

MIND IN ARCHITECTURE

**NEUROSCIENCE, EMBODIMENT,
AND THE FUTURE OF DESIGN**

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EMBODIED SIMULATION, AESTHETICS, AND ARCHITECTURE: AN EXPERIMENTAL AESTHETIC APPROACH

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Every human contact with the things of the world contains both a meaning- and a presence-component. ... The situation of aesthetic experience is specific inasmuch as it allows us to live both these components in their tension.

Hans Gumbrecht¹

Cognitive neuroscience today offers a novel approach to the study of human social cognition and culture. Such an approach can be viewed as a sort of “cognitive archaeology,” as it enables the empirical investigation of the neurophysiological brain mechanisms that make our interactions with the world possible, thereby allowing us to detect the possible functional antecedents of our cognitive skills and to measure the sociocultural influence exerted through human cultural evolution on that very same cognitive repertoire. Thanks to cognitive neuroscience we can deconstruct some of the concepts we normally use when referring to intersubjectivity or to aesthetics, art, and architecture, as well as when considering our experience of them.

This chapter, written by a cognitive neuroscientist and an architect, endeavors to suggest why and how cognitive neuroscience should investigate our relationship with aesthetics and architecture—framing this empirical approach as experimental aesthetics. The term

experimental aesthetics specifically refers to the scientific investigation of the brain-body physiological correlates of the aesthetic experience of particular human symbolic expressions, such as works of art and architecture. The notion “aesthetics” is used here mainly in its bodily connotation, as it refers to the sensorimotor and affective aspects of our experience of these particular perceptual objects.

Of course, this approach covers only one aspect of aesthetics, since it refers to an early component of our perceptual experience of the object: to what is happening before any explicit judgment is formulated. The neurophysiological and behavioral evidence of this early phase of aesthetic experience is strikingly similar to that which underlies the mundane perceptual experience of nonartistic objects. Thus, experimental aesthetics can also clarify how different the neurophysiological and bodily correlates of “real-world” experience are from those that characterize experiencing the symbolic representations of that world. We address some recently discovered multimodal properties of the motor system, introducing mirror neurons and embodied simulation, and discuss their relevance for an embodied account of aesthetic experience, summarizing recent empirical research that targets the relationship between gestures and meaning-making. We conclude by proposing several suggestions on how experimental aesthetics might help us to understand the experience of architecture. We believe that only a multidisciplinary approach can increase our understanding of these important and distinctive aspects of human culture.

FOUR REASONS WHY COGNITIVE NEUROSCIENCE MATTERS TO ARCHITECTURE

Cognitive neuroscience is not an alternative to the humanities but a different methodological approach that explains the same phenomena with a different epistemological attitude, a different level of description, and a different language. Cognitive neuroscience can contribute to addressing the following questions: What does it mean “to look at” a painting, a Greek temple or a film, in terms of the brain-body system? To what extent does the way we experience “reality” and fiction depend upon different epistemic approaches and different underpinning neurofunctional mechanisms?

The reasons why cognitive neuroscience is entitled to formulate such questions, and supposedly also to help in answering them, are the following, listed according to their decreasingly broad implications: The first reason deals with the relationship between perception and empathy. For many years aesthetics and cognitive science have shared a particular attitude toward the sense of vision when accounting for aesthetic experience and

the perceptual representation of the world, respectively. Both approaches endorsed a sort of “visual imperialism,” neglecting the multimodal nature of vision. In the following section we demonstrate that such a notion of vision no longer holds, and introduce neuroscientific evidence of the relationship between the motor system, the body, and the perception of space, objects, and the actions of others.



8.1 Greek temple at Segesta, Sicily.

the perceptual representation of the world, respectively. Both approaches endorsed a sort of “visual imperialism,” neglecting the multimodal nature of vision. In the following section we demonstrate that such a notion of vision no longer holds, and introduce neuroscientific evidence of the relationship between the motor system, the body, and the perception of space, objects, and the actions of others.

The notion of empathy, recently explored by cognitive neuroscience, can reframe the problem of how art functions and how architectural spaces are experienced—revitalizing and empirically validating old intuitions about the relationship between body, empathy, and aesthetic experience.

The second reason addresses how the real and fictional worlds relate to one another and to the brain-body system. Empirical research has shown that we experience fictional realities through neurobiological mechanisms fairly similar to those through which we experience real life. We show how, from a certain point of view, any experience of any possible world basically depends upon similar embodied simulation routines. The “as-if” mode of embodied simulation appears to qualify not just our appreciation of fictional worlds, but all forms of intentional relations, including those characterizing our prosaic daily reality.

The third reason deals with architecture and its aesthetic quality. Embodied simulation can illuminate the aesthetic aspects of architecture—both from the perspective of its making, as well as the potential experience it affords the beholder—by revealing the intimate intersubjective nature of any creative act: where the physical object, the product of symbolic expression, becomes the mediator of an intersubjective relationship between creator and beholder. The experience of architecture, from the contemplation of the decorative element of a Greek temple to the physical experience of living and working within a specific architectonic space, can be deconstructed into its grounding bodily elements. Cognitive neuroscience can investigate of what the sense of presence that some buildings possess is made. This approach can also contribute a fresher empirical take on the evolution of architectonic style and its cultural diversity, by treating it as a particular case of symbolic expression, and through identifying its bodily roots.

THE MULTIMODAL NATURE OF VISION

Observing the world is more complex than the mere activation of the visual brain. Vision is multimodal; it encompasses the activation of motor, somatosensory, and emotion-related brain networks. Any intentional relation we might entertain with the external world has an intrinsic pragmatic nature; hence it always bears a motor content. More than five decades of research have shown that motor neurons also respond to visual, tactile, and auditory stimuli. The same motor circuits that control the motor behavior of individuals also map the space around them, the objects at hand in that very same space, thus defining and shaping in motor terms their representational content.² The space around us is defined by the motor potentialities of our body. Premotor neurons controlling the movements of the upper arm also respond to tactile stimuli applied to it, to visual stimuli moved within the arm’s peripersonal space, or to auditory stimuli also coming from that same peripersonal space.³ The manipulable objects we look at are classified by the motor brain as potential targets of the interactions we might entertain with

them. Premotor and parietal “canonical neurons” control the grasping and manipulation of objects and respond to their mere observation, as well.⁴ Finally, mirror neurons—motor neurons activated during the execution of an action and its observation performed by someone else—map the action of others on the observer’s motor representation of the same action.⁵

More than twenty years of research on mirror neurons have demonstrated the existence of a mechanism directly mapping action perception and execution in the human brain, here defined as the mirror mechanism (MM).⁶ Also, in humans, the motor brain is multimodal. Thus, it does not matter whether we see or hear the noise made by someone cracking peanuts, or locking a door. Different—visual and auditory—sensory accounts of the same motor behavior activate the very motor neurons that normally enable the original action. The brain circuits showing evidence of the MM, connecting frontal and posterior parietal multimodal motor neurons, most likely analogous to macaques’ mirror neurons, map a given motor content like “reach out” or “grasp” not only when controlling its performance, but also when perceiving the same motor behavior performed by someone else, when imitating it, or when imagining performing it while being perfectly still.

These results completely change our understanding of the role of the cortical motor system and of bodily actions. The cortical motor system is not just a movement machine, but an integral part of our cognitive system,⁷ because its neurofunctional architecture structures not only action execution but also action perception, imitation, and imagination, with neural connections to motor effectors and/or other sensory cortical areas. When the action is executed or imitated, the corticospinal pathway is activated, leading to the excitation of muscles and the ensuing movements. When the action is observed or imagined, its actual execution is inhibited. The cortical motor network, though, is not activated in all of its components and not with the same intensity, hence action is not produced—it is only simulated.

The prolonged activation of the neural representation of motor content in the absence of movement probably defines the experiential backbone of what we perceive or imagine perceiving. This allows a direct apprehension of the relational quality linking space, objects, and others’ actions to our body. The primordial quality turning space, objects, and behavior into intentional objects is their constitution as objects of the motor intentionality that our body’s motor potentialities express.⁸

Other MMs seem to be involved with our capacity to directly apprehend the emotions and sensations of others due to a shared representational bodily format. When perceiving others expressing disgust, or experiencing touch or pain, the same brain areas are activated as when we subjectively experience the same emotion or sensation. We do not fully experience their qualitative content, which remains opaque to us, but its simulation instantiated by the MM enables us to experience the other as experiencing emotions or sensations we know from the inside, as it were.

EMBODIED SIMULATION AND THE EMPATHIC BODY

The discovery of mirror neurons provides a new, empirically founded notion of intersubjectivity connoted first and foremost as intercorporeality—the mutual resonance of intentionally meaningful sensorimotor behaviors. Our understanding of others as intentional agents does not *exclusively* depend on propositional competence, but also on the relational nature of action. In many situations we can directly understand the meaning of other people's basic actions thanks to the motor equivalence between what others do and what we *can* do. Intercorporeality thus becomes the main source of knowledge we have of others. Motor simulation instantiated by neurons endowed with “mirror properties” is probably the neural correlate of this human faculty, describable in functional terms as “embodied simulation.”⁹

The multiple MMs present in our brain, thanks to the “intentional attunement” they generate, allow us to recognize others as other selves, allowing basic forms of intersubjective communication and mutual implicit understanding.¹⁰ Embodied simulation provides a unified theoretical framework for all of these phenomena. It proposes that our social interactions become meaningful by means of reusing our own mental states or processes in functionally attributing them to others. In this context, simulation is conceived as a nonconscious, prereflective functional mechanism of the brain-body system, whose function is to model objects, agents, and events. This mechanism can be triggered during our interactions with others, since it is being plastically modulated by contextual, cognitive, and personal identity-related factors.

Embodied simulation is also triggered during the experience of spatiality around our body and during the contemplation of objects. The functional architecture of embodied simulation seems to constitute a basic characteristic of our brain, making possible our rich and diversified experiences of space, objects, and other individuals, and is the basis of our capacity to empathize with them.

Taken together, the results summarized thus far suggest that empathy—or, at the very least, many of its bodily qualities—might be underpinned by embodied simulation mechanisms. According to our proposal, empathy is the outcome of the natural tendency to experience our interpersonal relations fundamentally at the implicit level of intercorporeality: that is, at the level of the mutual resonance of intentionally meaningful sensory-motor behaviors.

It is perhaps worth emphasizing that embodied simulation not only connects us to others, it connects us to *our* world—a world populated by natural and man-made objects, with or without a symbolic nature, and with other individuals: a world in which, most of the time, we feel at home. The sense we attribute to *our* lived experience of the world is grounded in the affect-laden relational quality of *our* body's action potentialities, enabled by the way they are mapped in *our* brains.

EMPATHY, EMBODIED SIMULATION, AND AESTHETIC EXPERIENCE

The idea that the body might play an important role in the aesthetic experience of visual art is quite old. The notion of empathy (*Einfühlung*) was originally introduced to aesthetics in 1873 by the German philosopher Robert Vischer, well before its use in psychology. Vischer described *Einfühlung*, literally “feeling-in,” as the physical response generated by the observation of forms within paintings. Particular visual forms arouse particular responsive feelings, depending on the conformity of those forms to the design and function of the muscles in the body, from our eyes to our limbs and to our bodily posture as a whole. Vischer clearly distinguished a passive notion of vision—*seeing*—from the active one of *looking*. According to Vischer, *looking* best characterizes our aesthetic experience when perceiving images, in general, and works of art, in particular.

Aesthetic experience implies an empathic involvement encompassing a series of bodily reactions of the beholder. In his book *On the Optical Sense of Form*, Vischer wrote: “We can often observe in ourselves the curious fact that a visual stimulus is experienced not so much with our eyes as with a different sense in another part of our body. ... The whole body is involved; the entire physical being [*Leibmensch*] is moved. ... Thus each emphatic sensation ultimately leads to a strengthening or a weakening of the general vital sensation [*allgemeine Vitalempfindung*].”¹¹

Vischer posits that symbolic forms acquire their meaning predominantly because of their intrinsic anthropomorphic content. Through the nonconscious projection of her/his body, the beholder establishes an intimate relation with the artwork.

Developing Vischer's ideas further, Heinrich Wölfflin speculated on the ways in which observation of specific architectural forms engages the beholder's bodily responses.¹² Shortly afterward, Theodor Lipps discussed the relationship between space and geometry on the one hand, and aesthetic enjoyment on the other.¹³

The work of Vischer exerted an important influence over two other German scholars whose contributions are highly relevant for our proposal: Adolf von Hildebrand and Aby Warburg. In 1893, the German sculptor Hildebrand published a book entitled *The Problem of Form in Figurative Art*. In this book Hildebrand proposed that our perception of the spatial characters of images is the result of a constructive sensory-motor process. Space, according to Hildebrand, does not constitute an a priori of experience, as suggested by Kant, but is itself a product of experience. That is to say, artistic images are effective because they are the outcome of both the artist's creative production and the effect that the images elicit in the beholder. The aesthetic value of works of art resides in their potential to establish a link between the intentional creative acts of the artist and the reconstruction of those acts by the beholder. In this way, creation and artistic fruition are directly related. To understand an artistic image, according to Hildebrand, means implicitly grasping its creative process.

A further interesting and very modern aspect of Hildebrand's proposal concerns the relevance he assigns to the motor nature of experience. Through movement, the available elements in space can be connected; objects can be carved out of their background and perceived as such. Through movement, representations and meaning can be formed and articulated. Ultimately, according to Hildebrand, sensible experience is possible, and images acquire their meaning only because of the acting body.

Hildebrand strongly influenced another famous German scholar, Aby Warburg. From 1888 to 1889 Warburg studied in Florence at the Kunsthistorisches Institut, founded by the art historian August Schmarsow. As Didi-Huberman emphasizes, Schmarsow (1853–1936) was determined to open art history to the contributions of anthropology, physiology, and psychology, and emphasized the role of body gestures in visual art, arguing that bodily empathy greatly contributes to the appreciation of visual arts.¹⁴ As Andrea Pinotti writes, Schmarsow, “art historian and theoretician, centered his reflections, which exploited both the results of the theories of empathy and the analyses of the formal character of art works, on the idea of the transcendental function of corporeality as a constellation of material a priori, that is, on the idea of bodily organization as the condition of the possibility of sensory experience.”¹⁵

Warburg clearly learned this lesson, as he conceived art history as a tool that would enable a deeper understanding of the psychology of human expressive power. His famous notion of a “pathemic form” (*Pathosformel*) of expression implies that a variety of bodily postures, gestures, and actions can be constantly detected in art history, from classical art



8.2 Laocoön and his sons.
Vatican Museum, Rome.

to the Renaissance period, just because they embody, in an exemplary fashion, the aesthetic act of empathy as one of the main creative sources of artistic style. According to Warburg, a theory of artistic style must be conceived as a “pragmatic science of expression” (*pragmatische Ausdruckskunde*).

Warburg, writing about the classic marble group known as the *Laocoön*, identified transition as a fundamental element that turns a static image into one charged with movement and pathos. Years later, the Russian movie director Sergei Eisenstein, commenting on the same *Laocoön* sculpture in 1935, wrote that the lived expression of human suffering portrayed in this masterpiece of classical art is accomplished by means of the illusion of movement.¹⁶ Movement illusion is accomplished by means of a particular



8.3 Marcel Duchamp, *Nude Descending a Staircase (No. 2)*, 1912. Oil on canvas. The Philadelphia Museum of Art.

montage, condensing in one single image different aspects of expressive bodily movements that could not possibly be visible at the same time. A similar effect can be appreciated in Duchamp's *Nude Descending a Staircase*.

Maurice Merleau-Ponty further highlighted the relationship between embodiment and aesthetic experience by suggesting the relevance for art appreciation of the felt bodily imitation of what is seen in the artwork.¹⁷ Consistent with the role of *Einfühlung*, Merleau-Ponty also emphasized the importance of the artist's implied actions for the aesthetic experience of the beholder, taking as his example the paintings of Cézanne, when he famously stated that we cannot possibly imagine how a mind could paint.¹⁸

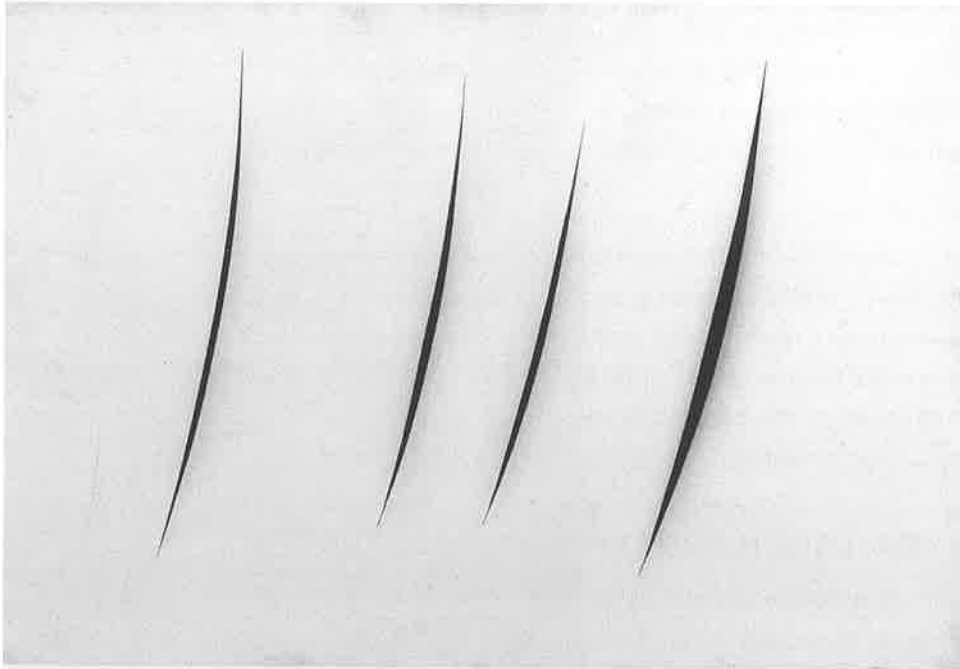
These scholars believed that the feeling of physical involvement with a painting, a sculpture, or an architectural form provokes a sense of imitating the motion or action seen or implied in the work, while enhancing our emotional responses to it. Thus, physical involvement constitutes a fundamental ingredient of our aesthetic experience of artworks. In the next section we discuss recent empirical evidence confirming bodily empathy as an important component of the perceptual experience of works of art, demonstrating its underlying neural mechanisms.

EMBODIED SIMULATION AND EXPERIMENTAL AESTHETICS

Embodied simulation can be relevant to aesthetic experience in at least two ways. First, because we relate to the bodily feelings triggered by works of art by means of the MMs they evoke. In this way, embodied simulation generates the peculiar "seeing-as" that characterizes our aesthetic experience of the images we look at. Second, the potentially intimate relationship between the symbol-making gesture and its eventual reception by beholders is enabled through the motor representation that produced the image by means of simulation.¹⁹ When I look at a graphic sign, I unconsciously simulate the gesture that produced it.

Our scientific investigation of experimental aesthetics applied to visual arts began with this second aspect. In three distinct experiments, we investigated, by means of high-density electroencephalography (EEG), the link between the expressive gestures of the hand and the images produced by those gestures. We recorded beholders' brain responses to graphic signs like letters, ideograms, and scribbles, or to abstract art works by Lucio Fontana and Franz Kline.

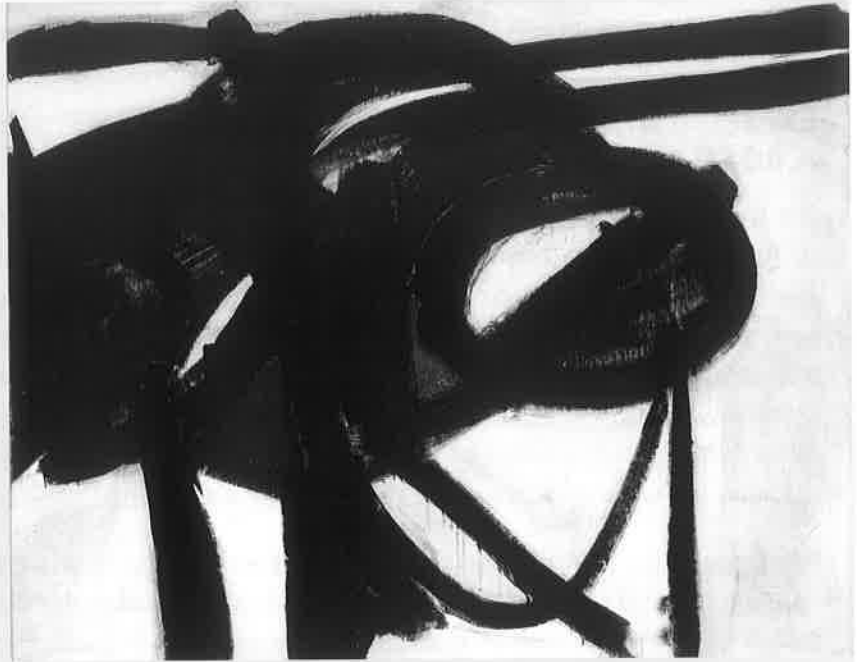
The results of the first study showed that observing a letter of the Roman alphabet, a Chinese ideogram, or a meaningless scribble, all written by hand, activated the hand motor representation of beholders.²⁰ In the two other studies we demonstrated that a similar motor simulation of hand gestures is evoked when beholding a cut on canvas by Lucio Fontana,²¹ or the dynamic brushstrokes on canvas by Franz Kline.²²



8.4 Lucio Fontana, *Spatial Concept #2*, 1960. Oil on canvas. The Philadelphia Museum of Art.

The visible traces of the creative gesture activated the specific motor areas that control the execution of that same gesture in the observer. Beholders' eyes not only capture information about the shape, direction, and texture of the cuts or strokes, by means of embodied simulation, they emulate the actual motor expression the artist used when creating the artwork. The sensory-motor component of our image perception, together with the jointly evoked emotional reaction, allows beholders to feel the artwork in an embodied manner.

A possible criticism of this model might point to the apparent passivity of this account of aesthetic experience, in which beholders are relegated to a deterministic empathic receptivity, hence losing sight of the peculiar individual quality of aesthetic experience that is largely determined by one's individual taste, background, memories, education, and expertise.



8.5 Franz Kline, *Chief*, 1950. Oil on canvas. The Museum of Modern Art, New York.

A second objection frequently raised against empathic-mimetic accounts of aesthetic experience consists of opposing the ambiguity and indeterminacy of art's symbolic content to the supposedly mechanistic quality of empathic responses, hence falling short of capturing the potential intrinsic ambiguity and polysemic quality of works of art.

We think it is possible to counter these criticisms by arguing that there is ample evidence that MMs and embodied simulation are dynamically modulated, and affected by contingent and idiosyncratic factors. Several studies have shown that one's previous experiences, memories, and expertise strongly determine the intensity of activation of MMs and the ensuing perceptual contents.²³

We posit that embodied simulation, by virtue of its diachronic plasticity and modulation, might be also the vehicle for the projective qualities of our aesthetic experience—where our personal and social identity literally shape the way we relate to a given perceptual object. Embodied simulation, if conceived of as the dynamic instantiation of our implicit memories, can relate the perceptual object and beholder to a specific, unique, and historically determined quality. This projective quality of embodied simulation refutes both objections.

EXPERIMENTAL AESTHETICS AND ARCHITECTURE: SUGGESTIONS FOR A ROAD MAP

We have already referred to Heinrich Wölfflin as one of the earliest proponents of the relationship between our bodily nature and our experience of architecture. According to Wölfflin, if we were merely visual creatures, the aesthetic appreciation of works of art and architecture would be precluded. The very nature of our body allows us to experience gravity, force, and pressure, and thus makes the enjoyment of contemplating a Doric temple, or the feeling of being elevated when entering a Gothic cathedral, possible in the first place. Furthermore, we offered a concise account of why the available empirical neuroscientific evidence seems to support this view.

We can now empirically test this view by recording the brain and bodily responses of volunteers perceptually experiencing and exploring virtual architectonic environments by means of immersive virtual reality. Today, virtual caves can reproduce high-accuracy, three-dimensional and richly dimensioned digital versions of temples, squares, churches, and buildings in which individuals can not only enjoy a vivid and realistic experience but may also virtually explore as if they are moving around, directing their gaze at different details and spatial locations. The ecological plausibility of such virtual experience can be established in the absence of any active movement on the part of beholders, making these ideal conditions in which to record brain signals and autonomic bodily responses, thereby minimizing movement-driven artifacts and signal noise.

This experimental approach could enable us to empirically address important aspects of architectural history, like the evolution of architectonic style, by charting its potential biological bodily roots. The same approach could also shed light on the plausibility of hypotheses about the supposed biomorphic and /or anthropomorphic origin of architectonic elements and decorations.²⁴ A second possible application of this approach to architecture deals with the relationship between architectural spaces and the way they are experienced by the people living and working in them.

Juhani Pallasmaa has criticized Western culture's excessive "oculocentrism," the overriding tendency that assigns a cognitive privilege to vision. With the invention of perspective, the eye becomes at once the center of the perceptual world and the center of the subject perceiving that world.²⁵ According to Pallasmaa, the scopic regime instantiated by visual perspective exemplifies the disembodied nature of the Cartesian subject, whose solipsism segregates the mind from the body, the subject from the object, and the I from the Thou. Such a "purovisibilist" attitude deeply influenced contemporary architecture by predominantly adhering, according to Pallasmaa, to a purely formalist perspective; as a consequence it has lost contact with the very people for whom the architectural project was originally intended.

As Sarah Robinson comprehensively reviews the body schema earlier in this book, she writes: "peripersonal space describes the space immediately surrounding our bodies; extrapersonal space refers to the space just beyond the peripersonal."²⁶ The constant weighting of architectonic and peripersonal space is mainly processed by premotor neurons mapping visual space on potential action or motor schemata. Furthermore, MMs for action are modulated by proxemics, as the potentiality for interactions between agent and observer measured by the distance separating them can affect the intensity of the discharge of mirror neurons in the beholder's brain.²⁷

As the experience of the built environment and its affordances is shaped through the precognitive activation of motor simulations, the role of embodied simulation in architectural experience becomes even more interesting if one considers emotions and sensations. A typical and recurring experience in everyday life is reacting with positive or negative feelings upon opening a door and going, for the first time, into a new architectural environment. Though, as Harry Mallgrave notes, to date little, if any, neuroimaging research has been done on the emotional experience of architectural environments.²⁸ The same applies to the haptic qualities of materials employed to design exterior and interior parts of architectonic spaces whose multimodal impact and desirability could be easily measured.

The knowledge acquired through experimental aesthetics might provide new insights, just to mention the most obvious ones, for the future design of office spaces or retail stores. Both are usually designed with strict and short deadlines by architectural firms specialized and routinized in this building typology. Such firms frequently need new fit-outs and refurbishments to stay ahead of challenging competitors.

The open office was originally conceived in the 1950s in Germany as *Bürolandschaft*, or office landscape, to facilitate communication and idea flow, and has since seen a dramatic growth in use (70 percent of all offices now have an open floor plan) as well as increasing levels of frustration in the employees who work in such environments. While proxemics contributed to more effective distribution of employees in open office layouts,



8.6 Office interior of Lombardini 22, DEGW Milano.

a neuroscientific approach to the study of peripersonal space could help architects shape working environments that ultimately promote employees' well-being and productivity.

As recently shown by architect Isabella Pasqualini, neuroscientist Olaf Blanke, and colleagues, “investigating bodily feelings, self-identification and self-location with respect to the architectonic unity or form and space of the observer may be confronted with architecture as an extension of the bodily volume.”²⁹ According to this study, the experience of a narrow room increases the somatosensory sensation of verticality, “thus enhancing bodily stability,” while conversely, a large room elicits “a destabilizing effect for the missing cue in peripersonal space provoking an illusory backwards movement.”³⁰

It is interesting to emphasize that these results prove to be coherent with Schmarsow's notion of space "from within." According to Schmarsow, "every spatial creation is first and foremost the enclosing of a subject."³¹ Indeed, the motor system is also responsible for the phenomenal awareness of the body's relations with the environment. We are planning to study how daily actions or social interactions virtually presented within differently designed architectonic spaces are experienced differently by beholders. We will also study if and how such different experiences correlate with different profiles of bodily and brain responses.

CONCLUSIONS

Even if the notions of embodiment and empathy within the architectural field are much older than cognitive neuroscience itself, the latter is shedding new light on a topic that is otherwise dismissed or neglected by mainstream theory. The theory of empathy began to have an impact within the contemporary architectural field—as Harry Mallgrave insightfully described—in the "Garden City" of Hellerau, an experiment by Wolf Dohrn on the outskirts of Dresden in 1908–1914; in the Bauhaus in 1919–1933; and in Richard Neutra's book *Survival through Design* in 1954. Architects and architectural scholars such as Juhani Pallasmaa, Steven Holl, Alberto Pérez-Gómez, and Harry Mallgrave have revitalized and brought the topic of empathy back into contemporary discourse, some of them in this volume.

Architecture is among the fruits of the new way in which humans, at a given point in their cultural evolution, were able to relate to the external world. The material world was no longer exclusively considered to be a domain to exploit for the utilitarian satisfaction of biological needs. Material objects lost their unique status as tools to become symbols, public epiphanies able to make something that is absent visible—to make tangible something that apparently is present only in the mind of the creator and the beholder. Humans, thanks to the expression of their symbolic creativity, acquired the capacity to give shape to material objects, conferring on them the meaning they intrinsically lack. Such meaning is the outcome of the creator's action of collectively building a temple or a cathedral, laying colors on a canvas, or turning a marble block into a *David* or a *Rape of Proserpina*.

Today, cognitive neuroscience can reveal—from its own peculiar perspective and methodology—the aesthetic quality of human nature and our natural creative inclination. This new research will help us to understand how and why art and architecture are among the most fundamental expressions of our human nature.

NOTES

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NEUROSCIENCE FOR ARCHITECTURE

Thomas D. Albright

Buildings serve many purposes. One might argue that their primary function is to provide shelter for the inhabitants and their possessions—a place to stay warm and dry, and to sleep without fear of predators or pathogens. Buildings also provide spaces to safely contain and facilitate social groups focused on learning, work, or play. And they provide for privacy, a space for solace and retreat from the social demands of human existence.

These primary physical requirements, and their many subsidiaries, simply reflect the fact that we are biological creatures. In addition to building constraints dictated by site, materials, and budget, an architect must respond to the nonnegotiable facts of human biology. Indeed, architecture has always bowed to biology: the countertop heights in kitchens, the rise:run ratio of stairs, lighting, water sources, heat and airflow through a building, are all patent solutions to salient biological needs and constraints. There are creative technology-based extensions of these solutions afoot in the form of smart homes. But there are subtler

instances in which a deeper understanding of human biology affords a qualitatively superior solution. Consider, for example, the ascendance of the door lever as a design imperative imposed by biology. Seen from a strictly biomechanical perspective, a door lever is a far better tool than a traditional round doorknob for opening the latch. Pressure to adopt this superior solution came largely from recognition that it could benefit people with certain biological limitations (“physical disabilities”). Not surprisingly, the U.S. Americans with Disabilities Act (1990) has mandated the use of door levers because their design is easy to grasp with one hand and does not require “tight grasping or pinching or twisting of the wrist to operate.”¹ Here is a case in which design centered explicitly on the details of a biological problem allows for greater accessibility and enhanced use.

At the same time that our buildings provide physical solutions to problems dictated by human biology, we also expect them to satisfy our psychological needs. We expect them to inspire and excite us, to promote mental states that lead us to discover, understand and create, to heal and find our way, to summon the better angels of our nature. We expect them to be beautiful. Not surprisingly, psychological considerations have been a part of the design process since humans began constructing lasting communal environments. The ancient tradition of Vaastu Veda, which dictated the design of temples and dwellings in early Hindu society, focused on ways in which a building directs “spiritual energies” that influence the souls of the inhabitants²—or, in today’s parlance, the ways in which design influences the many facets of mental well-being. Feng shui, the ancient Chinese philosophy of building design, emerged for similar reasons.³

VAASTU VEDA IN THE AGE OF NEUROSCIENCE

While the basic psychological needs of a building’s inhabitants today remain largely the same as they were in ancient times, we have one notable tool that promises a new perspective on how buildings influence our mental states: the modern field of neuroscience. Considered broadly, neuroscience is the umbrella for a collection of empirical disciplines—among them biology, experimental psychology, cognitive science, chemistry, anatomy, physiology, computer science—that investigate the relationship between the brain and behavior.⁴ There are multiple internal processes that underlie that relationship, including sensation, perception, cognition, memory, and emotion.

There are also multiple levels at which we can investigate and characterize the relationship between brain and behavior. We can, for example, describe behavior in terms of the interactions between large brain systems for sensory processing and memory. Or we can

drill down and explore how cellular interactions within circuits of brain cells (neurons) give rise to larger system properties, such as visual perception. Deeper still, we can explore the molecular components and events that underlie the behaviors of individual neurons, or the genetic codes and patterns of gene expression that produce the cellular substrates and organized circuits for brain function.

Most importantly, modern neuroscience affords the tools and concepts that enable us to identify the causal biological chains extending from genes to human behavior. This powerful approach, and the rich understanding of brain function that it affords, naturally has broad implications for and applications to many problems in human society, particularly in the field of medicine. But one might reasonably ask—and many do—whether there is any practical value for architecture and design that comes from knowing, for example, how neurons are wired up in the brain. I argue that there is value: knowing how the machine works can offer insights into its performance and limitations, insights into what it does best and how we might be able to tune it up for the task at hand. In the same way that understanding of an amplifier circuit in your car radio can lead to principled hypotheses regarding the types of sound it plays best, knowledge of how the human visual system is wired up may, for example, lead to unexpected predictions about the visual aesthetics or navigability of a building. At the same time, of course, the level of analysis of brain function should be appropriate for the question. In the same sense that knowledge of electron flow in a transistor offers few practical insights into what your radio is capable of, it seems unlikely that today's knowledge of patterns of gene expression that underlie brain circuits will yield much grist for the mill of design. That said, our understanding of brain development, function, and plasticity is still evolving, and we may find that the larger multilevel picture eventually leads to new ways of thinking.

THE BRAIN AS AN INFORMATION-PROCESSOR

In trying to understand more concretely how neuroscience might be relevant to design, it is useful to think of the brain as an information-processing device, which of course it is. Indeed, it is the most powerful information-processing device known to man. The brain acquires information about the world through the senses and then organizes, interprets, and integrates that information. The brain assigns value, affect, and potential utility to the acquired information, and stores that information by means of memory in order to access it at a later time. These memories of information received form the basis for future actions.

Thinking further along these lines, we can make the argument that architecture is a multifaceted source of information. The sensory appearance tells us how space is organized, and thus its utility and navigability. Similarly, the appearance and its relationship to intended function may be profoundly symbolic, conjuring up a broader view of the responsibility to the users of the space and their relationship to society. Prior experiences with the world will of course come into play in understanding the meaning of the space and how it might most effectively serve its intended purpose, or inspire other unintended uses. And, of course, information conveyed by our senses, considered in a symbolic and functional context, may be the source of strong aesthetic and emotional responses, including our perception of beauty.

Building on this information-processing perspective, we can begin to articulate a few basic principles about how knowledge of the brain may bear upon architectural design. These principles conveniently fall into categories of information *acquisition*, *organization*, and *use*. In terms of acquisition, the built environment should be optimized to neuronal constraints on sensory performance and information-seeking behavior, and optimized with respect to the adaptability of those constraints. At the simplest level, for example, knowing something about human visual sensitivity—what we see best and what we have difficulty seeing—may define rules for efficient design of environments for labor, learning, healing, and recreation. I will elaborate on some examples of optimizing sensory performance later in this chapter.

In terms of organization, the built environment should facilitate perceptual organization and engender the formation of cognitive schema/neuronal maps for the task at hand. An example of the relevance of neuronal maps can be found in research on wayfinding behavior.⁵ A rich vein of neuroscience research has revealed much about how space, and the location of an observer in space, is represented by populations of neurons—neuronal maps of space—in a brain structure known as the hippocampus.⁶ This knowledge, in conjunction with an understanding of how landmarks and other sensory cues in the built environment facilitate wayfinding, may lead to new ideas about how to facilitate navigability by design. These ideas, in turn, may help those who suffer from memory disorders associated with dementia, and help to improve design of transportation hubs and public areas in general.⁷

In terms of use, the built environment should elicit internal states that benefit sensory, perceptual, and cognitive performance and behavioral outcomes. “Internal states” here refers to those associated with focal attention, motivation, emotion, and stress. A number

of recent studies support the plausible conjecture that certain environments elicit attentional states,⁸ or states of anxiety and stress,⁹ which can either facilitate or interfere with the ability of observers to respond to information embedded in the environment or to carry out actions for which the environment was intended. In work with Alzheimer's patients, for example, John Zeisel¹⁰ has shown that architectural design elicits certain outcomes that have clinical value: anxiety and aggression are reduced in settings with greater privacy and personalization; social withdrawal is reduced in settings with limited numbers of common spaces that each have a distinctive identity; agitation is reduced in settings that are more residential than institutional in character. This type of knowledge could similarly inform the design of classrooms, lecture halls, health care facilities, workspaces, and more.

VISUAL FUNCTION, PERCEPTION, AND ARCHITECTURE

One area of neuroscience research that is particularly amenable to this kind of information-processing approach—and its relevance to architecture—is that associated with study of the visual system. This is true in part because vision plays a primary role in architectural experience, but also because we now have a wealth of information about how the visual system works.¹¹ In the following sections, I will highlight some examples drawn from our current understanding of vision, in order to illustrate the merits of this way of thinking. To set the stage, I will first briefly summarize the basic organization of the human visual system, as well as the neuroscience research methods used to study it.

Visual experience depends, of course, on information conveyed by patterns of light. Most of the patterned light that you see originates by reflectance from surfaces in your environment—sunlight returned from the façade of a building, for example. This reflected light is optically refracted by the crystalline lens in the front of your eye, yielding a focused image that is projected onto the back surface of the eye. This back surface is lined with a crucial neuronal tissue known as the retina, which is where phototransduction takes place: energy in the form of light is transduced into energy in the form of electrical signals, which are communicated by neurons. Retinal neurons carrying information in the form of such signals exit the eye via the optic nerve and terminate in a region near the center of the brain, known as the thalamus. Information reaching this stage is conveyed across chemical synapses and relayed on by thalamic fibers to reach the visual cortex. The visual cortex comprises the most posterior regions of the cerebral cortex, which is the large wrinkled sheet of neuronal tissue that forms the exterior surface of the human brain. The visual cortex is where high-level processing of visual images takes place, and it

is the substrate that underlies our conscious visual experiences of the world. Our objective here is to understand how the organization of the visual cortex might have implications for the design of human environments.

EMPIRICAL APPROACHES TO UNDERSTANDING VISION

There is a variety of powerful experimental tools for studying the organization and function of the brain, which are summarized here as they apply to an understanding of the visual system.¹² Perhaps the simplest approach involves analysis of behavioral responses to sensory stimuli. This method, known as psychophysics, dates to the nineteenth century and involves asking people under very rigorous conditions to tell us what they observe when presented with visual stimuli that vary along simple dimensions, such as wavelength of light or direction of motion. From this we are able to precisely quantify what stimulus information observers are able to perceive, remember, and use to guide their actions. This approach is particularly valuable when used in conjunction with other experimental techniques, such as those that follow.

One important complement to psychophysics is neuroanatomy, which reveals the cellular units of brain function and their patterns of interconnections. With this approach we can, for example, trace the neuronal connections from the retina up through multiple stages of visual processing in the cerebral cortex, thereby yielding a wiring diagram of neuronal circuits.¹³ Such wiring patterns reveal, in turn, computational principles by which visual information is combined and abstracted to yield perceptual experience.

Another powerful experimental technique is electrophysiology, the main goal of which is to understand how information flows through the system. To measure this flow, we use microelectrodes—fine wires that are insulated along their lengths and exposed at the very tips—that are inserted into the brain to monitor electrical signals (known as action potentials) from individual neurons. From such experiments we know that the frequency of electrical signals carried by a visual neuron is often correlated with a specific property of a visual stimulus. A neuron might thus “respond” selectively to a particular color of light, or to a specific shape.¹⁴ These patterns of selective signaling reflect the visual information encoded by neuronal circuits. Moreover, by monitoring the ways in which signals are transformed from one processing stage to the next, we can infer the “goals” of each stage and gain insights into the underlying computation.

Fine-scale electrophysiology of the sort described above is largely restricted to use in experimental animals, but there are larger-scale approaches that involve assessment of

patterns of brain activity recorded from the surface of the scalp. Despite the relative coarseness of the latter approach, electroencephalographic (EEG) methods are advantageous for our interest in architecture because they can be used to assess broad patterns of neuronal activity noninvasively in humans who are actively exploring an environment.¹⁵

Electrophysiological approaches are often complemented by a newer experimental technique known as functional magnetic resonance imaging (fMRI). This noninvasive method exploits the fact that: (1) oxygenated blood has a distinct signature in a magnetic resonance image, (2) oxygenated blood is dynamically redirected to regions of the brain that are metabolically active, and (3) neurons that are electrically active have a higher metabolic load. Thus the fMRI blood flow signal serves as a proxy for measurements of neuronal activity and can be used to identify brain regions that are active under different sensory, perceptual, cognitive and/or behavioral conditions.¹⁶

The various experimental techniques of modern neuroscience, summarized above, are most powerfully used in concert with one another, where they can collectively yield a rich and coherent picture of the ways in which information is acquired and organized by the brain, and used to make decisions and guide actions.

ON THE STATISTICAL PROPERTIES OF VISUAL INFORMATION

With this brief introduction to the organization of the visual system and the methods by which it can be studied, we can consider how current knowledge of information processing by the brain might suggest principles for design of human environments. I will begin with the premise that the brain has evolved to maximize acquisition of behaviorally relevant information about the environment, but must do so in the face of biological constraints. These constraints include various sources of noise and bottlenecks inherent to the neuronal machinery of the brain itself, the consequence of which is that our sensory systems are less than perfect transducers. Or, to put it more concretely, there are some things that we see better than others.

To illustrate how this limitation applies to architecture and design, we can start by measuring the physical properties of visual scenes from which the brain extracts information. There are many ways to do this—both natural and built environments have measurable statistics and we can quantify simple things like the frequency distributions of primary features, such as the different colors in a scene, or the orientations of contours (for example, those forming the frame of a window, or the branches of a tree). These simple

statistics can be compared with the empirically determined sensitivity of the visual system for the same features, which provides a measure of the extent to which people can actually acquire (and thus use) certain classes of information present in the environment.

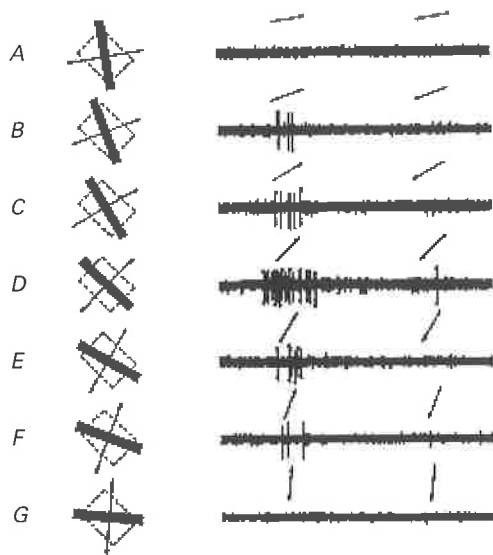
Employing the same approach, we can also quantify the statistics of higher-order image features—which are arguably more directly relevant to human behavior in natural and built environments—such as particular shapes and the joint probabilities of certain features (e.g., how often a specific color coincides in space with a certain shape). One specific example that has been looked at in some detail is the relationship between different line orientations as a function of their proximity in visual space.¹⁷ As intuition suggests, there is a strong tendency for image contours that are nearby to have similar orientations, but as distance between them increases there is a progressive increase in the variance between pairs of contour orientations. One need only look at the contours of common man-made or natural objects—a teapot, for example, or a rose—to see that this distance-dependent contour orientation relationship simply reflects the physical properties of things in our visual world. The functional importance of this relationship can be seen by contrasting it with man-made objects that violate the principle: the image statistics of a Jackson Pollock painting,¹⁸ for example, reflect a riot of angles and colors whose relationships yield no real perceptual synthesis.

FUNCTIONAL ORGANIZATION OF THE VISUAL BRAIN

Some unexpected insights and predictions come from consideration of image statistics in conjunction with knowledge of the organizational features of the visual cortex. Over the past few decades we have learned that there are a number of different regions of the visual cortex that are specialized for the processing of unique types of visual information; one region processes contour orientation, another motion, another area processes color, and so on.¹⁹ This knowledge has come, in part, from electrophysiological studies of the sort described above, in which the response (measured as frequency of action potentials) of a given visual neuron varies with the value of a simple stimulus along a specific feature dimension: for example, the particular angle of an oriented contour, or the particular direction of a moving pattern.

Figure 10.1 illustrates this type of cellular “tuning” as originally discovered for neurons in primary visual cortex.²⁰ The data represent action potentials recorded as a function of the orientation and direction of motion of a simple visual stimulus (an oriented contour). In this case, the recorded neuron responded best to a slightly off-vertical orientation

moving up to the right, and the neuronal response waned as a function of the angular deviation of the contour relative to this preferred orientation. The vast majority of neurons in the primary visual cortex exhibit this property of “orientation selectivity.” Their discovery in the 1960s by David Hubel and Torsten Wiesel transformed the way we understand the visual system, and fostered the development of a whole new set of techniques to study it. The existence of this specialized population of neurons in the cerebral cortex, and other populations that represent stimulus direction²¹ and color,²² accounts for the primacy of such simple features in our visual experience of the world.



10.1 Orientation selectivity in the primary visual cortex. D. H. Hubel and T. N. Wiesel, 1968.

Each of these functionally specific areas is further arranged according to certain organizational principles. One of these is columnar organization, which means that similar values of a given feature dimension (such as contour orientation or direction of motion) are represented in adjacent cortical tissues.²³ These functional columns extend through the thickness of the cerebral cortex and are mediated by neuronal microcircuits that correspond anatomically to the functional columns.²⁴ The neuronal architecture is such that the preferred value of the relevant feature (e.g., the preferred contour orientation) remains constant as one moves from the surface through the depth of the cortex, but changes gradually as one moves in the orthogonal plane, i.e., parallel to the cortical surface.²⁵ The scale of this system is fine, with a complete cycle of preferred orientations contained within less than a millimeter of cortex. A highly similar columnar system exists in a

region of visual cortex specialized for encoding direction of motion.²⁶ In this case, the individual neurons represent specific directions, rather than contour orientations, and a complete cycle of direction columns similarly spans a region of cortex less than a millimeter across.

Another organizational principle of the visual system is built around the concept of association fields.²⁷ Association fields reflect patterns of local anatomical connections that link neurons representing specific values of a visual feature dimension. In the primary visual cortex, the specificity of these connections is made possible by the existence of an organized columnar system for representing contour orientations (see above). The connections are manifested as anatomical links between columns representing specific contour orientations. In particular, within cortical regions representing close-by locations in visual space, there exist strong connections between columns that represent similar orientations and only weak connections between columns that represent widely different orientations (perpendicular being the extreme).²⁸ As the spatial distance grows, the pattern of anatomical connections becomes more isotropic.

ASPECTS OF PERCEPTION FACILITATED BY NEURONAL ARCHITECTURE

These highly specific organizational properties for representing information about the visual environment raise interesting questions and conjectures about their relationship to visual perception. For one, we note that there is an apparent symmetry between the association fields for contour orientation and the statistics (summarized above) of contour orientations in the visual world. As we have seen, contours that are nearby in visual space are more commonly similar in orientation, relative to those that are distant in visual space. Analogously, in the visual cortex, cells representing similar orientations are preferentially interconnected provided that they also represent nearby locations in visual space. There are evolutionary arguments one can make: it seems highly likely that this cortical system for organizing visual information conferred a selective advantage for detecting statistical regularities in the world in which we evolved. At any rate, we hypothesize that the existence of the system helps to facilitate the processing of commonly occurring relationships between visual features.

A key part of this conjecture, which has implications for architecture and design, is the word *facilitate*. Human psychophysical experiments have shown, for example, that when people view random patterns of line segments, any colinear, or nearly colinear, relationships within those patterns tend to stand out perceptually from a background of



10.2 Field of wheat.



10.3 Green bodhi leaves.



10.4 Alaskan tundra.

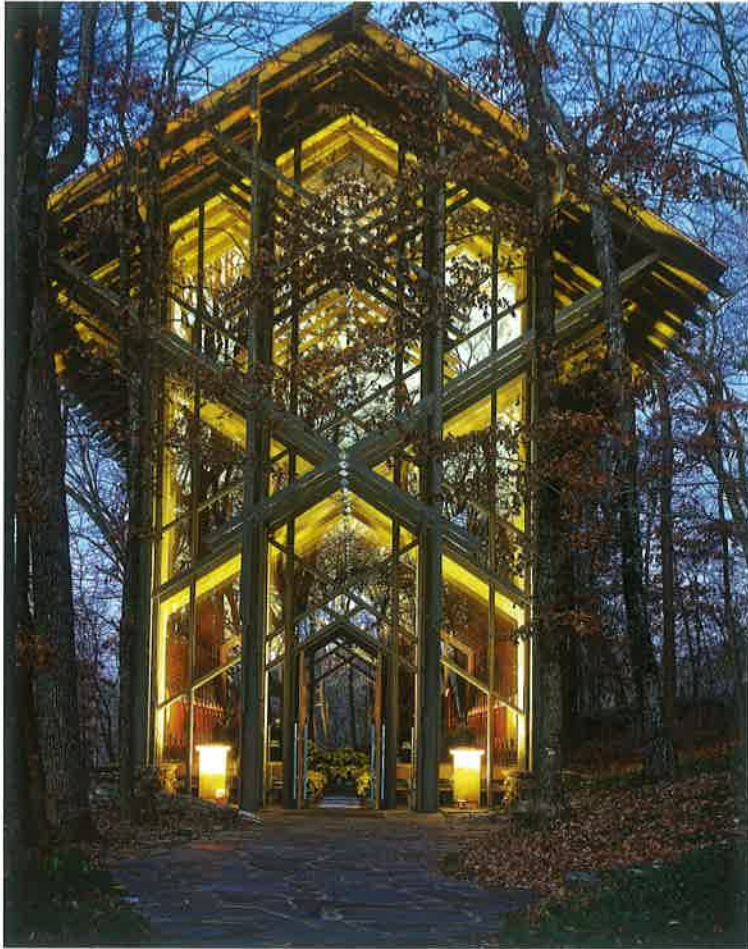


10.5 Feathers of an ostrich.

noise²⁹—according to our hypothesis, perceptual sensitivity to these arrangements is *facilitated* by the organizational properties of the visual cortex.

As implied by the foregoing arguments, visual patterns in which there is a statistical regularity between adjacent contour orientations—repeating lines in colinear, curvilinear, parallel and radial patterns, for example—are ubiquitous in the natural world. Fields of grass, waves in the ocean, the veins of a leaf, the branches of a tree, the leaflets of a palm frond, or the barbs of a feather are all commonly encountered examples that embody this principle.

We hypothesize that man-made designs that adopt this same principle “benefit” in some way—detection of them is “facilitated”—by tapping into the highly organized neuronal



10.6 Fay Jones, Thorncrown Chapel, Fayetteville, Arkansas.

system for representing contour orientations. One need not look hard to find prized exemplars in the built environment that feature colinear, curvilinear, parallel and radial patterns: Fay Jones's Thorncrown Chapel in Fayetteville, Arkansas, the colonnades in Romanesque churches and monasteries such as the abbey at Assisi, or the rose window in the cathedral of Notre Dame. The cable-stayed bridge, which is commonly constructed using radial fans of cables to cantilever the road bed, is a particularly notable example. This is the most commonly built highway bridge today. There are many reasons for this that stem from advances in materials science and engineering, as well as economy of construction. But I speculate that the popularity of the cable-stayed bridge is also due, in part, to the fact that the gradually changing contours tap into something fundamental in the native organization of our visual system. There is, I will argue, an attractiveness to



10.7 Cloisters, Monreale, Sicily.

these designs that originates from the ease with which they are processed and perceived by our visual systems.

THE SENSE OF ORDER

Neuroscientists were not the first to make this connection. Ernst Gombrich, one of the great geniuses of twentieth-century arts and humanities, wrote and reflected deeply on the relationship between art and visual perception.³⁰ His text *The Sense of Order: A Study in the Psychology of Decorative Art* addresses the use of certain timeless design features in art and architecture. Summarizing his thesis elsewhere, Gombrich wrote: “I claim that the formal characteristics of most human products, from tools to buildings

and from clothing to ornament, can be seen as manifestations of that sense of order which is deeply rooted in man's biological heritage. These ordered events in our environment which exhibit rhythmical or other regular features (the waves of the sea or the uniform texture of a cornfield) easily 'lock in' with our tentative projections of order and thereby sink below the threshold of our attention while any change in these regularities leads to an arousal of attention. Hence the artificial environment man has created for himself satisfies the dual demand for easy adjustment and easy arousal."³¹

Gombrich was not a neuroscientist, of course, but his concept of "manifestations of that sense of order which is deeply rooted in man's biological heritage" and his suggestion that "these ordered events in our environment ... easily 'lock in' with our tentative projections of order" resonate deeply with the view that our perception of the world depends heavily upon highly ordered neurobiological characteristics of the human visual system. Again without knowledge of the neuroscience of vision, Gombrich expanded along similar lines: "There is an observable bias in our perception for simple configurations, straight lines, circles and other simple orders and we will tend to see such regularities rather than random shapes and our encounter with the chaotic world outside. Just as scattered iron filings in a magnetic field order themselves into a pattern, so the nervous impulses reaching the visual cortex are subject to the forces of attraction and repulsion."³² Gombrich's iron filings metaphor is striking in the present context, as it poetically captures the notion that the organizational properties of the visual system serve to efficiently encode statistical regularities in the visual world.

Gombrich spoke at length about designs that impart this sense of order. Some examples include the mosaics at the Alhambra, and the paper and textile patterns of William Morris. To these I would add the decorative designs of Frank Lloyd Wright from a similar period to those of Morris. For each of these examples, it is not necessary to sit and examine how it is put together; you see one part and a perceptual understanding of the whole follows without visual scrutiny—they are repetitive designs that capitalize on the ordered nature of the visual cortex.

Similar arguments apply to mandalas, which have been used as meditation aids for centuries in the spiritual practices of Hinduism and Tibetan Buddhism. As for the decorative patterns cited above, mandalas have image statistics that are complementary to the organization of the visual cortex. Our conjecture is that they have an ordering effect owing to the ease of visual processing—they are calming, regular structures.

10.8 Frank Lloyd Wright, textile block pattern.



10.9 Frank Lloyd Wright, textile block house, Los Angeles.

