that project, particular attention will go to the 'restorative' value of nature, which refers to its positive influence on the ability to focus, or to direct attention (Kaplan, 1995; Hartig et al., 2003). This effect of nature will be linked to 'flow theory' (Csikszentmihalyi, 1997). Usually, flow is used to describe states where one is totally immersed in a certain activity. An important characteristic of flow is the profound directed attention or focus on this one specific activity. Because nature strongly aids to direct attention, it can therefore be expected that visual contact with (representations of) nature will facilitate flow experiences, or bring subjects into a mindset that makes them more receptive to such states. Probably the facilitating effect of natural elements on flow will be most pronounced when subjects are in a state of attentional fatigue.

Importantly, in this project we will study the relation between nature's restorative capacities and flow by exposing subjects to a series of websites of differing content. The rationale behind this experimental setup is that there is some evidence that subjects experience flow states when they are engaged in online activities. Essential to the websites is that they will mutually vary in their degree of ‘naturalness’, due to the different types of representations they will contain (e.g. ‘trees’ versus ‘buildings’). Both functioning and structure of the websites will be held constant, which allows us to inquire the effects of the variable of interest, namely ‘presence of naturalness’.

The visitor of the website will first be asked to perform a task that is fatiguing for directed attention. After this, the degree of attentional fatigue will be measured (e.g. focussing on one interpretation of the Necker Cube). In a following stage, he or she is allowed to enter one of the possible websites, and is asked to navigate during a certain amount of time on the website, with the goal of gathering specific pieces of information from the sub-pages of the website. Next, the degree of attentional fatigue in the subjects will be measured for a second time. This will allow us to evaluate the effects of the contents of the website on attentional functioning. Finally, the subjects will be asked whether, and to which degree, they experienced flow during navigating on the website.

Several issues are of theoretical importance. Evidently, this experimental design will test the central research intuition of this project – i.e. whether exposure to naturalness correlates with a facilitation of flow experiences. Importantly, the representation of images on the websites will vary in that some will depict ‘actual nature’ while others will show ‘abstract nature’. Concretely, this means that the images will either depict *real natural elements* or *geometrical abstractions of natural forms*, such as fractal patterns. With these interventions we want to inquire whether certain abstract-geometrical properties of natural elements can also generate the desired effects. This implies an empirical extension of the theoretical framework proposed in this doctoral research. It can be expected that exposure to fractals will enhance directed attention, and thereby lead to a facilitation of flow (Taylor, 2006; Joye, 2006c).

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Figure 70: Hundertwasser Haus. Source : www.w-meier.com/DIE%20GRUENE%20ZITADELLE%20VON%20MAGDEBURG%20%20Hundertwasserhaus.JPG

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Chapter 3

Appendix

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