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A THEORY OF ARCHITECTURE

CHAPTER 4

THE SENSORY VALUE OF ORNAMENT

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Ornament is a valuable component in any architecture of buildings and cities that aims to connect to human beings. The suppression of ornament, on the other hand, results in alien forms that generate physiological and psychological distress. Early twentieth-century architects proposed major stylistic changes — now universally adopted — without having a full understanding of how the human eye/brain system works.

1. INTRODUCTION.

This Chapter argues that ornament is valuable for us to experience architectural form in a positive way. Chapter 3 presented mathematical reasons for why ornament is necessary. The visual coherence of a complex form, as defined by *systems theory*, requires ordered substructure on all scales: from the overall size of the building, down to the detailed grain in the materials. Natural structures have this (essentially fractal) property. If a man-made form lacks ordered structure on one or more obvious scales, it is perceived by human beings as being visually incoherent, and consequently as alien to our conception of the world (which is based on visual consistency). A building's visible substructure on the range of scales from 1 mm to 1 m has been achieved in the past through traditional ornament and detail.

Our neurophysiology is set up so that we expect visual input from our surroundings to contain many of the characteristics of traditional ornament. Human visual and mental make-up is linked through evolutionary processes to the informational richness of our environment. This biological background helps to explain some aspects of why human beings create ornament. Going deeper than the usual "artistic" analysis of architectural ornament, I try to place it within the context of shared biological mechanisms. It is part of human nature to order our world and establish scaling relationships so as to better understand our relationship to it. Here, I will present several rules derived from our cognitive mechanism — these rules are intended to help understand how we conceive a form as visually coherent, and thus meaningful. I then discuss the relationship between cognitive rules and the creation of ornament.

Altogether, eight "cognitive rules for *structural order*" can be established. They represent the neurophysiological equivalent of the three laws of *structural order* presented in Chapter 1, together with detailed rules for achieving *scaling coherence* given in Chapters 2 and 3. It is remarkable that the concept of *structural order* can be reached from three entirely different viewpoints: we can use science to discover how structures are put together coherently; we can use art and architecture to do the same thing; and we discover that our own mind works in precisely the same way. This reveals a universality for all the concepts discussed in this book — a level of validity that cannot possibly be dismissed as accidental.

Table 4.1. Summary of the Eight Cognitive Rules.

1. A region of contrast, detail, or curvature is necessary.
2. The center or the border should be well-defined.
3. Attention is drawn to symmetric ornamental elements.
4. Linear continuity orders visual information.
5. Symmetries and patterns organize information.
6. Relating many different scales creates coherence.
7. We connect strongly to a coherent environment.

8. Color is indispensable for our well-being.

I propose two arguments against both the minimalist design, and the random design of built forms. The first is that both cause anxiety and physiological distress, because they inhibit human mental connection with a given structure, normally experienced when meaningful information is available. Minimalist design omits aspects of warmth and comfort from our surroundings. A geometrically pure space can generate anxiety. The second argument centers on a concern about a very disturbing similarity. Minimalist and disordered built environments resemble the perception of a normal, visually complex environment by persons with a damaged perceptual apparatus or cognitive mechanism. I shall discuss how different types of injury to the eye and brain result in precisely the same effects offered by either minimalist or intentionally disordered design. This coincidence is serious because our body is programmed to respond to and so avoid perceptual and cognitive damage, and environments that are deliberately conceived in this manner are often triggering a reaction of distress.

The broader implication is that architecture adapted to human beings requires ornament for a sense of well-being. To prove this in a fully rigorous fashion is outside the scope of the present Chapter. I acknowledge other factors that influence the appreciation of architecture, including past experience, cultural formation and environment, and upbringing. Other authors argue for innate preferences for certain types of physical landscape, giving convincing reasons based on the environment's fractal qualities, which support the necessity for ornament and detail. At the same time, however, it has been shown that innate preferences are displaced by factors such as familiarity and psychological conditioning. It is probably true that living life in a minimalist architectural environment will make a person more familiar with it, yet such types of structure are not in harmony with our neurophysiological make-up.

2. VISUAL MEANING.

A form's visual organization communicates information to people through the surfaces and geometry it presents. Environmental experience is based upon an intimate interaction of human beings with surfaces and spaces, as it relates to our senses. This influences our emotions and physiological state, and consequently our actions. A building's exterior and interior surfaces either "connect" in an emotionally positive manner with the user; remain neutral by having no effect; or act in a negative fashion so as to repel. This interaction resides in the information content of space and the transitions from one region to another, and is independent of cultural bias. Even though surface qualities are usually assumed to be separate from the spatial geometry in a building, the two are in fact interdependent, and both contribute to how people respond to their surroundings.

Traditional architecture uses organized information to establish a positive connection with human beings. Throughout history, nonfunctional architectural components were deemed necessary for a building to offer a pleasant environment, and thus to enhance its attractiveness and use. Moldings, color, decoration, and richly-textured materials serve this purpose. Traditional architectural environments are inconceivable without such psychological design enhancements. Their architects were extremely sensitive to the need of appealing to and satisfying human psychological responses.

In the twentieth century this connective mechanism was abandoned to focus on pure geometrical form. Nevertheless, the emotional link established between people and built structures had led us, through feedback, to produce traditional ornamented structures. Human emotional response is based on neurophysiology and information input. It should not be undone for the sake of any particular architectural design style that eschews ornament. An environment lacking in texture, color, and ornament (in the form of organized detail) can be punishing for a human being, as exemplified in the design of prisons throughout history. Going to the other extreme, an environment that is supercharged with uncoordinated visual stimuli (the geometrical analogy of musical cacophony) — such as the Las Vegas strip lit up by neon lights — exceeds the visual input that can be consistently tolerated.

We seek intelligibility and meaning from our environment and are repelled by environments that convey no meaning, either because they lack visual information, or because the information present is unstructured (Klinger & Salingaros, 2000). The need to interpret environmental information has driven human evolutionary development: both vision and intelligence developed to increase our capacity for processing information. The eye and the brain form a single mechanism (Hubel, 1988). Design is itself a product of human vision and intelligence, therefore the organized complexity of traditional designs seems to parallel cognitive structures of the human brain. This observation makes the underlying reasons of why we build complex things less of a mystery. People are motivated to build so as to extend their consciousness to a wider domain outside their own mind.

3. HOW THE EYE SCANS A PICTURE.

In classic experiments on human eye motion while scanning a picture (Hubel, 1988; Noton & Stark, 1971; Yarbus, 1967), the eye is observed to focus most of the time in the regions of a picture that have the most detail, differentiations, contrast, and curvature (the experiments referred to did not include color). These are clearly the high-information regions in the picture. Eye fixations establish a fairly narrow "scan path" where the eye spends about one-third of its time, with random excursions to low-information (i.e. plain) regions of a visual image. The brain thus selects informative details such as convoluted, detailed contours and contrasting edges for recognizing and remembering an object. Our visual system is built to select those items of concentrated information that can provide the most complete response in the shortest possible time. (Color is extremely important in this process, playing a principal role in the realm of visual stimuli, and will be discussed separately in Section 7, below).

The information content of visual images lies precisely where the eye spends its energy scanning; the rest of the picture is easily reconstructed by extrapolation (Nicolis, 1991). That is, empty regions don't need to be stored since they are all the same. This is how the brain stores information via a compression algorithm (a concept discussed in Section 4 of Chapter 3). Selective weighting of information to minimize coding also provides the basis for information storage in artificial systems such as computer graphics

(Klinger & Salingaros, 2000). We comprehend an object by seeking to define its boundaries and any characteristic details within the boundary. Note, however, that a discontinuity or sharp interface such as occurs when two edges (of flat empty surfaces) come together has no width or dimension, and so does not provide any detail. A precise straight edge has no information. A frame has information, and so does a curve. The more complex a frame or a curve are, the more information they contain (see Figure 4.1).

Figure (4.1) The eye is drawn to regions of high contrast and detail.

Detail is nothing more than contrast on the smallest scales. In principle, therefore, contrast coupled with hierarchy is necessary for detail. Nevertheless, as the concept of hierarchical scales is not widely known, I will continue to discuss contrast and detail as separate entities.

There is another reason why our eye/brain system has evolved to perceive detail, and that is our capacity to predict future events (Llinás, 2002). An intelligent, mobile animal focuses on details that give it crucial information about an adversary during combat; about changing physical conditions crucial to survival; the recognition of familiar animals and their facial expression; visual cues from a prey being hunted; etc. This is an adaptive trait that is essential for species survival. All of this information comes directly from telling details. Our cognitive system normally has no time to process all available visual information in those instances, and has to rely on first input in order to make almost instantaneous decisions.

Recent work (VanRullen & Thorpe, 2004) suggests that a first, rough image is created using only the salient parts of a retinal image — that is, regions of high contrast and detail. In this first burst of signals, it is contrast that encodes sufficient information to make a decision on our need to respond. The rapidity of this first image, which is entirely subconscious, is faster than our motor response time (see Figure 4.2). For example, a person will stop suddenly in front of a camouflaged snake, reacting to the brain's clear but non-visual message "snake" long before the image of a snake has fully formed. Sometimes, we react to the message but have to search very carefully before we can distinguish the animal from the background. This is an absolutely necessary feature, which makes possible a rapid response to any potential threat while the full image is still being processed. Our "instinctive" response to a form is therefore based on contrast and selected detail. Further information from the retina is processed more slowly, and any kind of rational analysis of the form can begin only after the retinal image itself is completed.

Figure (4.2) High contrast and detail determine first response.

First response depends on an incomplete image that somehow has enough detail for recognition. With more processing time, the image progresses to evolutionary higher levels of the midbrain, where single neurons can recognize complex wholes. Islands of such neurons capable of sophisticated pattern recognition exist at the same level as islands of neurons responsible for seeing fine detail. The ability to recognize detail is thus an advanced cognitive skill that the brain has developed over time. It is now established experimentally that the first, rough image is processed via different channels of the brain than the slower, more complete image (Johnson, 2004). The point is that our body responds viscerally to forms and textures in our environment in a way that we have no control over, and we are hardly aware of what triggers those responses.

The above considerations suggest two cognitive rules on how we perceive our world. I propose that artificial structures in general should follow similar rules, precisely because our perceptual apparatus (i.e., our eye) has evolved to use them. The following two rules are the cognitive analogues of the first law of *structural order* in Chapter 1, Section 3, consequences 1b, 1c, and 1d. Understanding how our cognitive mechanism works implies that we use analogous rules for constructing the man-made world.

Rule 1. Every structure should have at least one region with a high degree of contrast, detail, and curvature. That corresponds to high values of the first and second spatial derivatives (i.e., the change over a short distance).

The mathematical derivative computes the difference in surface qualities such as articulation along a given direction, whereas the second derivative computes the difference of the difference, i.e. the curvature.

Let me discuss Cognitive Rule 1 through its contradiction. Large, plain objects or surfaces disturb the observer by presenting little or no information — the most disturbing being surfaces of glass or mirrors that prevent the eye from even focusing on them. Glass is great for looking through, but terrible for looking at. Those structures have a low degree of contrast, detail, and no observable curvature. We instantly look for reference points, either in a form's interior, or at its edge, because our physiology is programmed to do so (Zigmond *et. al.*, 1999). We need to comprehend a structure as quickly as possible, to make sure that it poses no threat to us. Large uniform regions with abrupt, ill-defined boundaries such as an infinitesimally thin line generate psychological distress (which then has negative physiological consequences) as the eye/brain system seeks visual information that isn't there. This frustrates our cognitive process.

Rule 2. Plain surfaces require either their interior regions, or their borders, to be defined through contrast and detail.

Rule 2 reminds us of the principles involved in message transmission. In sending a message, it is necessary to indicate its limits. For example, a one-dimensional piece of information needs to be identified as such by noting where it begins and ends. This requires additional coding for the message's boundaries (limits). Without those boundaries, the receiver has no idea of what it is receiving, and cannot distinguish a message from other portions of a signal. In ordinary writing, a sentence begins with a capital letter and ends with a period. In any computer language, encoded text — even if it consists of no words at all — is always bounded by BEGIN and END tags. In architecture, this is best described by door trim or window trim used to transition between wall and open space. Every place where the condition changes from solid to void, from inside to outside, needs these well-defined transitional borders (see Figure 4.3).

Figure (4.3) Transitions require defining boundaries (limits).

4. NEUROPHYSIOLOGY OF THE EYE/BRAIN SYSTEM.

Starting from a light-sensitive spot on protozoans and primitive worms capable of judging direction, the primitive eye developed a sense for various degrees of light intensity so as to perceive distance, or the shadow of an aggressor. Movement detectors, requiring first and second derivatives of the signal in time, were among the first to appear during evolutionary development. Finer and finer tuning corresponds to an increase in the brain's information channels and capacity. Researchers believe that the brain developed concurrently with the eye in order to handle the increasingly complex optical information input from the evolving eye (Fischler & Firschein, 1987). Some accept the co-evolution of the left/right reversal of functions in the two brain hemispheres, and the left/right reversal of an optical image on the retina, as proof of the concurrent evolutions of the eye and brain.

Geometrical uniformity is decoupled from our neurophysiology, because a majority of cells in both the retina and visual cortex will not fire in response to a uniform field (i.e., an empty region with no identifiable features) (Hubel, 1988; Zeki, 1993). Visual receptors in the retina (either single cells, or groups of cells) compare the characteristics of adjacent regions — they spatially differentiate the signal. Color wavelength is determined by comparing the output from three different types of cone cells due to the response from a single point. Neurobiologists have identified specialized neurons and clusters of neurons that perceive angles, curvature, and contrast (Hubel, 1988). The latter work via lateral inhibition (i.e. signal comparison) and are successfully simulated in artificial (computational) visual systems to achieve edge detection (Fischler & Firschein, 1987). The eye/brain system is thus idle in a visually homogeneous environment, the lack of stimuli reducing the need for activity.

Particular brain cells, and some groups of cells, have a preference for all possible oblique orientations in addition to vertical and horizontal. The directional preference of successive cells in a cortical region distinguishes between angles of 10 to 20 degrees (Hubel, 1988; Zeki, 1993). The existence of orientation-specific cells in the visual cortex proves the importance of angular information, since such a cell will fire only when confronted with diagonal lines at the particular angle the cell is created for. None of these neurons will fire in a strictly rectangular environment, thus diminishing the sensory connection to it.

In addition, "end-stopped" cells in the visual cortex respond to lines of a distinct orientation up to a small maximum length, beyond which their response drops to zero. These are neurons that exist only to recognize detail and differentiation. End-stopped cells are biological receptors that are directly sensitive to corners, curvature, and to discontinuities in lines. All these brain cells are again inactive in a visually homogeneous environment, which supports Cognitive Rules 1 and 2. Our brain works much like a scanner, which spends the bulk of its processing energy copying the highly detailed areas of an image.

Figure (4.4) Cortical neurons respond directly to ornamental elements.

More impressive is the finding of individual neurons in the cortex that are optimized for complex shapes. Experiments show that such cells preferentially fire when presented with complex symmetrical figures such as concentric circles, crosses with an outline, stars of various complexity, and other concentrically-organized areas of contrast (see Figure 4.4) (Zigmond *et. al.*, 1999). Furthermore, these neurons coexist with "silent surrounds", which help the neuron to recognize a complex figure better when that figure stands out in a plain background. From all appearances, our brain has ornament recognition built right into it. I therefore propose another cognitive rule:

Rule 3. Our visual attention is immediately attracted to symmetric ornamental elements, such as star shapes, concentric circles, crosses with an outline, etc.

Our eye/brain system evolved to perform a very specific function, and this suggests that human beings, as the animals that can create the greatest variety of physical structures, reproduce in artifacts what stimulates our brain directly. It is no coincidence that the elementary ornamental elements mentioned above appear on pottery, bone designs, non-representational paintings, and textiles over a period of several millennia (Washburn & Crowe, 1988). Early people represented visual aspects of their environment in an effort to codify it, and thus gain better control over it. Symbolic representations aided in ordering elements of cultural and physical landscapes, and therefore helped to understand the unknown. Cognitive Rule 3 is analogous to Consequence 1a of the first law of *structural order*, and to Consequence 2a of the second law given in Chapter 1.

Neurophysiological findings link our ability to recognize ornament with our evolutionary development. Complete visual information (not the fast, approximate image used to detect danger) is processed hierarchically in the brain, moving through different regions in succession. Two features point to increasing complexity. First, as one progresses forward into the brain's major processing pathway, there is a progression of the complexity and the critical visual detail needed to activate certain individual neurons (Zigmond *et. al.*, 1999). That is, as one progresses into the more advanced regions of the brain, more complex patterns are required as visual input before certain neurons will respond. Second, the relative numbers of neurons that are selectively driven by a complex pattern increases.

Minimalist surfaces and edges negate the way human beings have evolved to process information. It is known that when we go against our neurophysiological makeup for whatever reason, then our body reacts with physical and psychological distress. Such effects are measurable, and include raised blood pressure, raised level of adrenaline, raised skin temperature, contraction of the pupils — all symptoms of triggering our defensive mechanisms against a threat. When it recognizes a threat, the eye/brain system initiates physiological actions in order to protect the organism. Stress is an adaptive reaction to disease, injury, or toxins. The same mechanism extends to cope with unpleasant sensory input from the environment (Mehrabian, 1976).

The opposite effect — depression — results from understimulation. Studies of sensory deprivation show that we require above a minimum threshold of informational load from our environment in order to function normally (Mehrabian, 1976). I would like to see more experiments to measure human physiological response to different architectural environments. Already, studies by environmental psychologists tend to confirm what is proposed in this Chapter (Klinger & Salingaros, 2000). Depressing work environments are a result of poor architecture. Conversely, people are more productive in environments rich in ordered fractal information, such as is provided by trees and plants.

Degradation of our ability to see fine detail signals the onset of different pathologies of the eye itself rather than the brain. The first group of problems occur with the lens — either the lens can no longer focus, or it becomes opaque due to a cataract. The second group of problems have to do with the retina; in particular, with the macula, the central region of the retina where cone cells that are responsible for seeing fine detail and color are concentrated. The retina can be damaged by detachment, or the macula can degenerate because of inadequate blood flow. The loss of visual information cuts us off from our environment, and creates anxiety by lowering our ability to respond to it. These pathologies make us experience normal, informationally-rich environments as if they were minimalist environments.

All of this strongly suggests that we become uneasy in architectural settings where we experience a reduction of perceptual or cognitive input. This is unsettling because the circumstance of being unable to define our surroundings makes us feel helpless and lost. Those environments mimic signs of our own pathology. Are we subconsciously reminded of a failure of our visual system when we spend time in a minimalist environment? Such a response is probably so deeply-seated that it can only be overridden via a concerted conscious effort, if at all.

The brain has novelty detectors, which have alerting functions as consciousness. Unfamiliar patterns or constructs (not found in nature or traditional artifacts) trigger an immediate response that is physiologically based. This makes sense given our evolutionary development, which had to learn to protect us from potential dangers. People who are taught (i.e., have had to be trained) to look at novel constructs without alarm have undergone psychological conditioning, which establishes aesthetic preferences that contradict their basic instincts.

5. VISUAL ORDERING AND PATTERNS.

Cognitive Rules 1, 2 and 3 explain the necessity of visual information. Now we turn to the opposite problem: the case when there exists too much information. The first three cognitive rules are by themselves not sufficient to explain the geometry of form, since they say nothing about how visual information may be ordered. We know very well, however, that our cognitive system craves structured information and is overloaded with disordered (i.e. random) information. Information overload causes distress. Too little information has no meaning, and too much information also has no meaning. We can comprehend a lot of information when it is ordered. Ordering via patterns is discussed in (Klinger & Salingaros, 2000), where a complexity index is used to measure visual coherence. This leads to additional cognitive rules that govern how visual information can be organized. The easiest way to order information is to group objects along a curve or straight line (see Figure 4.5).

Figure (4.5) Visual information may be ordered via linear continuity.

Rule 4. Visual information can be ordered efficiently via linear continuity.

This corresponds to the simplest grouping, lining up high-contrast objects on end; not necessarily always in a straight line, but it could also be on some sort of curve. The units do not need to repeat to be connected in Cognitive Rule 4 (one could align different objects). What this lining-up does is to significantly narrow the scan path that the eye needs to follow in order to grasp the information encoded in the components, since now there are fewer excursions to visual regions away from the line. Lining-up corresponds to a condensation of two-dimensional information.

It is probably no accident that we read text that is organized on a line. Also, artists know the advantages of a pencil line sketch in capturing information — as in a quick portrait sketch — as opposed to the more difficult task of representation by means of shaded areas without abstracted linear information. A successful line sketch (which contains reduced but still fractal information) can represent an object or person's portrait just as well as a photograph, because it has captured the essential physiognomic details, and those are linearly ordered.

There exist other techniques of organizing information spatially without condensing it along a line. The alternative is to organize high-information units using symmetry, which leads to patterns in two dimensions. A further savings of effort is accomplished in visual compression, by repeating a similar unit. Repetition can give rise to the wide range of traditional symmetries, such as reflectional, rotational, translational, and glide symmetries (Washburn & Crowe, 1988). High-contrast objects on the small scale can be spatially arranged in a symmetrical pattern, and the smaller units made similar so as to cut down the total amount of information. This leads us to:

Rule 5. Symmetries and patterns organize visual information, significantly decreasing the mental computational effort.

A well-defined unit (with coherent internal geometry and boundary) that is repeated does not need to be processed by our cognitive mechanism each time we encounter it. We apparently have the means to recognize similarity very easily, so the eye/brain system can encode a pattern in terms of one or more basic units, plus their positional distribution. If the units are repeated in some symmetric fashion — i.e., the units' positions are themselves symmetric — then only a little additional information is needed to specify the pattern. For this reason, patterns tend to be preferred over a random distribution of repeated units (Klinger & Salingaros, 2000). In the absence of any symmetry or ordering, our eye/brain system has to compute the position of each unit separately, which increases effort and comprehension time. Cognitive Rules 4 and 5 relate to the second law of *structural order* in Chapter 1.

It is now established that we have a built-in preference for symmetry, and this is singled out as the key visual characteristic that determines how we choose a mate. Symmetry on the large scale is thus linked to human attraction.

Organization structures information and endows it with meaning, which in turn connects that object with the human mind without the need for conscious reflection. Here is where *scaling coherence*, the topic of Chapter 3, comes into play in an essential manner. A symmetric arrangement of units is perceived on a higher level of scale than the units themselves (see Figure 4.6). Together, the smaller units define some pattern — a cognitively coherent whole that is larger than, and has more information than its components alone. As soon as one starts to do this, then recursion can be applied to define increasingly higher levels of scale, with each coherent arrangement on a particular level being very easily comprehended.

Figure (4.6) A symmetric arrangement of units defines a higher scale.

This nesting of patterns within patterns has occupied mankind for millennia (Washburn & Crowe, 1988). One could even claim that it forms a significant percentage of creative output over the history of the human species. It is seen in architectural ornament (especially Islamic), oriental carpets and traditional textiles, geometric designs on pottery, etc.

Readers will undoubtedly note a relationship between the cognitive rules proposed here and the well-known Gestalt laws of perception from psychology (Fischler &

Firschein, 1987), as follows. Cognitive Rule 4 relates to the Gestalt Laws "Proximity" and "Good Continuation", while Cognitive Rule 5 relates to "Similarity", "Closure", and "Symmetry".

Failure to perceive patterns indicates a pathology of the brain; in particular, the failure of different specialized regions and mechanisms that process visual information to integrate their functions (Zeki, 1993). Specific causes of such disintegration include Carbon Monoxide poisoning and cerebral lesions due to strokes. In what is known as "visual agnosia", a person perceives detail but cannot integrate this information to recognize an overall form. This could be manifested as an inability to recognize objects or faces. Such afflicted persons can see but cannot understand their environment, and the trauma makes them anywhere from mildly to severely dysfunctional.

Agnosic patients can draw an artifact so that others can recognize it, but which they themselves don't. They are found to copy pictures strictly according to their local structure (i.e., their details), without a grasp of the global structure (i.e., the overall shape) (Zigmond *et. al.*, 1999). Their drawings lack an overall coherence, and they will classify two pictures differing in only a minor detail as different objects. Some patients with brain damage complain that their environment appears fragmented; components are isolated and they cannot discern any meaningful spatial relationship among them.

I conjecture that, presented with an environment that deliberately breaks patterns and large-scale visual coherence, human beings will instinctively react in a manner similar to feeling an internal loss of integration; namely the different pathologies I just described.

6. HIERARCHICAL COOPERATION.

In order to identify exactly what it is that successful ornament achieves, I need to discuss the many ways it serves to connect and integrate structures with humans. The first way is the most obvious one — ornament connects spatially separated regions by giving them a informationally similar surface. That is, using the same ornamental design on opposite walls connects them in the mind of the observer. This is an application of translational symmetry. Without having an identifiable similar design or geometry somewhere on them, two disconnected, separate surfaces are not likely to appear as being related.

The second way in which ornament connects is through *hierarchical cooperation*. This is a term introduced in Chapter 3 to summarize part of what is a fundamental theory of "wholeness" developed by Christopher Alexander (2004). In the previous Section of this Chapter, I mentioned how patterns within patterns define different scales of structure. The existence of a natural scaling hierarchy is not sufficient, however. The different scales must cooperate visually in order for the ensemble to appear coherent. One way to achieve this is to have scaling symmetry, in which a design is repeated at a higher magnification. The eye/brain system thus perceives a connection between the two different scales.

Practical methods of *hierarchical cooperation* utilize scaling properties of fractals. Establishing *scaling coherence* plays a fundamental integrative role. Linking different scales in this manner serves to make a large-scale structure appear internally coherent. It also provides an easy point for external connection at every scale. Since all scales are visually connected to each other, then a person connecting to one scale will immediately connect to all the scales. This is the purpose of the mechanism of *hierarchical cooperation* — to make possible an effortless human connection to a structure defined on several different levels (see Chapter 7, *Pavements as Embodiments of Meaning for a Fractal Mind*). These points may be summarized by two additional cognitive rules:

Rule 6. Visual coherence occurs when each scale is related to many different scales — it is often necessary to introduce new structures on the smaller scales to create a hierarchy of connected scales.

Rule 7. Human beings connect to their environment on a number of different scales, and the connection is strongest when the environment is visually coherent.

Human beings establish a critical dialogue with artifacts that have been formed by the human hand — or with natural objects that exhibit geometrical substructure on that range of scales 1 mm to 1 m (see Figure 4.7). The exact reasons are unknown. One can guess, however, that it has to do with the more intimate matching of scales that the human body itself possesses, and is also greatly influenced by our tactile sense. This is far more important than is usually assumed in discussions of aesthetics, where the role of the tactile sense is undervalued. Since tactile connections exist purely on the smallest scales, this favors the smaller scales in the overall scheme. Our sense of touch helps to connect us to the smallest scale of a building. Cognitive Rules 6 and 7 reflect the third law of *structural order* from Chapter 1, which was developed into the rules for *scaling coherence* in Chapters 2 and 3.

Figure (4.7) Human beings connect to geometrical structure through details.

A study of the neurophysiological mechanisms whereby we connect to our environment reveals that concurrent mental processes operate at different perceptual scales (see Chapter 7, *Pavements as Embodiments of Meaning for a Fractal Mind*). The visual cortex is organized in a hierarchical fashion, and signals proceed up the hierarchy through a processing stream traversing several cortical areas (Zigmond *et. al.*, 1999). At the same time, at all stages in the pathway, connections tend to be reciprocal, feeding back processed signals from later regions (which respond to complex visual stimuli) into earlier regions (which respond to basic stimuli such as edges and orientation). This creates an iterative loop among hierarchically-organized clusters of neurons that parallels the linking among the components of a hierarchically-organized complex pattern.

I emphasize connectivity and integration because I believe it to be a central factor in experiencing our environment (see Chapter 7, *Pavements as Embodiments of Meaning for a Fractal Mind*). Visual coherence at all scales is perceived as "beauty". Descriptions of this effect are found more often in philosophy and religion than in science — a harmonious environment is considered connected on all scales, and we experience peace (i.e., psychological and physiological well-being) when we ourselves connect to it. Once we establish what is behind this effect, then we can analyze the various mathematical methods that are responsible for connectivity.

Although there is insufficient experimental confirmation on this topic, it is believed that intelligence, thought, reasoning, and consciousness, are emergent properties — products of an enormous number of ordered connections. Intelligence is measured by our ability to establish a connection between thoughts. Drawing a very broad analogy between neurons, individual thoughts, and physical structures, we mimic our own mind when we create coherent objects and buildings. While this conclusion is conjectural, it nevertheless offers a way of understanding the human urge to connect designs on artifacts and the built environment in many different ways. It helps to explain our instinctive need to integrate or "harmonize" our surroundings.

Rodolfo Llinás (2002) posits that 40 Hz coherent oscillations observed in the brain are related to consciousness. He offers this mechanism as one possible explanation of the observed phenomenon of spatial coherence, in which different groups of perceptual functions interlock. Perceptual unity links together independent sensory components, in what is called "cognitive binding". This represents a synchronous neuronal activation during sensory input. It is indeed observed that neural mechanisms operating independently in the spatial domain, each responsible for separate processing of sensory stimuli, link physiologically. Whether it is driven by the observed 40 Hz oscillations or not, cognitive binding is irrefutable.

The breakdown of integration, when it occurs due to a pathology in our own brain, diminishes our ability to function at the full level of a human being. It is not clear what happens when an analogous breakdown is intentionally imposed on the built environment, by suppressing both perceptual components, and the possibility of their integration. Nevertheless, I cannot help but think that willfully disconnecting a sentient being from surfaces and structures has strongly negative implications.

7. COLOR AND INTELLIGENCE.

Color vision represents a significant information increase over monochromatic vision found in otherwise intelligent animals such as dogs and cats. The sensation of color resides just as much in the computational part of the brain as it does in the optical mechanism of the eye (Hubel, 1988; Zeki, 1993). This is shown by "color constancy", which is the ability of the eye-brain system to adjust a biased color illumination and reconstruct a faithful color image. In the experiments of Edwin Land, a color painting or collage illuminated by red, green, and blue lights together appears the same to us regardless of the relative intensities of the three different lamps used for illumination. Color photographs of an object under different lights, however, look very different (everything is either too red, too green, or too blue). An enormous amount of computation is taking place in the brain to help us maintain the same experience of color under widely different circumstances.

Color perception evolved to support higher cognitive processes occurring in the human brain (Llinás, 2002). This is shown by the well-known evolutionary tradeoff between sensitivity to dim light, which is necessary to detect movement, and sensitivity to color, which is useful for identifying and classifying objects. For most animals, it is more important to be able to detect objects (a lower-level function) than to identify them (a higher-level function) (Fischler & Firschein, 1987). This tradeoff is present in our own eyes, where the most color-sensitive central fovea is not very good at detecting a wide range of grayscale contrast, whereas this situation is reversed in the peripheral regions of the retina (which detect contrast well but color poorly).

Color perception takes place in the most evolutionary developed region of the brain's cortex, so color perception is related to intelligence. We know that from direct experiments. Positron Emission Tomography (PET) can measure the varying blood flow to the most advanced cortical regions, which correlates with the level of neuronal activity corresponding to the eye's input sensation of color. Blood flow to the region of the brain responsible for color vision increases by threefold when subjects first view a picture only in shades of gray, then again in full color (Zeki, 1993). This corresponds exactly to what one would expect from an increase in information due to jumping from one sensory dimension (grayscale) to the three color dimensions.

Three different types of cone cells are needed in order to perceive color hue or wavelength, and to distinguish color intensity from white (colorless) (Hubel, 1988). Interestingly, the cone cells in the retina responsible for color vision are also responsible for our ability to see fine detail (Hubel, 1988), thus linking color with geometry in our perceptual apparatus. Contrary to what is frequently assumed, therefore, color and linear design are intimately related. This leads us to the final cognitive rule.

Rule 8. Color is an indispensable connective element of our environment.

Three arguments support this claim: first, our highly-developed color sensitivity; second, the neurophysiological coupling between our ability to see detail — something that is necessary for our survival — and our ability to see color; third, psychological experiments demonstrating how colors affect us profoundly. Not only does color have the ability to change our mood (with the greater pleasure offered by the more saturated hues); it can also directly affect our physiological state (Mehrabian, 1976). Finding the appropriate color, however, is a very difficult problem, which will not be treated here. A significant portion of the world's economy — that driven by the advertising and fashion industries — is based on the emotional connection between human beings and color.

Cognitive Rule 8 reveals a more profound role for color than was originally anticipated in Chapter 1. While color helps to define contrast in the first law of *structural order* (consequence 1b), and also to define harmony in the second law (consequence 2c), it appears that color is by itself responsible for an intense, different, and independent connection of humans to their environment (Alexander, 2004).

For a long time, the importance of color in architecture was dismissed because it is normally so easy to change. One can build with very expensive naturally-colored stone, but it is much easier to paint a wall with the pigments of one's choice. Even though wall coloration affects a building's users to a remarkable degree, the ease by which this major emotional effect can be changed has led to its being classified as "interior decoration" and not architecture. It is also felt to be outside an architect's control, since this is the single component of a building that a user can alter without problems. We see architects going to extraordinary lengths in an effort to maintain their hegemony over color. Such measures include forbidding users from painting their own walls; deliberately using colorless surfaces made from materials that are very difficult to paint over; and coming up with false philosophical arguments whose only purpose is to prevent people from expressing their need for color.

Color vision is an essential tool for acquiring knowledge about objects and the physical world. As pointed out by Semir Zeki (1993), consciousness and the acquisition of knowledge are inextricably linked to those neural organizations concerned with color vision. Indeed, he defines a system that can see and experience color as being "conscious".

Common color-blindness (inherited retinal achromatopsia) is experienced by about 8% of the male population. This is a common though not debilitating condition. People who are color blind lead normal lives, but have persistent problems in negotiating their world because their color perception is reduced from three color dimensions to only two color dimensions.

Total loss of color occurs in a pathology known as "cerebral achromatopsia" (Zeki, 1993). Cortical lesions in the specific region of the brain responsible for color vision destroy the ability to see in color, usually as a result of a stroke. Alternatively, transient achromatopsia can be caused by inadequate blood supply to this region. This is an experience well known to jet pilots who fly in high-G aircraft. As a consequence, the world is seen entirely in shades of gray, but the ability to distinguish detail is not affected. Patients who are permanently stricken with this condition describe their surroundings as "drab" and "depressing", and frequently live lives of despair after their injury (Zeki, 1993). Organic objects (such as foods and person's faces) are now repellent. A gray coloration is normally associated with decay and death.

These findings are so powerful that I am surprised they are not known by architects. In flat contradiction, we see an infatuation with drab, gray surfaces of raw concrete. Everyone I ask (with the notable exception of some architects) finds such surfaces morbid and depressing; and yet architects keep building them. Even worse, they go to great lengths to prevent their users from painting them with color so as to stop the deadening effect. Where paint is allowed to be used, again it is often restricted to depressing shades of gray. This is in stark contrast to historical and vernacular architectures around the world. The greatest buildings of the past are very colorful (or were before their color faded from weathering). Owner-built dwellings employ all the color they can find to intensify visual response from wall surfaces. Color appears to satisfy a fundamental human need, as shown by children's art (before they are conditioned to a gray industrial world) and folk art.

8. THE VALUE OF ORNAMENT.

Ornament helps to connect us to our environment. In order to satisfy the eight cognitive rules given above, buildings should have either a continuous swath of highdensity visual structure that the eye can follow in traversing their overall form, or focal points of intense detail and contrast arranged in the middle or at the corners of compositional regions. These contrasting elements could include a thick border or edge of the building; a thick boundary (frame) around openings and discontinuities; concentrated and detailed structure in the centers or corners of walls; etc. (Alexander, 2004). The visually-intense framework should organize information via patterns and symmetries.

Color has three distinct functions. First, it can help to define visually-intense regions due to the sensation of color intensity. Second, complementary colors can be used to define contrasting regions. Third, a common color can appear throughout the structure, and help to define an overall visual coherence.

The above cognitive rules would seem to have influenced architecture from around the world up to the beginning of the twentieth century, including Art Nouveau. Note, however, that key examples of the world's architectural heritage have lost their original bright coloration (which has never been restored because of the stylistic prejudices of today's architects who are in charge of restoration). It is far easier to classify those examples that do not comply with these rules, which happen to be primarily buildings from the twentieth century. Starting from the perspective of well-being, ornament seems a valuable factor in realizing a human architecture (Alexander, 2004; Bloomer, 2000). This Chapter argues that our neurophysiology requires us to resurrect the ornamental element of architecture that was arbitrarily condemned a century ago.

My conclusion also challenges a basic assumption of twentieth-century architects: that a building could be conceived in an abstract design space unrelated to physical space and to human beings. In fact, people actively seek perceptual connection with their physical environment to satisfy a fundamental physiological need (see Chapter 7, *Pavements as Embodiments of Meaning for a Fractal Mind*). This is consistent with the view of buildings and people forming a unified, interacting system (Alexander, 2004). Buildings do not exist in isolation from nature; the complexity of natural structures establishes the level at which information is valued. This threshold is part of our physiology. A building is successful or not after it is erected, for many different reasons. In addition to its strictly utilitarian aspects, "liking" a building depends on establishing visual and tactile connections with it.

Ornament is an indispensable part of this connection, but people today, after a century of doing without it (and hearing that it is somehow immoral), have almost forgotten how to generate ornament. Architects who reject ornament for ideological reasons are quick to point to unsuccessful, visually detracting examples of applied decoration to justify their decision for eliminating ornament altogether.

Since we no longer think about ornament as an integral part of architecture, most ornament created today fails in its task. Ornamentation that does not aim at coherence produces its opposite — incoherence. Garish or uncoordinated ornament is not satisfying, and could be visually disturbing. Ornament produced within the design canon of minimalist architecture is equally ineffective because it does not register with us. Its detail is too small or indistinct, and its differentiations are too faint or excessively subtle. On the other hand, sometimes effective ornamental components are used in contemporary architecture, but they are intentionally randomized so as to avoid coherence. This also makes them ineffective, because it frustrates our attempts to comprehend them in the context of the whole.

Successful ornamentation requires the recursive capacity (i.e., the ability to analyze images at different levels, then to synthesize that information) of only the most highly-developed brains, those of human beings. Different types of recursion include rhythm and repetition that generate translational and rotational symmetries; the iteration of geometrical structure on smaller and smaller scales that generates fractal patterns; and iteration on the same scale that generates denser and denser connections (Alexander, 2004; Bloomer, 2000). The human capacity for spoken and written language is in fact made possible by our capacity for recursive logical thought.

Students ask me how a building that already embodies a natural scaling hierarchy — which includes built structure on the ornamental scales — can accommodate additional ornament in the form of paintings, vases, plants, etc. That is no problem whatsoever, since a natural scaling hierarchy will simply extend to include those new objects. Too many decorative objects in a room may eventually lead to clutter because they will define too many uncoordinated scales, but that is strictly up to the user, and has nothing to do with the architecture.

9. ORNAMENT AND WRITING.

Ornament presents organized information that is entirely distinct from text as encoded in letters and signs. Ornament does not communicate a message in written language, but instead something equally as relevant in a subconscious language. I will use the example of typography to discuss this difference. When early typeface fonts for printing were cut by hand, they were created with the aim of having maximal legibility, guided by aesthetic considerations. Those were serif fonts (in which open lines end with a dot or T-stroke) like present-day Times and Garamond, which are more pleasing to the eye.

The introduction of radically new typefaces at the beginning of the twentieth century confirms that removing the ornamental serifs also removes a level of meaning. Sans-serif fonts such as Helvetica were popularized along with the modernist Bauhaus design style. They were promoted for their mathematical simplicity. It has been experimentally established that sans-serif fonts degrade legibility. People's reaction to these stripped-down typefaces was strongly negative; so much so that the first sans-serif font was named "grotesque" by the Berthold foundry, which introduced it commercially (the sans-serif typeface Berthold Akzidenz-Grotesk eventually gave rise to Helvetica).

Typography and text formatting ought to provide the simplest possible interface between information encoded in a text, and the mind of the reader. Everything should ideally facilitate the transmission of the text's message. Any imposition of visual elements or ideas as "design" extraneous to the text's meaning can easily degrade this transmission. Such is the case, unfortunately, with much of typography nowadays, where a "contemporary" visual appearance characterized by sans-serif fonts, grey ink, and paragraphs not separated from each other with either space or indentation takes precedence over the information in the text itself. By contrast, traditional fonts and text formatting evolved towards optimal legibility and psychological comfort, so as to enable reading without visual or emotional distractions. These practices facilitate the transmission of the text's meaning, and moreover produce a complex visual appearance that is aesthetically beautiful.

The transition from sans-serif to serif fonts shows clearly how ornament works to make form clearer, sharper, hence more distinguishable. Classic serif fonts go much further in establishing a positive emotional connection with the reader. In Chapter 3, I support the necessity of detail from arguments based on the properties of hierarchical systems. It is not just any added detail that improves the legibility of the font, however. Adding dots or small cross-strokes anywhere other than at the terminals of open lines (and even there, at some arbitrary angle) would degrade the font (see Figure 4.8). This provides one of the clearest illustrations that successful ornament is integral to the form, and is not merely "added on".

Figure (4.8) Demonstration of how ornament improves a typeface. On the left, the serif letter is the result of highly complex nonlinear operations on the basic design. In the middle, the overly simple sans-serif typeface is neither as attractive nor as legible as the serif typeface. On the right, adding substructure in the wrong places further reduces legibility.

Ornament organizes detail in a very precise and sophisticated fashion in order to make a larger form more comprehensible. Adjustments are necessary for a better comprehension of letters. The most effective serif fonts are vastly more complex mathematically than a similar sans-serif font. They show substructure on a hierarchy of decreasing scales. A serif typeface doesn't simply add end-strokes; the entire font is adjusted so that new, more detailed elements cooperate to define a coherent whole. The font's line thickness is everywhere different. Correcting an old misunderstanding, ornamentation does not superimpose unrelated structure; rather it is a subtle operation that generates highly-organized internal complexity. It therefore has to be extremely precise in order to be effective.

10. CONCLUSION.

This Chapter reviewed results from neurobiology and experimental psychology, which together provide evidence of an informational connection between people and the built environment. Visual information input helps to create a physiological state in the user, triggered by the design of the environment. Eight cognitive rules for *structural order* were given that facilitate this. The quality of information and its organization affects the emotional connection that human beings establish with forms and surfaces. Traditional architecture sponsors the interaction between human beings and environmental information, connecting people with a building. Detail, differentiations, curvature, and color appear necessary in at least some part of a building, implying that ornament is a valuable component of our environment. Without it, buildings tend to be perceived as having alien qualities.

Architects in the twentieth century created a visual condition similar to the environments experienced by brain-damaged patients, most certainly without knowing the physiological conditions of eye and brain pathologies that reduce human visual and spatial perception. The architecture of the twentieth century successfully reproduces the spatial experience of persons with eye conditions such as cataract, retinal detachment, and macular degeneration. It also recreates the experience of patients with cortical lesions, who suffer from visual agnosia, cerebral achromatopsia, and other causes of neurophysiological disintegration that destroy the ability to integrate visual information. Architects did this in their quest for pure expression, and in an effort to impose a certain conception of order on the built environment. With the knowledge we now have, it is appropriate to reconsider the effects architecture has on us, and how architectural education and practice can use this information to make more human buildings.