Architecture and Neuroscience

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Architecture and Neuroscience

with essays by

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Contents

Towards a Neuroscience of Architecture 5
Juhani Pallasmaa

Should Architects Care about Neuroscience? 23
Harry Francis Mallgrave

(Why) Should Architects Care about Neuroscience? 43
Michael Arbib

Author Biographies 77
About the TWRB Foundation 78
Juhani Pallasmaa

Towards a Neuroscience of Architecture: Embodied Mind and Imagination

While the brain controls our behavior and genes control the blueprint for the design and structure of the brain, the environment can modulate the function of genes and, ultimately, the structure of our brain, and therefore they change our behavior. In planning the environments in which we live, architectural design changes our brain and behavior.¹

[Fred Gage]

Architecture: An Impure Discipline
Architecture is a hybrid and “impure” discipline. The practice of architecture contains and fuses ingredients from conflicting and irrecosncilable categories such as material technologies and mental intentions, construction and aesthetics, physical facts and cultural beliefs, knowledge and dreams, past and future, means and ends. Besides its traditional reliance on the tacit knowledge of timeless practices of construction, architecture relies largely on theories and findings of other areas of research and knowledge, instead of possessing an independent theoretical foundation of its own. During the past decades, architecture has been viewed from various theoretical perspectives, provided by, for instance, psychology, psychoanalysis, structural linguistics and anthropology as well as deconstructionist and phenomenological philosophies, just to name a few. It is evident that in the field of architecture, scientific criteria or methods have mainly been applied in its technical, physical and material aspects, whereas the mental realm has been left to individual artistic intuition. On the other hand, the fast development of computerized digital technologies have provided an entirely new
horizon for architectural production. In fact, these technologies seem to have developed beyond our complete grasp of what really is the essence in the interaction of digital technology and the innate nature of our biologically grounded perception, experience and lived reality. In the face of the miracles brought about by technical innovations, we tend to underestimate, or entirely neglect, the miracles of life itself.

The complexity of our neural system is beyond comprehension: the human brain contains more than one hundred billion neurons, and each neuron has in average 7000 synaptic connections. That amounts to the staggering fact that each one of us has roughly 500 trillion synapses. Along with the current discourse arising from ideas of human embodiment and the new emphasis on sensory experiential qualities, various findings and views emerging in the neurosciences are promising a deeper understanding of the mental implications and impacts of the art of building. In addition to its essence as an artifact, architecture now needs to be seen in its biological and ecological context. Recent findings in the complexities and plasticity of the human brain and neural systems emphasize the innately multi-sensory nature of our existential and architectural experiences. These views challenge the traditional and still prevailing visual understanding of architecture and suggest that the most significant architectural experiences arise from existential encounters rather than retinal percepts, intelligence and aesthetics of the new. In these encounters the world and the perceiver become merged, and the boundary between outer and inner mental worlds turn vague, as they merge. As Maurice Merleau-Ponty argues, “The world is wholly inside, and I am wholly outside myself”.

Most importantly, the recent discovery of mirror neurons begins to help us to understand the origins of empathy and emotion, and how we can experience emotion and feeling in material and spatial phenomena. How can a painting, consisting of paint on canvas, and a building made of dead matter, make us feel anguished or happy, bored or stimulated, rooted or alienated? Why does the stair hall of Michelangelo’s Laurentian Library, built of mere *pietra serena*, make me weep?

Today, scientific experiments reveal the processes taking place in the human brain as well as their specific locations, dynamics and interactions. Yet, experiencing mental and poetic meaning through space, form, matter, and illumination is a phenomenon of different category and order than observations of electro-chemical activities in the brain.
That is why combining the quickly advancing neurological knowledge to appropriate philosophical framing and analyses seems a particularly suitable methodology in approaching the mysteries of artistic meaning. This approach with a double focus has been appropriately called neurophenomenology.

**The Measurable and the Immeasurable**

Instead of attempting to enter the ground of neuroscience, I wish to say something about the specific mental essence of architecture, that ought to be understood before any hasty conclusions are made about the relations of distinct brain activities and architectural qualities. Architecture

Above: We emulate the physiognomy of the architectural setting through our unconscious sense of identification, muscular imitation and empathy, and we experience touching sensations of melancholy. Michelangelo based even his architectural works on the expressive dynamics of the human body, not geometry.

Architecture and Neuroscience

is a realm that is deeply biologically, culturally and mentally grounded, but today frequently neglected in theoretic studies, education as well as professional practice. I hope that the biological sciences and neuroscience, which are opening exciting doors to the essence of brain, mental functions and consciousness, can valorize the interaction of architecture and the human mind, and reveal the hidden complexities that have escaped rational analyses and measurement. In our consumerist society, often dominated by shallow and prejudiced rationality and a reliance on the empirical, measurable and demonstrable, the embodied, sensory and mental dimensions of human existence continue to be suppressed. “The genuineness of an expression cannot be proved; one has to feel it”, Ludwig Wittgenstein points out, and this applies to existential qualities as well. Or, as Jean-Paul Sartre argues: “Essences and facts are incommensurable, and one who begins his inquiry with facts will never arrive at essences... understanding is not a quality coming to human reality from the outside; it is its characteristic way of existing.”

I believe that neuroscience can give support to the mental objectives of design and arts, which are in danger of being disregarded because of their “uselessness” and apparent subjectivity. The new biological sciences can emancipate us from the limits of the “naïve realism” of our culture. Architecture has its utilitarian qualities in the realm of rationality and measurability, but its mental values are most often concealed in embodied metaphors and ineffable unconscious interactions; it can only be encountered, experienced and lived.

Instead of attempting to suggest the new insights of the neuroscience, that may be applicable in architecture, I have chosen to focus on the mental dimensions of buildings, the essences that could be valorized by new scientific research. I believe that neuroscience can reveal and reinforce the fundamentally mental, sensory, embodied, and biological essence of architecture against today’s tendencies towards ever increasing materialism, intellectualization, and commodification.

The Task of Architecture

The purpose of our buildings is still too often seen narrowly in terms of functional performance, physical comfort, economy, symbolic representation, or aesthetic values. However, the task of architecture extends beyond its material, functional, and measurable dimensions, and even beyond aesthetics, into the mental and existential sphere of
life. Besides, architecture has practically always a collective impact and meaning. Buildings do not merely provide physical shelter or facilitate distinct activities. In addition to housing our fragile bodies and actions, they also need to house our minds, memories, desires, and dreams. Our buildings are crucial extensions of ourselves, both individually and collectively. Buildings mediate between the world and our consciousness through internalizing the world and externalizing the mind.

Landscapes, built settings, houses and rooms are integral parts of our mental landscape and consciousness. Through structuring and articulating lived existential space and situations of life, architecture constitutes our most important system of externalized order, hierarchy and memory. We know and remember who we are as historical beings by means of our constructed settings. Architecture also concretizes “human institutions”—to use a notion of Louis Kahn—the accumulation and structuring of culture, as well as the layering of time. It is not generally acknowledged that our constructed world also domesticates and scales time for human understanding. It is usually accepted, that architecture gives limitless and meaningless space its human measures and meanings, but it also scales endless time down to the limits of human experience. As Karsten Harries, the philosopher, suggests, architecture is “a defense against the terror of time.” Architecture slows down, halts, reverses, or speeds up experiential time, and we can appropriately speak of slow and fast architectures; it is evident that in our era of speed and acceleration architecture becomes ever faster. As Paul Virilio has remarked, speed is the most important product of the contemporary culture.

The human essence of architecture cannot be grasped at all unless we acknowledge its metaphoric, mental, and expressive nature. “Architecture is constructed mental space”, my colleague Professor Keijo Petäjä used to say. In the Finnish language this sentence projects simultaneously two meanings: architecture is a materialized expression of mental space, and our mental space itself is structured by architecture. This idea of a dialectical relationship, or inter-penetration, echoes Maurice Merleau-Ponty’s phenomenological notion of “the chiasmatic bind” between the world and physical space, on the one hand, and the self and mental space, on the other. In the philosopher’s view, this relationship is a continuum, not a polarity. It is exactly this chiasmatic merging and mirroring of the material and the mental that has made
the artistic and architectural phenomena unattainable for an empirical scientific approach; the artistic meaning exists fundamentally in the experience, and that is always unique, situational and individual. Scientific thinking needs to accept the first person perspective in phenomena which do not have another projection. Artistic meaning exists only on the poetical level in our encounter with the work, and it is existential rather than ideational. Merleau-Ponty also introduced the suggestive notion of “the flesh of the world”, which we are bound to share with our bodies as well as with our architecture. In fact, we can think of architecture as specific articulations of this very existential and experiential flesh; through architecture we mold our domicile and ourselves. In accordance with the motto of my essay, settings alter our brain, and our brain (or neural entity) changes our behavior and the world. It is now known that the architecture of each person’s brain is unique, and its uniqueness stems partly from the places he/she has experienced.  

**Boundaries of Self**

“What else could a poet or painter express than his encounter with the world,” Merleau-Ponty asks. An architect is bound to articulate this very same personal encounter, regardless of the basic utility and rationality of his task. This might sound like a self-centered position for the designer, but in fact, it emphasizes and concretizes the subtlety of the designer’s human task. In the essay written in memory of Herbert Read, Salman Rushdie suggests: “In the creative act the boundary between the world and the artist softens and permits the world to flow into the artist and the artist to flow into the world.” Profound pieces of architecture also sensitize the boundary between the world and ourselves, and they sensitize us to our domicile. The architectural context gives human experience its unique structure and meaning by means of projecting specific frames and horizons for the perception and understanding of our own existential situation.

Merleau-Ponty formulates the idea of the world as the primary subject matter of art (and architecture, we may again add) as follows: “We come to see not the work, but the world according to the work.” We are invited inside a unique ambience, an artistically structured world of embodied experiences, which addresses our sense of being, and temporal duration in a way that bypasses rationality and logic. As Alvar Aalto wrote: “In every case (of creative work) one must achieve the simul-
taneous solution of opposites. Nearly every design task involves tens, often hundreds, sometimes thousands of contradictory elements, which are forced into a functional harmony only by man’s will. This harmony cannot be achieved by any other means than those of art.”¹⁴

**The Secret Code**
The content and meaning of an architectural experience is not a given set of facts or elements, as it is a unique imaginative re-interpretation and re-creation of a situation by each individual. The experienced meanings of architecture are not primarily rational, ideational or verbalized meanings, as they arise through one’s sense of existence by means of embodied and unconscious projections, identifications and empathy.

We are mentally and emotionally affected by works of architecture and art before we understand them, or, in fact, we usually do not “understand” them at all. I would even argue that the greater the artistic work is, the less we understand it intellectually. A distinct mental short circuiting between a lived emotional encounter and intellectual under-

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Above: “An artist is worth a thousand centuries” [Paul Valéry]. The image is as vividly present and live as any image painted today.


Juhani Pallasmaa
standing is a constitutive characteristic of the artistic image. I wish to suggest that art is unconsciously more concerned with our past than the future; art desires to save or revitalize our mental connections with the biological and animistic world. A poetic understanding takes place through unconscious identification, simulation, and internalization. While rational understanding calls for a critical distance and separation from the subject, poetic “understanding” requires nearness and empathy. In fact, art is not about understanding at all, as an artistic image is an existential encounter which momentarily re-orient our entire sense of being. Great works possess a timeless freshness, and they project their enigmas always anew, as if we were each time experiencing the work for the first time. I like to revisit architectural and artistic masterpieces around the world in order to repeatedly encounter their magical sense of newness and freshness. I remember many of these masterworks by heart, yet they always appear enigmatic and unexpected as they embrace me in their unique ambience. The greater the work is, the stronger is its resistance to time. As Paul Valéry, the poet, suggests: “An artist is worth a thousand centuries.” The oldest rock paintings of Africa and Australia give evidence of experiential artistic values that have already survived four hundred centuries.

The interaction of newness and the primordial in the human mind is yet another aspect of the artistic and architectural image that can be understood through neurological research, I believe. We humans are essentially creatures that are suspended between the past and the future more poignantly than other forms of life, we are unnoticeably viewing the future through our collective bio-cultural past. The common view that art is interested in and a harbinger of future is certainly a hasty assumption—the main concern of art is to maintain our biological and historical integrity.

Identification and Empathy
As neurological research has recently revealed, we have a surprising capacity to mirror the behavior of others, and even to unconsciously animate and mimic inanimate material constructions and objects through our imagination. “Be like me”, is the call of a great poem according to Joseph Brodsky. A building certainly makes a similar invitation; a profound piece of architecture invites and guides us to be better and more sensitive human beings. The world of art and archi-
Architecture is fundamentally an animistic world awakened to life by the projection of our own intuitions and feelings. In this very sense, the artistic intention is in conflict with the scientific view.

We have an amazing capacity to grasp complex environmental entities through simultaneous multi-sensory sensing of atmospheres, feelings, and moods. This capacity to instantaneously grasp existential essences of vast entities, such as spaces, places, landscapes and entire cities, suggests that we intuit entities before we identify their parts and details. “The quality of the whole permeates, affects and controls every detail,” as John Dewey, the visionary philosopher, pointed out eighty years ago. This view of the dominance of unified entities over “elements” has been strongly suggested by neuroscience, and it casts a serious doubt on the prevailing elemental theories and methods of education. The attempt to teach a complete experiential entity gradually through its “elements” is doomed to failure- we learn to swim only by experiencing water through our body, not by intellectually knowing its chemical constitution.

**Human Biological Historicity**

We need to accept the essential historical and embodied essence of human existence, experience, cognition, and memory. In our bodies we can still identify the remains of the tail from our arboreal life, the *plica semilunaris* in our eye corners as the remains of our horizontally moving eye-lids from the Saurian age, and even the remains of gills in our lungs deriving from our fish life hundreds of millions of years ago. We certainly have similar remains in our mental constitution from our biological and cultural historicity; one aspect of such deeply concealed memory was pointed out by Sigmund Freud and Carl G. Jung, namely the archetype. I want to add here that Jung defined archetypes dynamically as certain tendencies of distinct images to evoke certain types of associations and feelings. So, even archetypes are not concrete or given “building blocks” in artistic creation, as Post-Modernism seemed to believe- they are dynamic tendencies with a life of their own. Architecture, also, has its roots and mental resonances in our biological historicity. Why do we all sense profound pleasure when sitting by an open fire if not because fire has offered our predecessors safety, pleasure and a heightened sense of togetherness for some seven hundred thousand years. Vitruvius, in fact, dates the beginning
of architecture in the domestication of fire. The taming of fire actually gave rise to unexpected changes in the human species and its behavior: “Control over fire changed human anatomy and physiology and became encoded in our evolving genome”, Stephen Pyre suggests. Some linguistic scholars have suggested that also language originates in the primordial act of gathering around the fire. Such bio-psychological heritage, especially the spatial polarity of “refuge” and “prospect”, has been shown to be significant in Frank Lloyd Wright’s houses by Grant Hildebrandt. The studies of proximity conducted by the American anthropologist Edward T Hall in the 1960s revealed unbelievably precise unconscious mechanisms in the use of space and its culture specific parameters and even meaningful chemical communication between our endocrine glands, which have been considered to be closed from the outside world and thus only have an internal metabolic function. Such studies are surely only a beginning in re-rooting modern man, the Homo Faber, back in his biological roots, and neuroscience can be expected to valorize the internal workings of these genetic and instinctual behaviors and reactions. Neurological studies can also be expected to reveal the neural ground for our fundamental spatial and environmental pleasures and displeasures, as well as feelings of safety and fear. Neurological research has suggested that all reactions of biological life can be deduced back to the pleasure principle, and undoubtedly even today’s technologized and “intelligent” buildings need to identify these primal human needs.

Understanding Architecture
Merleau-Ponty makes the significant remark, “The painter takes his body with him… Indeed, we cannot imagine how a mind could paint”. The same must certainly be said about architects, as our craft is unavoidably constituted in an embodied manner of existence, and architecture articulates that very mode of being. This argument turns more complex when we acknowledge that the notion of the “body” is not self-evident—we have at least four bodies: physical body, emotional body, mental body, and social body. In my way of thinking, architecture is more an art of the body and existential sense than of the eye, and more of emotive and unconscious feelings than rational deduction. This is where the logocentric and over-intellectualized theorizing of architecture, so popular in the recent past, has gone decisively wrong. But, again, neuroscience

Right: Alvar Aalto’s extended Rationalism. The fusion of the opposite image of a geometric architectural interior and an amorphous forest space.

can valorize these hierarchies and priorities. I believe that neurological research will confirm that our experiences of architecture are grounded in the deep and unconscious layers of the human mental life.

What I have said so far probably suggests an opposition between the scientific and artistic approaches. I wish to reiterate that they are two fundamentally different modes of knowledge: methodically formalized knowledge, on the one hand, and lived, existential knowledge on the other. But I wish to suggest an attitude of mediation, particularly in my own field of architecture.

I am not speaking against attempts to grasp the structure or logic of experiential phenomena; I am merely concerned with a reductionist or biased understanding of architectural phenomena. The study of artistic phenomena also calls for appropriate methods of study. In the mid-1930s, Alvar Aalto wrote about “an extended Rationalism”, and urged architects to expand rational methods even to the psychological and mental areas. Aalto states: “We might say that one way to produce a more humane built environment is to extend our definition of Rationalism. We must analyze more of the qualities associated with an object than we have done so far.”

Aalto continues: “It is not the rationalization itself that was wrong in the first and now past period of modern architecture. The wrongness lies in the fact that the rationalization has not gone deep enough. Instead of fighting rational mentality, the newest phase of Modern architecture tries to project rational methods from the technical field out to human and psychological fields... Technical Functionalism is correct only if enlarged to cover even the psychophysical field. That is the only way to humanize architecture.”

Aalto expresses a desire to expand the rational method to include phenomena explored in the fields of “neurophysiology and psychology”. He writes, “My aim was to show that real Rationalism means dealing with all questions related to the object concerned, and to take a rational attitude also to demands that are often dismissed as vague issues of individual taste, but which are shown by more detailed analysis to be derived partly from neurophysiology and partly from psychology. Salvation can be achieved only or primarily via an extended concept of Rationalism.” Eight years later, Aalto takes this concept one step further: “I would like to add my personal, emotional view, that architecture and its details are in some way all part of biology.” This is a suggestion I wish to support.
Intuitive “Neurologists”
Semir Zeki, neurologist who has studied the neural ground of artistic image and effect, regards a high degree of ambiguity, such as the unfinished imagery of Michelangelo’s slaves, or the ambivalent human narratives of Johannes Vermeer’s paintings, as essential contributors to the greatness of these works. In reference to the great capacity of profound artists to evoke, manipulate and direct emotions, he makes the surprising argument: “Most painters are also neurologists... they are those who have experimented with and, without ever realizing it, understood something about the organization of the visual brain, though with the techniques that are unique to them.” This statement echoes interestingly an argument of the Dutch phenomenologist-therapist J.H. Van den Berg: “All painters and poets are born phenomenologists.” Artists and architects are phenomenologists in the sense of being capable of “pure looking”, an unbiased and naive manner of encountering things. Jonah Lehrer’s recent book, Proust was a Neuroscientists, popularizes this topic by arguing that many masterful artists, such as Walt Whitman, Marcel Proust, Paul Cézanne, Igor Stravinsky, and Gertrude Stein, anticipated certain neurological findings of today in their art often more than a century ago. In his significant books The

Above: An experience of an artistic work calls for the fusion of perception, memory, identification, imagination, and compassion.


Architecture and Neuroscience
Architect’s Brain: Neuroscience, Creativity and Architecture, and Architecture and Embodiment: The Implications of the new Sciences and Humanities for Design, Harry F. Mallgrave has connected the findings in neuroscience with the field of architecture directly in accordance with the objective of our seminar.  

In Inner Vision: An Exploration of Art and the Brain, Semir Zeki suggests the possibility of “a theory of aesthetics that is biologically based”. Having studied animal building behavior and the emergence of aesthetically motivated choice in the animal world for forty years, I personally have no doubt about this. What else could beauty be than Nature’s powerful instrument of selection in the process of evolution? Joseph Brodsky assures us of this with the conviction of a poet: “The purpose of evolution, believe it or not, is beauty.” In his study on the neurological ground of art, Zeki argues that “art is an extension of the functions of the visual brain in its search for essentials.” I see no reason to limit this idea of extension, or externalization to the visual field only. I believe that art provides momentary extensions of the functions of our perceptual and neural systems, consciousness, memory, emotions, and existential “understanding”. The great human quality of art is that it permits ordinary mortals to experience something through the perceptual and emotive sensibility of the greatest individuals of human history. We can feel through the neural subtlety of Brunelleschi, Mozart, and Rilke, for instance. And again, we can undoubtedly make the same assumption of meaningful architecture; we can sense our own existence amplified and sensitized by the works of great architects of history from Ictinus and Callicrates to Frank Lloyd Wright and Louis Kahn. Great architecture elevates our experience of ourselves and it emanates unspoken but contagious existential wisdom.

The Role of Imagination
It is arguable that the most human of our capacities is that of imagination. Imagination is often thought of as a kind of daydreaming, and sometimes even as something suspect. Yet, even perceiving and memorizing places, situations and events, engage our imaginative capacities. The acts of experiencing and memorizing are embodied acts, which evoke imaginative realities with specific meanings. The existence of our ethical sensibility alone calls for imaginative skills. Recent studies have revealed that the acts of perceiving and imagining take place
in the same areas of the brain, and consequently, these acts are closely related. Even perceptions call for imagination, as percepts are not automatic products of the sensory mechanism; they are essentially creations and products of intentionality and imagination. We could not even see light without our “inner light” and formative visual imagination, Arthur Zajonc, the physicist, argues. To conclude, “Reality is a product of the most august imagination,” Wallace Stevens, the poet, suggests.

We do not judge environments merely by our senses, we also test and evaluate them through our imagination. Comforting and inviting settings inspire our unconscious imagery, daydreams and fantasies. Sensuous settings sensitize and eroticize our relationship with the world. As Gaston Bachelard argues: “[T]he chief benefit of the house [is that] the house shelters daydreaming, the house protects the dreamer, the house allows one to dream in peace... [T]he house is one of the greatest powers of integration for the thoughts, memories and dreams of mankind.”

Collaborative Understanding of the Mind

The widening interest in the neuroscience of architecture has already led to the establishment of the Academy of Neuroscience for Architecture (ANFA) in San Diego, California. In addition to its research projects, the Academy hosts annual conferences on various aspects of the neuroscience of architecture. In November 2012 the Frank Lloyd Wright School of Architecture and the Academy organized a symposium entitled “Minding Design: Neuroscience, Design Education and the Imagination” at Taliesin West, Arizona, which brought together scientists and architects. Today there are two schools of architecture which include neuroscience in their programs, the NewSchool of Architecture + Design (NSAD) in San Diego, California, and the University of Arizona in Tucson, Arizona.

The interaction of neurosciences and architecture offers vast potential to enhance the quality of our settings. Any scientific proof of mental phenomena and their consequences concerning the characteristics of the environments of our lives will certainly help to make claims for better architectural qualities better acceptable in our surreally materialist culture. This conversation is in its beginning, and so far it has been largely directed by neuroscientists. It is obvious that the neurological investigation of architectural experiences and meanings has to be based on a deep dialogue between scientists and the makers of architecture.
NOTES


7 Paul Virilio, Katoamisen estetiikka [The aesthetics of Disappearance], [Tampere: Gaudeamus, 1994].


11 Maurice Merleau-Ponty, Signs, [Evanston, IL: Northwestern University Press, 1982], 56.


15 Paul Valéry, Dialogues [New York: Pantheon, 1956], XIII.


20 Grant Hildebrandt, The Wright Space: Pattern and Meaning in Frank Lloyd Wright’s Houses [Seattle: University


35 Ilpo Kojo, 'Mielikuvat ovat aivoille todellisia' [Images are real for the brain], *Helsingin Sanomat* [Helsinki, March 26, 1996]. The article refers to research at Harvard University under the supervision of Dr. Stephen Rosslyn in the mid-1990s.


37 Quoted in Lehrer, *Proust was a Neuroscientist*, VI.


Architecture and Neuroscience
When, a few years ago, I began to become interested in some of the recent discoveries of the social and biological sciences, I suddenly found myself with fewer of my older friends. At the root of this development was the fact that many of us had been trained as architects in the second half of the 1960s, at a time when great curricular importance was attached to such fields as psychology, sociology, and anthropology. And the problem was twofold. On the one hand there was a behaviorist strain to the underlying social-science models at that time, which implied a form of determinism in practice. On the other hand there were the many failed efforts at translating the research of the social sciences into architectural practice—and I am thinking here of the spectacular failure of various design strategies (the highrise ghettos) that, in the United States at least, postured under the name of urban renewal. It would not take long before my former friends and I quickly became disillusioned with the sciences in all of their guises.

I am of course overstating this situation to a certain extent, but the issue in any case soon became a moot one. By the early 1970s the postmodern police had more or less excluded these areas of study from any or all discussion, as architects had suddenly become more interested in such extracurricular matters as politics or rediscovering architecture’s long-lost “meaning.” Similarly, design, for the next decade or so, had largely become reduced to strategies of Loosian rationalism or populist symbolism, depending on whether one was inclined toward the classical “typology” of Aldo Rossi or the “decorated sheds” of Robert Venturi.

Things have changed for me at least, and I need not bore you today with the details of the paths that architectural theory has taken in the years since—the starts and fits of the Frankfurt School, semiotics, postmodernism, “weak thought,” Derridian Decon, and poststructural
theory in general. Suffice it to say that by the turn of the present century the theories of architecture that had been so diffusive and effusive in this gilded age of theory (and I am speaking here of the 1980s and early 1990s) had, historical speaking, had a brief run. Today the importation of “isms” of any kind is largely frowned upon, and rightly so.

The practice of architecture has also changed in other ways, as the desk-top computer has replaced the drafting table and parallel bar, and architectural projects have grown so large that they generally exceed the control of any single individual. The pace of building activity has similarly affected many changes. Today we probably build more square meters of enclosed space in any given decade than any two or three centuries had built in the past. Architectural programs were forced to respond by raising their student populations, particularly during the economic boom years, and when booms turn to bust finding one’s way into the architectural profession becomes all the more difficult. This situation in turn put a strain on school curricula, as educating students to find jobs requires that practical course work such as software programming consume an ever growing part of the curriculum. Rarely does a program offer a course or seminar on how one might think about design or the built environment. Reflection has been forced out of our schools by the realities of the workplace.

None of this is to say that a few have not prospered from these realities. Celebritydom, for example, has come to the profession. Today’s ‘star’ architects are heralded as arbiters of taste, in the same way that a generation or two ago a Mondrian or a Matisse personified the idea of a transformative modernity. And because these stars spend a healthy percentage of their waking and sleeping hours on airplanes, they now engage their very large projects with a cadre of consultants to help steer their way through the labyrinth of regulations and litigation that characterizes so much of today’s construction process. When successfully orchestrated, the formal extravaganza of every new museum electrifies the print and cyber media, at least for a few days or so.

Nevertheless, there is a faint disquiet discernible in many quarters of the architectural world today, and this unease is even more widespread if we move beyond our professional ranks. Many people, it must be confessed, do not like their habitats, their work stations, their shopping malls, their commutes to work, and the frustration that the slow-driving person in the automobile in front of you is talking on
his cell phone. And even fewer like what the modern metropolis has become. From Beijing to Chicago to Abu Dhabi—local urban cultures have been flattened, and the air is filled with a yellowish haze that is certainly not healthy to inhale. Massive urban migration and commensurate economic shifts in wealth are creating a world that resembles a London Underground map of exploding metropolises, globally interconnected and seemingly designed by the same architect, using the same “Orwellian” software.

I will open this segment with the simple observation that something seems to be missing from architectural practice today, a practice that is too often centered on novelty of form and the showmanship of personalities. And what seems to be missing, in my view, is an understanding of who we are as human individuals—what are our real needs, dreams, and desires? Who are these people for whom we design?

And it is in this sense that I will argue that the new sciences and humanities do indeed have something to teach us. For I believe it is fair to say that we have probably learned more about the biological workings of our human organisms over the past quarter-century than we have throughout all of human history. And this new understanding of our neurological mapping, our chemical and synaptic systems, our DNA molecules and their sequencing has transcended the strict sciences and their implications have begun to be translated into the humanistic sciences. A bevy of new fields have rushed to define themselves over the last few years: neuroethology, evolutionary biology, evolutionary psychology, neuroaesthetics, to name a few. And from the neurophenomenological perspective of Evan Thompson, I fully agree with his characterization of our human condition as one of “radical embodiment”—that is, “the knowing and feeling subject is not the brain in the head, or even the brain plus the body, but the socially and culturally situated person, the encultured human being.”! Drawing upon our new understanding of neural plasticity, Thompson’s larger argument is that culture is not some outside force acting upon or altering our genetic structure, but something already woven into the human mind from the very beginning. We are encultured human beings from the first moments of life, and we must therefore frame our discussion within the larger context of human culture.

But if philosophy, sociology, psychology, and the other humanities have begun to take note of the implications of these dramatic biological

Harry Francis Mallgrave
discoveries, where have architects been? Are they making use of these new insights into our human natures? Is this interest even possible, given the one-sided, technological bias of architectural education today? These questions bring me back to the skepticism toward the social sciences I noted at the top of this essay, and I want to underscore this point forcefully. What the new sciences and humanities are revealing is not the simplicity of human nature (an unstated tenet of earlier behaviorist models) but rather the great complexity and mutability of the human organism. The new inter-disciplinary theories of whom we are as human beings will never tell us to paint all our walls green, and the architect should therefore be relieved.

Know Thyself
What, then, will they tell us? I would like to point out that if architects have been presumptuous in defending the so-called autonomy of their fields, this caution, given the course of architectural theory over the past few decades, is partly justified. Science cannot in any way make theory when it comes to architectural design. What science can do, however, is offer us an ever more revealing portrait of who we are, where we have come from, and where we might be going in an evolutionary sense. For the theme of this talk, therefore, I would like to invoke the phrase “Know thyself,” which, according to Pausanias, was inscribed in stone at the entrance to the Temple of Apollo at Delphi. The maxim, he reports, was written by one of the seven wise men of ancient Greece, and Plato was so infatuated with it that he invoked it in no fewer than six of his dialogues. He used the term to caution those who in their vanity seek to understand obscure and far-flung knowledge without first understanding their own human natures. And it is in this sense that I intend the phrase, for I believe it is time for us as architects to introduce another variable into the design process—a consideration of the human beings for whom we construct our built environments.

Before I proceed with my remarks, let me offer one small example of someone trying to know thyself. For some years now the ethnologist Ellen Dissanayake has been tracking the origin of the arts: first in evolutionary forms of play, then in ritualistic and ceremonial behaviors, such as early human exercises in costume-making, music, and communal dance. In a more recent study, Art and Intimacy, Dissanayake buffers her case by citing the work of the neuroscientist Colwyn Trev-
arthen, who has studied such things as how mothers and infants build loving bonds through such means as ‘baby talk,’ the cooing patterns of intonation, vocal and rhythmic exaggerations, and repeated visual and tactile give-and-takes.\(^4\)

Accepting the rather obvious fact that humans are biologically predisposed to join in emotional communion with others, Dissanayake goes on to offer the hypothesis “that these same sensitivities and capacities, which arose as instruments of survival in our remote hominin past, are later used and elaborated in the rhythms and modes of adult love and art.”\(^5\) She made this statement in a book published in the year 2000, and around the same time several neuroimaging studies were indeed undertaken that demonstrated that the pleasure we take in observing artistic beauty and the pleasure we find in love do indeed share a similar hedonic or pleasure circuit in the lower regions of the brain—igniting those joyful chemical reactions in our upper reaches.\(^6\) But Dissanayake took her case one step further, first by arguing that these “rhythms and modes” underlying artistic expression extend back into pre-Paleolithic stages of human evolution and are pre-symbolic in their biological underpinnings. Second, that these rhythms and modes are related to emotional drives associated with enculturation, manifested in such things as social affiliation, making sense of our surroundings, acquiring competence in skills, and what she refers to as “elaborating upon.” These last two points are what are of interest to architects, for what she goes on to conclude is that art “emerged through human evolution as multi-media elaborations of rhythmic-modal capacities that by means of these elaborations gave emotional meaning and purpose to biologically vital activities.”\(^7\)

If we transpose such a model to architecture, we might say that it is only when the architect taps into these “cross modal sensations of tactility and kinesis” (Dissanayake’s words), through the use of materials, colors, forms, patterns, and textures, that a building or an aspect of a city attains the charm of being both creative and revelatory—that is, of becoming something special to the people who inhabit it. I want to follow upon her hypothesis with two aspects of contemporary biological research that have a direct relevance to our built environments: the first are the newer models of emotion that are presently evolving, and the second is emotion’s underpinning in human mirror systems.

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Harry Francis Mallgrave
Emotions

At first blush, emotion might seem like an odd word to bring into an architectural discussion. The last architectural theorist of any stature to speak of emotion was John Ruskin, and his thought (which incidentally emphasized both the cultivation of skill and its manual elaboration) might be best characterized as the culmination of a century of British picturesque theory. A historian would be hard pressed to find a few other theorists who have employed the term in more recent times. Therefore, the best way to begin is with a simple biological definition, which will convey the outmoded nature of so many of our thinking concepts. Emotion, in the words of the neuroscientist Joseph LeDoux, “is the process by which the brain determines or computes the value of a stimulus.” Another biologist, Jaak Pankseep, defines emotions as genetically prescribed “affect” programs generated from below, that is from the subcortical areas of the basal ganglia and brainstem. Still another neuroscientist, Douglas Watt, emphasizes that “emotion probably reflects a special kind of carefully routinized and evolutionarily carved set of operations for protecting our homeostasis.” The gist of all three definitions can be summarized as follows. Emotion is a primal activity at the very core of human nature. It is the lens through which we engage or perceive the world, and for this reason many neuroscientists like to distinguish between emotion and feeling. Emotional processing takes place during the perceptual act, while feeling is our conscious awareness of these emotional events. The essential issue for architecture is also clear. The built environment is initially perceived emotionally—that is, prior to our conscious reflection on its many details.

Emotions, as we all know, can be of many kinds, but the key point is that emotion is always a multimodal or multisensory experience of someone moving through an environmental field. We engage the world holistically on all sensory levels, as philosophers such as Maurice Merleau-Ponty and Juhani Pallasmaa have emphasized. The psychologist Lisa Barrett, who has attempted to summarize contemporary biological theory in this regard, notes that when an organism engages with an environmental stimulus the body first produces a “core effect,” an initial state of pleasure or displeasure arising from how the sensory properties of the stimulus (read the environment) affect the organism’s vital condition. This core effect is routed or proceeds along two closely related neurological pathways, both based in the orbitofrontal cortex.
or OFC, the part of the brain’s neocortex (gray matter) tucked just behind the eyes. Without going into the details of these two systems, it is sufficient to say that one system (the “sensory” system) establishes a preliminary value for the stimulus and its impact on homeostasis, while the second system (the “visceromotor” circuit) modulates the autonomic, chemical, and behavioral response to the stimulus. Collectively, they produce an affective state bound to a particular situational meaning, giving us the disposition to act in a certain way.\textsuperscript{11}

There are three key points to be gleaned from such a model. The first is that emotions condition our response to specific events or sensory fields (the built environment), and they do so pre-reflectively—that is, much of the activity takes place prior to our “feelings” about events. This is a crucial point because architectural theory over the last half-century has rarely considered human emotional responses, except perhaps with regard to a church or cemetery. Yet I think we can all agree that before we sit back and “reflect” on an architectural experience, we have in fact already made judgments about such things as the comfort of a door handle or handrail, the proportioning of a stair riser or tread, the texture of the floor material, the acoustic resonance or visual ambiance of a room, the hand of a fabric, the smell of materials, the presence of natural light, and we do so largely intuitively, or more precisely, prior to conscious reflection. We also, in various ways, make embodied judgments about the materials selected, spatial relations, dimensional proportions, scale, patterns, rhythms, tactile values, and even (as we will discuss later) the creative intentions of the architect. And then of course we have those important matters of comfort, warmth, convenience, craftsmanship, presence, as well as that presumably outdated notion of beauty, a valuation that non-architects express quite openly although architects of course are not permitted to use this term. Why, then, have emotions been summarily excluded from all architectural discussion or theory? Why do we not concern ourselves with the most obvious aspects of how we engage the built environment?

The second point is that emotional responses are fundamentally embodied, in the sense that emotions also involve or implicate the sensorimotor areas of the brain related to our bodily movements and corporeal awareness of them. This is a difficult point to summarize succinctly, but the fact is we do not simply stand back and mechanically record the events of the world; rather—if I can invoke a term of Robert H.

\textit{Harry Francis Mallgrave}
Vischer of more than a century ago—we *einfühlen* or “feel into” this world through our bodies in an immediate and multisensory way. If we walk down a corridor with a low ceiling, we walk with a crouch. If we enter a spatially luxurious space, we stand tall and our respiration deepens. If we are forced to work in a cramped space, we feel trapped and even angry. If we see a natural light in a room ahead, we gravitate toward it. The largely metaphoric nature of our languages reflects this embodied condition. If I build my argument on a strong foundation, I am giving architectural form to an abstract idea. If I pierce the heart of your argument, I am reenacting a deadly activity of survival from our Paleolithic past. George Lakoff and Mark Johnson make the vital point “that human concepts are not just reflections of an external reality, but they are crucially shaped by our bodies and brains, especially by our sensorimotor system.”

This degradation of our embodied natures is particular important in our new era of computer design, which tends toward ever greater abstraction. Students are quite naturally fascinated with the new power to wield or manipulate forms endlessly on a computer screen, yet design is indeed a zero-sum game. The aspects on which one focuses one’s effort during the stages of design determine, to a great extent, what the final result will be. When one devotes an inordinate amount of one’s attention to manipulating compositional form, for example, one will tend to play down materiality and detailing. When one seeks out novelty for its own sake, one will tend to ignore historical examples that may indeed solve the problem quite efficiently. And even when one is sensitive to the fact that architecture has a thoughtful heritage to draw upon, it is often understood only abstractly. The image of a Brunelleschi church in a history book does not prepare the student for the actual experience of leaving the Florentine summer heat and walking down the spatial expanse and thermal coolness of the nave of Santo Spirito. Can our eyes perceive—as the eyes of Brunelleschi’s contemporaries could—the ingenuity it took to quarry and raise those tall monolith columns at the site? Of course not, we have cranes.

A third point related to these new models of emotion is the recognition that our responses to stimuli seem to be integrated with our peripheral autonomic nervous system—that is, the working of our sympathetic and parasympathetic subsystems that regulate homeostasis. These neural subsystems work in a reciprocal and opposing

Right: Filippo Brunelleschi, Nave of the Basilica of San Lorenzo, Florence [1419-59]. Photograph by Stefan Bauer, courtesy of Wikimedia Creative Commons.
fashion. The sympathetic system, for instance, accelerates the heart rate in response to one bodily condition (such as running), while the parasympathetic subsystem slows it down in response to another condition (such as rest). These two subsystems, in turn, are separately wired into the insular cortices in each hemisphere of the brain: a cortical region behind each ear yet tucked toward the central limbic modules of the brain. As the neuroscientist A. D. “Bud” Craig reports, the sympathetic subsystem terminates in the right insula and is associated with energy expenditure and arousal, while the parasympathetic subsystem terminates in the left insula and leads to energy nourishment, relaxation, and affiliative emotions. The insula is one area of the brain heavily implicated with our “feelings.”

This fact is important because the built environment, as every architect knows, can be aligned with these two poles, which is why these two buildings standing alongside one another in Berlin—Mies van der Rohe’s New National Gallery and Hans Scharoun’s Philharmonic Hall—affect us in two very different ways. The New National Gallery is tectonic and highly rational in its conception, minimalist in its execution, aspatial in its sense of enclosure, and highly focused on its detailing. The fact that steel and glass are materials that are perceived as cool to human touch may be one reason why Mies’s architecture is often described as cool in its overall demeanor. Perhaps fittingly, it is a quiet building that allows a place for artistic contemplation. By contrast, Scharoun’s Philharmonic Hall is arousing in every sense of the term. Its design is a multisensory production with a colorful orchestration of materials, textures, and forms. It is a stimulative environment that demands little in the way of conceptual understanding or analysis, in fact

nowhere is the logic of its formal composition ever clearly revealed—inside or out. It is a building conceived as an allegory to tribal rituals and affiliative events, one eliciting strong emotional responses that seems quite appropriate to an enclosure that houses the very emotional art of music.

Such a contrast underscores the fact that we experience our built environments in many different ways because we in fact embody our buildings. If the warped metal sheets of a Frank Gehry structure may convey an overall sense of fluttering lightness, Herzog’s and de Meuron’s Dominus Winery in Napa Valley strikes us as a heavy building. It appears so because we know the weight of stone and these stacked gabions are indeed very heavy.

Some years ago, at the start of the 20th century, the English writer Vernon Lee, together with her collaborator Clementina Anstruther-Thomson, attempted to measure the biological and muscular effects that a building has on us—by reading the facade simply as pattern. The bilateral and tripartite organization of the facade, they reported, “prevents the thorax from collapsing as much as usual during the act of expiration,” while the overall rate of breathing seems to accord with the building’s proportions. The fact that the building is solidly planted on the ground also alters our posture: “the perception of this fact involves a sense of weight and lifting up in ourselves; we feel a faint desire to enclose the form between the pressure of our feet on the ground and the very slight downward pressure of the head, and the two pressures result in a sense of resisting gravitation.” Collectively, the “various pressures, and the varying ratios which may exist between them,” lead to the overall sense of “harmonious completeness.”

One may quibble with such early efforts to evaluate a building in such terms, but the fact is that architecture has this capacity to alter our physiological disposition. And it leads us to the interesting question of how much of architectural design might be, in fact, biological based. Could one argue, for instance, that the spectacular mosaic effects of an Islamic Mosque, located along a caravan route within a desert landscape, might be a welcome place of perceptual recollection and healing—a conscious act of sensory stimulation to repair the effects of sensory deprivation? If this is the case, then what happen then when we live in cities overtaken with look-alike hardscapes and ubiquitous glass boxes and that offer precious little relief in sight? What would be the long-term effects of such sensory degradation?

**Mirror Systems in Humans**

These questions arise today because of another biological discovery of the 1990s that explains in part how our bodies react to events or stimuli—that of mirror neurons. The discovery took place in a lab at the University of Parma, in experiments during which scientists had inserted electrodes in the brains of monkeys to record the neural activity involved in such activities as grasping. They found this activity but they also found something initially perplexing: the fact that groups of neurons within this neural activity were also recorded in monkeys who were not grasping objects but merely observing other animals and humans who were grasping them. It was as if the monkeys were neurologically simulating the activities they saw or heard.16

Since then, literally hundreds of neuroimaging studies have been carried out on humans in search of similar mirror systems. Whereas this matter is complex—mirror systems do not act alone but in concert with many other systems—we now have indispensible evidence
for such activity in the premotor cortex and posterior parietal lobe in humans, activity that is sometimes described as embodied simulation. Mirror systems thus help to explain why we feel empathy for others who may be experiencing emotional traumas or pain (the brain even maps the location of another’s pain onto our own body), or the joy we take in observing a dancer on stage. It is as if the pre-motor circuits in our brains, in mirroring the motor movements of others, take pleasure in simulating ourselves moving with such agility and poise. Such activity is also dependent on how well we know the skill that is being displayed. The brain scan of a skilled pianist listening to another pianist playing a piece, for example, closely mirrors the scan of the other playing, except in the area of motor cortex that actually moves the hands and fingers. This mirroring is less evident in a novice or someone who has never learned to play the piano. Architects obviously look at buildings in a different way than non-architects do.

Whereas the scans of someone experiencing architecture cannot be studied with the same neuroimaging technologies, such as the fMRI, that might record someone looking at paintings or listening to music, there have been several fMRI studies that have make intriguing suggestions of how we might relate to architectural forms and materials. In one study scientists were recording the activity of mirror systems involved with touch, such as volunteers watching someone touching another person. We might expect such responses from what we now know of social empathy, but in their control study the scientists also found evidence of mirror activity when people observe two inanimate objects touching one another. Here as how they conclude their findings:

...the domain of touch appears not to be limited to the social world. Space around us is full of objects accidentally touching each other, that is, without any animate involvement. One could observe a pine cone falling on the garden bench in the park, or drips splashing on the leaves of a plant during a downpour. Models of embodied simulation posit that the same neural structures involved in our own body-related experiences contribute to the conceptualization of what we observe in the world around us.17
Architecture, of course, design objects or materials in a way that they touch one another—purposely, not accidentally. And what I find striking about such a statement is how much it in fact resembles earlier aesthetic theories of the 19th century, the Einfühlung or empathy theories of Gottfried Semper, Robert Vischer, and Heinrich Wölfflin. In Semper’s lengthy study Style in the Technical and the Tectonic Arts (1860-63), for instance, he makes various references to “telluric expression” and the “organic vital principle” of numerous architectural elements. The active force in a Doric column, for Semper, is not the downward pressure of a gravitational load, because the column has been “artistically enlivened, supporting elements become organisms,” which “activate the life inherent in the column.”\(^1\) Vischer, as we noted earlier, coined the term Einfühlung (feeling into) to describe the empathetic relationship that we maintain with the world, through which the self projects or merges with the phenomenal object in an act of “aesthetic simulation.”\(^2\) Wölfflin pointed out that we animate architectural events “because we ourselves possess a body”—that is, because the optic nerves stimulates the motor nerves and thereby sympathetically works on our own neural system through our bodily organization. Because we know the force of gravity through our own corporeal experience, we read the weight and balance of a building in gravitational terms. We judge a work of architecture to be beautiful because it in fact mirrors the “basic conditions of organic life.”\(^3\)

All of which leads me to the second recent study that very much relates to the experience of architecture. In 2007 the art historian David Freedberg, in collaboration with the neuroscientist Vittorio Gallese (one of the discoverers of mirror neurons in Parma), argued that the experience of art and architecture worked through the precognitive activation of embodied mirror mechanisms involved with the simulation of actions, emotions, and corporeal sensations. This contention seems entirely plausible with figurative works of art, in which we form some powerful emotional or empathic attachment. We silently mourn, for example, when we observe the well-known late-Hellenic sculpture Laocoön, the figurative story of a Trojan priest and his sons being murdered by the wrath of Athena.

But the authors go one step further. They argue that we can also read “the visible traces of the artist’s creative gestures, such as vigorous modeling in clay or paint, fast brushwork and signs of the movement
of the hand more generally.” 21 One of the examples that the authors give is how Michelangelo’s Prisoners often prompt the response of activating muscles within our own systems, as if we, like the prisoners only partially carved out their stone blocks, were struggling to free our body from the stone.

But there are many architectural examples of the same embodied sensations, as the authors suggest. Think of how a twisted column induces a state of tension within our bodies, as our mirror systems viscerally simulate the twisting of the column. In the case of the twisted columns and piers in the Portuguese church of the Monastery of Jesus in Setúbal, such simulation can be read both symbolically and emotion-

Above: Laocoön and His Sons, early 1st century B.C.E., Vatican Museum. Photograph by Marie-Lan Nguyen, courtesy of Wikimedia Creative Commons.

Harry Francis Mallgrave
ally. Symbolically, the twisting visually strengthens the supports for assuming the load of the heavy vaults, while emotionally this tense gesture seems entirely appropriate in a chapel that was designed specifically to house the ritual sacrifice of Christ.

Or we might take this alabaster bas-relief of the Assyrian warrior. In an art-history textbook, we might read that these panels are a narrative history depicting the proud warrior in victory, someone who has just dispatched his enemies and brought greater glory to his nation. We may indeed read the panel in this manner, but when we go to the British Museum to study this panel in person we generally find ourselves reading it in a different light. We study the delicate chisel marks that created the composition; we admire the intricacy and detail of the author’s hand, the skill that is inevitably present in a great work of art. We are simulating what it feels like to have our own hands chiseling the stone.

Architecture, indeed, comes with a character and a personality that cannot be captured by a pixilated photograph or image on a computer screen. There is nothing new in such a statement. The Danish architectural theory Steen Rasmussen once chastised an art historian for his description of a town that he had gleaned through photographs. Rasmussen knew that we do not experience a city in the same way that we experience images. When we physically come to a town we observe or feel its overall character, atmosphere, topography, sounds, colors, scale, odors or fragrances, and material presences. If a child happens to be kicking a football against the side of a church, we know this church better.

We in fact judge every building with which we come in contact in this way, as bodies moving through materially sensuous spaces, and our sensory modalities, as neuroimaging studies amply document, are fully connected and integrated with each other. When we view an architectural material, for instance, we know that the tactile areas of the somatosensory cortex become active; in other words, in an act of visual simulation we at the same time simulate the touch of the surface with our hands, we inhale its odor, we pick up traces of its acoustic resonance or hardness. And, if we are children still in a state of exploration, we might even lick it with our tongues.

Left: Church of the Monastery of Jesus, Setúbal, Portugal (1490-95). Photograph by Georges Jansoone, courtesy of Wikimedia Creative Commons.
Conclusion
I am making these points because, as I noted at the top of this talk, our educational system in recent years has been systematically paring away almost all studies relating to our biological, social, and encultured natures. And in omitting these aspects of an architect’s education, do we really want to hire yet another team of consultants on very large projects to inform architects of the people for whom they design? Would it not be better to bring these insights into discussion?

For too many years now we have viewed architecture as a speculative exercise clothed in philosophical abstractions, as the creation of self-satisfying objects under the guise of aesthetic hypotheses that are, quite frankly, obsolete. Let us at least admit that it is time to reevaluate the matter, and perhaps employ the new tools at our disposal to explore other aspects of our beings, such as those “rhythms and modes” of which Dissanayake spoke. At the same time new questions are arising all the time. What are these empathetic systems underlying

Above: Gypsum Assyrian panel from the Palace of Ashurnasirpal II, Nimrud (9th century B.C.E), British Museum, London. Photograph by author.
our sociability, and how can they be clothed in suitable architectural forms? Why is it that we seem to have this innate capacity for acquiring skills or appreciating craftsmanship, and again what are the architectural implications for such drives?

The information to be gleaned from the new research will not in any way inhibit technological advances or undo creative thinking. In fact I believe the opposite will be the case, because these new models will offer architects a means to rethink their tasks and provide design with a more secure theoretical footing—because knowing ourselves, as Socrates would undoubtedly agree, will help us better understand the people for whom we build.

NOTES
3 See especially Plato’s *Phaedrus*, 229 & *Philebus*, 48.
5 Ibid., p. 6.
7 Dissanayake, *Art and Intimacy* [note 4], p. 145.


19 Robert Vischer, in *Empathy, Form, and Space* [note 12], p. 92, 104.

20 Heinrich Wölfflin, “Prolegomena toward a Psychology of Architecture,” in *Empathy, Form and Space* [note 12], p. 151, 160.


Michael Arbib

[Why] Should Architects Care about Neuroscience?

My title combines two questions. “Should architects care about neuroscience?” and, if so, “Why should they care?” Juhani Pallasmaa and Harry Mallgrave (these proceedings), both architects, answer the first question with a resounding “Yes.” The present article, then, furthers this discussion from the perspective of a neuroscientist.

I first had the privilege of sharing the stage with Juhani Pallasmaa in November of 2012 in Taliesin West at the Symposium Minding Design: Neuroscience, Design Education and the Imagination. On that occasion I used his book The Thinking Hand (Pallasmaa 2009) as my entry into architecture because the study of brain mechanisms which enable hand and eye to work together has been a prime concern of my work in neuroscience. In particular, I noted that my book How the Brain got Language (Arbib 2012b) suggests how the ability to act with the hands and to recognize the manual actions of others may have laid the basis for the evolution of the language-ready human brain—and my talk was thus entitled From Hand to Symbol and Back Again. My aim in the present article is to complement what was stated there, not to repeat it.

In thinking about this issue of how neuroscience and architecture might connect, I have come up with three different ways in which we might explore their linkages. The one that I am going to emphasize here is the neuroscience of the design process, asking “What can we understand about the brain of the architect as he or she designs a building?” I will offer only a preliminary analysis, but hope to encourage further thinking about how the design process can be illuminated more and more by future research in neuroscience. In addition, I will briefly in-
introduce two other areas as well. One is the neuroscience of the experience of architecture: not what goes on in the head of the architect, but what goes on in the head of the person experiencing a building. The other is what I call neuromorphic architecture. But before I explain these three types of linkage, let me first say a few words about neuroscience.

A few words about neuroscience
Much of the discussion of neuroscience in the other two papers starts with some quality we commonly talk about without knowledge of neuroscience, and then shares the excitement of experiments that correlate degrees of involvement of people in such a quality with degrees of activation of brain regions as seen during brain imaging. I want to probe more deeply to ask how circuitry within the brain mediates our action, perception and memory—all in relation to our interactions with and experiences of both the physical and social worlds in which we are immersed. In this article I can only point you in the general direction of such studies—a reasonably full yet accessible exposition may be found

Figure 1. A view of the left cerebral cortex showing Brodmann’s numbered areas, together with some color coding of functions—but it must be emphasized that human cognition always involves complex patterns of interaction between diverse areas.
in *How the Brain Got Language* (Chapters 4 and 5 of Arbib 2012b). I want to understand “how the brain works”. Figure 1 indicates what the neuroanatomist Brodmann did over a hundred years ago (Brodmann 1909) in staining the brain and looking through a light microscope to see how the layered structure of cerebral cortex differed from place to place. He then assigned numbers to cortical regions which had a distinctive pattern of layering. We can then make claims like Brodmann area 17 (BA 17) is the primary visual cortex, while BA 44 and BA 45 form Broca’s area which is especially important for language. However, the brain is not a set of different boxes each doing a separate job—rather, multiple regions compete and cooperate, making their own specialized contributions to a range of cognitive functions.

Other neuro-anatomists, starting with Ramón y Cajal in Spain over a hundred years ago, moved from staining that showed patterns of layering to staining a sampling of individual neurons in exquisite detail. Figure 2 (due to the Hungarian neuroanatomist Janos Szentágothai) shows a selection of individual neurons of cerebral cortex revealed in their

![Figure 2. A schematization of the neural circuitry of cerebral cortex by Janos Szentágothai. In the real brain, many many more cells are packed into a patch corresponding to this figure, and the distribution of cells differs markedly from region to region – with these differences providing the basis for the distinctions drawn by Brodmann (Figure 1).](image)

*Michael Arbib*
beautiful particularity, along with a sketch of the elaborate circuits that they form. And so, for me, this is the level at which I worry most about neuroscience. What is it that’s going on, not at the level of the gross Brodmann areas, but in terms of the circuitry, whereby patterns of activation mediate our perception, our actions, our memories, our desires?

But of course there are many other levels too. Below the neuron we have synapses—the connection points between neurons. These are elaborate molecular and membrane structures. I think that, in pursuing this project of neuroscience for architecture, it will suffice to simply think of synapses as loci of change. Molecules and membranes may be too detailed for our regard for the time being, but we are concerned with how experience shape the way one neuron talks to other neurons by adapting the strength of the synapses between them. Above neurons, I’ve already talked about circuits. What about schemas? These serve to bridge between our psychology, our experience and behavior, and what neural circuits are doing. We can’t just jump directly from the experience of architecture or the design process to the fine details of neural circuits. I’ll tell you a little more about schema theory later.

But moving up beyond the study of the brain inside a single head, we need to assess how we, as persons, experience not only the physical but also the social world. What is it that makes us a person rather than a bunch of brain areas with a bunch of muscles? And above that, what is it about membership in a social group that determines who we are as individuals? Social interactions as well as embodied interactions shape who we are.

Neuroscience of the experience of architecture

One of the three areas into which I divide the conversation between neuroscience and architecture is the neuroscience of the experience of architecture. The Academy of Neuroscience for Architecture (www.anfarch.org), was founded when John Paul Eberhard was president of AIA, the American Institute of Architects (Dougherty & Arbib 2013, Whitelaw 2013). For his presidential symposium, at the meeting held in San Diego in 2001, he chose the theme of neuroscience and architecture. AIA then gave him a two year Latrobe Fellowship to spend two years talking with neuroscientists in the San Diego area as a basis for his book Brain Landscape: The Coexistence of Neuroscience and Architecture (Eberhard 2008). For him, I think, the emphasis was as much on what
neuroscience can tell us about people who are different from us as it is about the experience of the built environment by someone like oneself (which, of course, varies from self to self, and from architect to architect). How can neuroscience inform the architect designing a building for those whose experience differs greatly from her own? For example, how might one design a building to help keep the elderly alert as they move about their environment? Eberhard also considered how classroom design might affect the cognitive processes of children. In this he was trying to make contact with the notion of neural plasticity, of a brain that is in a process of ongoing change. Other issues include work environments and their effect on productivity. We could even look at circadian rhythm and, for example, the lighting rooms in hospitals or homes for the elderly (Ellis et al 2013). If the nurse has to enter the room in the middle of the night, how do we stop the light from disrupting the circadian rhythm and thus presumably impairing the healing process or the restorative power of sleep?

Let me get very specific about wayfinding. An area of the brain called the hippocampus (Figure 3 left) has become very interesting in human terms because of the case of HM, whose identity as Henry Gustav Molaison was revealed after his death (MacKay et al 2007, Mackay et al 1998, Skotko et al 2005). When he was young, he had uncontrollable epilepsy and his neurosurgeon William Scoville, in Montreal, removed a huge portion of the brain centered on the hippocampus. As a result, he lost episodic memory, the ability to form new memories of episodes in his life, even though he could recall episodes from life before the operation. One might be talking to him, leave the room, come back a few minutes later, and apologize for the delay—but he would not remember having seen you before. He still had working memory, the ability to recall items relevant to an ongoing activity, but once that activity ceased, this transient memory could no longer be activated (Scoville & Milner 1957). And yet there was a surprise. For example, play a new board game with him one day (remember, he could exploit working memory). Come back a day later and he declared he had never seen the board game before. And so it would be on successive days. And yet, as he played it each day, his skill kept improving. In other words, he retained some procedural memory, the ability to gain new skills, even though he had no explicit memory of the occasions on which he had built up those skills (Milner et al 1968). In summary, the hippocampus

Michael Arbib
plays a crucial role in the creation of memory of episodes, yet the cerebral cortex is still able to hold old memories once they have been consolidated even when the hippocampus has been removed. Moreover, skill memory can be developed without a hippocampus, and involves regions like the basal ganglia and cerebellum. Thus the interaction between cerebral cortex, hippocampus and these other regions has been of great interest to neuroscientists.

But in rats, the emphasis has been on looking at the role of hippocampus in spatial navigation. Figure 3 center, this time from Ramón y Cajal the Spanish neuro-anatomist mentioned earlier, schematizes the detailed circuitry. John O’Keefe and his colleagues in London (O’Keefe & Dostrovsky 1971) placed electrodes in the hippocampus of rats, and found that some of these cells would tend to respond not to what the rat was seeing or what the rat was doing, but to where it was in the lab. They called these ‘place cells’. This fine tracery in Figure 3 right shows the rat’s traversal of its little room while the red dots show where the cell was active as the rat moved around. A single cell does not tell you (or the rat) all that much. However, one of the interesting properties of the brain as we get down to the cell circuit level is called population coding. No single neuron knows anything with any precision. It is the populations of neurons that between them develop knowledge. In the present example, one cell may signal ‘you’re somewhere here’ and another cell might signal ‘you’re a little bit up’ or ‘you’re a little bit to the right’ — and between them the population gives the rat very precise information as to its location. Of course, one of the big mysteries for neuroscience is how do we or the rat have that embodied experience of being in a specific place when cells are firing across a broad region of the map. A partial answer is that selective strengthening of synapses on the basis of individual experience links place neurons to neurons elsewhere in the brain that represent sensory, motor and other experiences that the rat has had when traversing the regions that each place cell correlates with.

Inspired by such studies, neuroscientists have used brain imaging to show that the hippocampus plays a role for humans in navigation as well as episodic memory. For example, Maguire (1997) showed how right hippocampus works with other brain regions in processing spatial layouts over long as well as short time-courses, participating in both the encoding and the retrieval of topographical memory.
All this makes the hippocampus very interesting in terms of our navigation in time, episodic memory as studied in humans, and our navigation in space, as shown by the place cells which bring us down to the circuit level in the hippocampus. This is why neuroscience of the hippocampus and related brain regions become relevant to wayfinding as a particularly component or property of a building. I mentioned earlier the meeting in Taliesin West where Juhani Pallasmaa and I were both speakers. Where his book *The Thinking Hand* emphasized the role of the hand in, for example, invoking our embodied experience in using the hand in drawing sketches for further design, I spelled out my interest in the evolution of language (Arbib 2012b) in which I show how the brain mediates a conversation between vision and the hand not only in praxis but also in communication, including language. In particular, where both Pallasmaa and Mallgrave in the present symposium emphasized embodiment, I want to say that rationality may to a greater or lesser extent be disembodied and that this is not such a bad thing for humans, as long as it does not make us neglect our embodied interaction with the social and physical (including built) environment. So, returning to the idea of wayfinding, as architects you would be thinking, on the one hand, how clients will experience their passage through the spaces of a building based on cues afforded by the spatial structure of the building and, on the other hand, how to use signage, appealing to the symbolic aspect of their cognition to help assist their navigation when other cues fail.

Figure 3. Left: Location of the hippocampus in the human brain, with an indication of the area removed in H.M.’s neurosurgery. Center: A view of the neural circuitry seen in a cross-section of rat hippocampus [Ramon y Cajal]. Right. Tracery indicates a rat’s movement around a square arena, while the red dots show where in the room a particular “place cell” was active.

*Michael Arbib*
Neuromorphic architecture

*Neuromorphic architecture* is based on the attempt to answer the question: What if a building had a “brain”? When we study an animal we are looking at a creature whose brain has evolved to support its exploration of the environment around it—its embodiment is external to its (again, physical and social) environment. Complementing this is the idea that if a building had a “brain,” its embodiment would be internal. I’m not referring here to our blood pressure or visceromotor state as I would with a human, though insights might be gained by revisiting heating, ventilation and air condition in terms of brain mechanisms which support homeostasis in an animal, keeping crucial physiological variables within appropriate limits. Rather, I am thinking of an “interactive infrastructure” for a building that, for example, might contain something cognitively equivalent to what the hippocampus is doing—but keeping track of people within the building and perhaps communicating with them to provide a whole new, adaptive, level of human support. This may sound like science fiction, but I see it as part of the future of architecture.

If the building is a cognitive entity, not just a fixed structure possibly modified by shifting the furniture around, it may become dynamically reconfigurable on the basis of its interacting with the people within. Moreover, thinking of each piece of furniture as a form of perceptual robot rather than a static piece of equipment, may help us design environments that can dynamically respond to the needs of its inhabitants. To return to the issue of meeting the needs of special populations, consider how, if an elderly infirm person is trying to get out of bed, the bed would recognize her intention and assist her. In this case the bed is in some sense a robot—as a dedicated system with coupled sensory and motor abilities—but with little if any resemblance to an autonomous humanoid. Such furniture need not be human-like, but at least some of the furniture would be designed to interact with the people in the environment. We are getting very comfortable now with the idea that our smart phones have various useful apps that can do different things, but still the interface is primarily symbolic, though augmented by finger motions. What happens when the interface extends to dynamic interaction with a building and its furniture?

I have already devoted a full paper to this topic and some of the relevant neuroscience (Arbib 2012a), so let me close this section simply by quoting the abstract of that paper:
We introduce neuromorphic architecture, exploring ways to incorporate lessons from studying real, biological brains to devise computational systems based on the findings of neuroscience that can be used in intelligent buildings, adding a new biologically grounded perspective to the more general view that future buildings are to be constructed as perceiving, acting and adapting entities. For clarity, the term ‘brain’ is reserved for the brains of animals and humans in this article, whereas the term ‘interactive infrastructure’ refers to the analogous system within a building. Key concepts of neuroscience are presented at sufficient length to support preliminary analysis of the possible influence of neurobiological data on the design and properties of interactive infrastructures for future buildings. Ada—the intelligent space, a pavilion visited by over 550,000 guests at the Swiss National Exhibition of 2002, had an interactive infrastructure based (in part) on artificial neural networks [ANNs], had ‘emotions’ and ‘wanted’ to play with her visitors. We assess the extent to which her design was indeed grounded in neuroscience. Several sketches for rooms that exemplify neuromorphic architecture are used to demonstrate the way in which research on how its brain supports an animal’s interactions with its physical and social world may yield brain operating principles that lead to new algorithms for a neuromorphic architecture that supports the ‘social interaction’ of rooms with people and other rooms to constantly adapt buildings to the needs of their inhabitants and enhance interactions between the people who use them and their environment.

The neuroscience of the design process
I do not presume to know what the neuroscience of the design process will turn out to be. Rather, in the rest of the paper I want to present ideas that may constitute part of the foundation for future work in this area, using a quote from Peter Zumthor’s essay ‘A way of looking at things’ in his bookThinking Architecture (Zumthor 2012) to start the discussion [the highlights are mine]:

Michael Arbib
When I think about architecture, images come into my mind.

When I design, I frequently find myself sinking into old, half-forgotten memories .... Yet, at the same time, I know that all is new and that there is no direct reference to a former work of architecture ...

Construction is the art of making a meaningful whole out of many parts. ... I feel respect for the art of joining, the ability of craftsmen and engineers ... the knowledge of how to make things ...

Unlike the sculptor, I have to start with functional and technical requirements.

The challenge [is one] of developing a whole out of innumerable details, out of various functions and forms, materials and dimensions. ... Details ... lead to an understanding of the whole of which they are an intrinsic part.

One comment before we proceed. Zumthor titles his essay “A way of looking at things,” but these quotes evoke motor imagery as much as visual imagery—not just looking at things but also at how those things could be made. This evokes the phrase “action-oriented perception” that was the touchstone for my book The Metaphorical Brain: An Introduction to Cybernetics as Artificial Intelligence and Brain Theory (Arbib 1972). The notion is to look at the perceptual systems of the brain not as ends in themselves (reconstructing the world in our heads) but rather in terms of our ongoing courses of action, a point emphasized in the notion of the action-perception cycle (Arbib 1989, Fuster 2004, Neisser 1976). My son, the architect Ben Arbib, has been through Zumthor’s thermal baths in Vals and has talked about the way Zumthor’s design manages the visitor’s movement through the space, merging from one sensory experience to another. Different sensory modalities can be engaged. In one room there are fragrant flowers in the water to engage the sense of smell; elsewhere a heavy leather curtain may engage a sense of tactility and heaviness in the action of moving the curtain aside.
Confronting this quote from Zumthor with the description of an experience of one of his buildings, an important issue for “Neuroscience for Architecture” is this: “What is the job of neuroscience here?” Neuroscience rests on the design of repeatable experiments and the development of reasoned explanations that address a growing range of empirical data. Among other goals is to understand what different parts of the brain do during various tasks and how they interact. What do the circuits do? How do the various factors change with development, aging and various neurological disorders? Many neuroscientists study the underlying neuro-chemical details and patterns of gene expression—though I think that, for now at least, these latter details may be overlooked in the conversation between architects and neuroscientists. Given all this, I do not see it (though I may be wrong!) as a

Figure 4. The Action-Perception Cycle. [Adapted from Ulric Neisser. 1976 Cognition and Reality: Principles and Implications of Cognitive Psychology, W. H. Freeman and Co.]
Above: Peter Zumthor, Design sketches for Therme Vals, Switzerland [1994-96]. Images courtesy of Peter Zumthor.

Architecture and Neuroscience
goal for neuroscience per se to explain how Peter Zumthor designed the thermal baths at Vals. What we can do instead is to glean from biographical, even autobiographical, statements of the stages that different architects go through to ask what it would take for a human brain to mediate the set of processes involved in design. Only at the latter level can we do replicable studies of brain structure. We are not going to be able to get into the particular resonance between the biography of Zumthor and the environment of Vals and the demands of thermal baths, but we may have an understanding of what processes were involved. And this may well feed back into the educational process for architecture students. If we can say “these are the skills that are needed for exceptional design” then, even for students who are preparing for non-exceptional design, it may be useful to cultivate those skills in a way that is informed by neuroscience. So let me focus on extracts from the above quote from Zumthor, and briefly note opportunities for relevant neuroscience.

When I think about architecture, images come into my mind.

When I design, I frequently find myself sinking into old, half-forgotten memories ... Yet, at the same time, I know that all is new and that there is no direct reference to a former work of architecture ...

What is an image? Images can be very precise, as for example the glossy photograph of a building or they could present some general feeling, perhaps multi-modal, of certain aspects of the building. So one topic we might want to pursue through a neuroscience project is how is the variety of images? How do different parts of the brain collaborate in creating images? How do those images change?” Here are a few recent studies that assess some relevant brain imaging, and one that offers some interesting possibilities for technological aids for visualization of situated buildings.

Ishai et al (2000) found that visual perception of houses, faces, and chairs evoke differential responses in ventral temporal cortex. They used fMRI to compare brain activations evoked by perception and imagery of these object categories and found content-related activation during imagery in extrastriate cortex (i.e., visual areas just beyond the

Michael Arbib
primary visual cortex, which is also known as striate cortex)—but only in small subsets of the regions that showed category-related activation during perception. However, activation during imagery evoked stronger responses in the left ventral temporal cortex whereas perception evoked stronger responses in the right ventral cortex. Then, in parietal and frontal cortex, they found that activity evoked by visual imagery was not content-related. They suggest that content-related activation during imagery in visual extrastriate cortex may be implemented by “top-down” mechanisms in parietal and frontal cortex that mediate the retrieval of representations from long-term memory and then maintain them through visual imagery (my italics). Reflecting on Zumthor’s words, though, we may suggest that images (these representations) are not so much retrieved as constructed from fragments of memories to yield something that is new yet informed by past experience. Again, where Ishai et al stress visual imagery, we may consider the combination of visual, haptic and sensory impressions with motor imagery, as in imagining the pushing back of those heavy leather curtains. Incidentally, the topic of motor imagery has been treated in fascinating and accessible detail by Jeannerod (1994).

Complementing this talk of “top-down” mechanisms whereby imagery can activate sensory cortices, Passingham et al (2013) suggest that fMRI has established a new principle concerning the flow of information through the cortex, exhibiting the flexibility needed to match the demands of the task or current context. They suggest that this flexibility is achieved by feedback connections from the prefrontal and parietal cortex, and that these include connections to sensory and motor areas. However, the nature of the selective effect differs. They claim that parietal cortex can have the same influence on different processing streams, for example the dorsal and ventral visual systems, but that only the prefrontal cortex can also select between processing streams with the difference between the prefrontal and parietal effects is due to their different positions within the processing hierarchy. However, I’m not convinced that this is a new principle revealed only by fMRI since much relevant data has been gained from studies of the neurophysiology and neuroanatomy of macaque and other monkeys.

Elman et al (2013) probed episodic memory by comparing retrieval of recently learned spatial locations (photographs of buildings) with retrieval of previously familiar locations (photographs of familiar cam-
Architecture and Neuroscience

In fMRI analyses, the posterior parietal cortex (PPC)—which is closely coupled with the hippocampus—is particularly active during the successful retrieval of episodic memory. Episodic retrieval of recently learned locations activated a circumscribed region within the ventral PPC (lower parts of PPC) as well as medial PPC regions (i.e., those situated on the inner surface of the cerebral hemispheres). Retrieval of familiar locations activated more posterior regions in the ventral PPC (those further down) and more anterior regions in the medial PPC (those further back). These dissociable effects define more precisely PPC regions involved in the retrieval of recent, contextually bound information as opposed to regions involved in other processes, such as visual imagery, scene reconstruction, and self-referential processing.

The intriguing challenge is to go from this region-by-region analysis to assess the details of interactions of intricate patterns of neural activity across multiple regions, how neural plasticity encodes fragments of experience, and how the subtly rewired brain can then respond in novel ways to various tasks and contexts—with the ability to choose stimulating contexts a key element on the path to creativity. The hippocampus working with the cerebral cortex may remember some episode and other parts of the brain may work to bring some aspect of a general skill into play. Half-forgotten memories—some of specific moments, some of general feelings, some of procedural skills—all serve to reshape the current directions in which imagination can lead the design process.

Can new results in neuroscience support new insights into educational innovations that can support improved design? It may well be that new insights from neuroscience will combine with insights from computer science that provide immersive design environments. In one study that may be suggestive for such innovations, Kopf et al (2010) studied how systems such as Google Street View and Bing Maps Streetside enable users to virtually visit cities by navigating between immersive 360 panoramas, or bubbles. However, the discrete moves from bubble to bubble supported by these systems do not provide a good visual sense of a larger aggregate such as a whole city block. By contrast, multi-perspective “strip” panoramas can provide a visual summary of a city street but lack the full realism of immersive panoramas. To address these shortcomings, Kopf et al developed Street Slide,
which, they claim, combines the best aspects of the immersive nature of bubbles with the overview provided by multi-perspective strip panoramas. They integrate annotations and a mini-map within the user interface to provide geographic information as well as additional affordances for navigation. Such innovations may enable future architects to better situate their emerging design of a building in relation to the surrounding cityscape (or countryside, for that matter).

Construction is the art of making a meaningful whole out of many parts. ... I feel respect for the art of joining, the ability of craftsmen and engineers ... the knowledge of how to make things ...

Unlike the sculptor, I have to start with functional and technical requirements

Although tool use has been observed in other species, in his article “The cognitive bases of human tool use,” Krist Vaesen (2012) systematically compares humans and nonhuman primates with respect to nine cognitive capacities (both social and non-social) deemed crucial to tool use: enhanced hand-eye coordination, body schema plasticity, causal reasoning, function representation, executive control, social learning, teaching social intelligence, and language. He documents striking differences between humans and great apes in eight out of nine of these domains. He demonstrates how several of these cognitive traits help to explain our unique ability for cumulative culture, as well as the astonishing technological complexity this has produced: some traits enable high-fidelity cultural transmission, yielding preservation of traits across successive generations; and others, by facilitating individual learning, further the introduction of new cultural variants, necessary for incremental change.

My response is not to disagree with Vaesen so much as to shift of attention from tool to construction. Many creatures can use tools of a specific kind and in some cases even make them, as do New Caledonian crows (Hunt 1996, Weir et al 2002). Lefebvre et al. (2002) conclude that the complex cognitive processes involved in tool use may have independently co-evolved with large brains in several orders of corvine and passerine birds. Nonetheless, it seems to me that nest building by birds is even more impressive than their tool making. Animal Architecture

Michael Arbib
(Pallasmaa 1995) documents the far wider range of constructions across many species. Indeed, Hansell & Ruxton (2008) urge that we view tool behaviors as a limited subclass of construction behavior. Nest building in birds has been a key driver of habitat diversification and speciation in these groups (Collias 1997, Hansell 2000). It is thus intriguing that Stewart et al (2011) show that re-use of specific nest sites by savanna chimpanzees may be a result of “niche construction” (Iriki & Taoka 2011, Laland et al 2000) through formation of good building sites within trees. They speculate that environmental modification through construction behavior may have influenced both chimpanzee and early hominin ranging by leaving behind recognizable patterns of artifact deposition across the landscape.

However, I think it important to differentiate between animal architecture as the result of genetic programs which guide the behavior of animals in constructing their habitats, and human architecture which can change across many dimensions in ways in great part removed from genetic constraints. Rather, the skills examined by Vaesen each develop, thanks to the genetic changes which separate humans from apes and supported by the cultural evolution of new human cultural and technological environments, to allow humans to conceive of constructions in new and surprising ways.

Let’s shift attention, then, from “using a tool” to the ability to deploy multiple tools to solve a problem. To join a piece of wood to the wall, I may employ a screw of sufficient length plus a screwdriver; or a nail and hammer. I may also employ a stud finder, but if I need to affix an object where there is no stud, I deploy a rawlplug, a drill and a hammer to prepare for the screw. For household repair, I may deploy these tools and more to solve a truly novel problem by breaking it down into subproblems for which I have routine solutions. Or I may call in a handy-man, thanks to the great specialization within human society, and the social construction of monetary incentives.

Of the nine cognitive capacities listed by Vaesen, only three—enhanced hand-eye coordination, body schema plasticity and function representation—relate directly to using a tool for its intended purpose. Two—causal reasoning and executive control—relate not so much to tool use as to the more general skill of problem solving (of which construction, with or without tool use, is a crucial subcase). The remainder—social learning, teaching, social intelligence, and language—all
relate to social interaction in general or the transfer of skills in particular, whether or not they involve tool use.

Vaesen argues that only one of these nine capacities, body schema plasticity, cannot be invoked to explain what makes human technological abilities unique since “we share the trait with our closest relatives.” However, the issue is not whether the body schema can be extended, possibly by extensive shaping as in monkeys (Iriki et al 1996, Umiltà et al 2008). Rather it is (in part) the uniquely human rapidity and flexibility with which different extensions of the body schema can be deployed in some overall task, switching back and forth between using some part of the body or some part of a tool as the end-effector for the current action (Arbib et al 2009).

I remarked at the start of this paper how I used Juhani Pallasmaa’s book *The Thinking Hand* as my entry into my discussion of architecture and noted that my book *How the Brain got Language* (Arbib 2012b) suggests how the ability to act with the hands and to recognize the manual actions of others may have laid the basis for the evolution of the language-ready human brain—which is why my talk at Taliesin West was thus entitled *From Hand to Symbol and Back Again*. My theory of how the brain got language stresses complex imitation, the ability to recognize and imitate combinations of actions used to reach a perceived goal, together with variations on known actions. Recently, inspired by Stout’s (2011) essay on stone tool making and the evolution of human culture and cognition, I have developed a scenario (still in rather rudimentary form) in which complex imitation underwrites the co-evolution of language and tool making, with neither required to reach a critical complexity to initiate the evolution of the other (Arbib 2011, a somewhat modified account appears in Arbib 2012b). In this regard, it is useful to think of the grammar of a language not as a very general set of syntactic rules but rather as involving a large number of constructions which provide tools for assembling words hierarchically to meet the communicative goals of both familiar and novel social situations (Arbib & Lee 2008, Croft 2001, Goldberg 2003, Kemmerer 2006, Verhagen 2005).

This, for me, is really crucial. How do I express my ideas by putting together words in order to have some chance of conveying to you the ideas that I have in mind? We don’t have brain-to-brain transfer, and yet I am able to put those parts (those words) together, reflecting the
rules of English grammar, to make a whole. But when I utter a sentence, I may seek to express an idea that does not determine the exact words and it many only be through conversation (whether with another person or with myself; whether in words alone, or mediated by hand gestures, sketches, or appeals to the passing scene) that the original idea may become shapely and well-expressed so that I can at last feel I have truly shared my insights with others. So, too, with a building: The architect may begin to shape some overall whole without yet knowing how the details will fit together, and so much work is required to shape the design. The architect’s design of the skills of the builder and the artisan—of what different forms of construction may achieve—no less than ideas about how the building is to be used and what aesthetic statement it is to make, will all contribute to bringing the design to so explicit a form that actual construction of the building can begin.

No matter how poetic the space in Vals may be, getting the water to the appropriate temperature, finding ways for people to get to the water, and providing changing rooms all provide functional requirements that the final design must meet. These vary from tight to very loose constraints and we see that Zumthor transformed them in a way that no one else would have done. But that conversation between “Here is what I want to realize with the building” and “Here in the end, calling upon my knowledge of architecture in general, my specific experiences in architecture, my embodied experiences, here is the way that I realize, I meet, those functions in a way that is constrained but not defined by those functional requirements.”

The challenge of developing a whole out of innumerable details, out of various functions and forms, materials and dimensions.

Details ... lead to an understanding of the whole of which they are an intrinsic part.

Notice, it is not that one fixes on a detail, adds another detail, adds yet another detail and finally the whole emerges. Rather, one has this general idea of the whole and details begin to come into place, and they begin to replace that vague understanding of the whole with a more precise understanding of the parts of the whole, which now con-
strain how you will fill in other parts of the whole.

**Mirror Neurons, Schemas and the Multi-Faceted Brain**

It is now time to introduce a number of facts and concepts that may prove important in developing a neuroscience of the design process.

**Mirror neurons**

A group of neurophysiologists working in Parma recorded the activity of single neurons in the premotor cortex of the brain of macaque monkeys (the particular area was called F5, the fifth area of frontal cortex in their nomenclature), and found cells that fired preferentially as the monkey executed some types of action, but not others (di Pellegrino et al 1992, Gallese et al 1996, Rizzolatti & Craighero 2004, Rizzolatti & Sinigaglia 2008). Some “preferred” a power grasp, some a precision pinch, and so on. But then, in a subarea of 5, they found cells that had a surprising extra property—such a cell fired not only when the monkey performed its preferred action, but also when the monkey observed the human experimenter perform a similar action. They called such cells mirror neurons.

Here I have to say something very important, but without much time to develop it. I talked before about a population of cells coding a range of possibilities. It is not that one cell says ‘I am specific to a precision pinch’ and another cell says ‘If I fire it means there is a power grasp’. Rather they are part of a whole. Each neuron is active for a feature of the executed or observed action. Many neurons may be active for a range of features related to the given action, but in different ways. Thus the activated population can give a nuanced representation of the current grasp, whether executed or observed—not a simple yes-no judgment. Harry Mallgrave’s talk uses mirror neurons and embodiment to relate empathy for a person to empathy for a building. The suggestion, then, is not to think of empathy in an all-or-none way but rather in thinking of how a diverse population of neurons may fire in different circumstances. If enough of the population fires in relation to the building it may invoke in you activity of a population similar to one that would correspond to your interaction with a human. In other cases, a different sub-population could be active, and one’s reaction to the building may be more formal rather than empathic and embodied.

I want to emphasize that mirror neurons are just a small part of the brain. They don’t do action execution and recognition (or empathy).
all by themselves. Consider an fMRI (brain imaging) study of humans recognizing actions performed by humans as well as nonconspecifics (Buccino et al 2004). When the subject being scanned observed, at separate times, videos of a human biting, a monkey biting and a dog biting, then an area of the subject’s brain thought to contain mirror neurons for facial movements was active in all three cases. In this case, the mirror neurons do seem to be active in mediating the subject’s understanding of biting. However, the story becomes more complicated when the general concept is oral communication. Now the subject observed videos of a human talking (no soundtrack but with lip movements), a monkey teeth-chattering or lip-smacking and a dog barking. There was a lot of “mirror system” activation while observing the human, a small amount of activation while observing the monkey and none while observing the dog. It is not that the subject does not know that the dog is barking, but rather that mapping the dog’s barking onto mirror neurons is not part of that particular understanding. Thus, where Buccino et al say ‘Actions belonging to the motor repertoire of the observer are mapped onto the motor system, in particular the mirror neurons. Actions that do not belong to this repertoire are recognized without such mappings,’ making a strict dichotomy between what you can do and what you can’t do, I would say that all these actions can be recognized without the aid of mirror neurons, but if an action is in our own repertoire the mirror neuron activity enriches it by tying it in to our own motor experience.

Let me emphasize this point by looking at a study from UCLA of autistic and typically developing children (Dapretto et al 2006). Children had their brains imaged while they were shown 80 faces with five different emotions: anger, fear, happiness, neutrality or sadness. For the typically developing group, there was a great deal of mirror system activity, but in the autistic spectrum disorder group that activity was greatly reduced. Moreover, when the experimenters assessed a clinical measure of autism they found that the more severe the autism, the less the mirror system activity. But here comes the shocker. There were no significant differences in how well the children imitated facial expressions! Does this mean the mirror system is not important in the recognition of facial expressions? I think the way we reconcile the data is to see that in one case, you see a happy facial expression and feel empathy for that person and then you smile, or you see the frown or expression of sadness and spontaneously express that emotion your-
self. However, the child who has severe autism cannot feel the emotion from that experience but can analyze the facial expression (the twist of the mouth, the inflection of the head and so on) and copy it much as we would imitate a strange grimace. I asked Mirella Dapretto, the lead author of the study, whether she had studied this and she had not, but she mentioned one piece of evidence that seemed consistent with my interpretation. In one case they observed an autistic child imitating and noticed the child getting the mouth right, and then the eyes right and so on. The idea is that the mechanism of piecemeal replication is distinct from the invocation of a known emotion or actions. My slogan is ‘going beyond the mirror’: Mirror neurons are crucial in relating things to your motor experience, but they are just part of the overall perceptual and perhaps rational apparatus of the brain.

Schemas
A particular challenge for any neuroscience of architecture is to bridge from the language of psychology to that of neural circuitry. The way that I’ve approached it is develop a neurally-based notion of ‘schemas,’ inspired in part by the genetic epistemology of Jean Piaget (Piaget 1954, Piaget 1971), but influenced more strongly by an attempt to advance neuroethology, the study of the brain mechanisms underlying animal behavior (Arbib 2003, Ewert 1987, Ghazanfar & Hauser 1999, Tinbergen 1963). I distinguish perceptual schemas from motor schemas, while acknowledging that many bridging schemas are required, especially in the human ability to contemplate concepts of increasing abstraction.

A perceptual schema is a process for recognizing an apple or a person’s face, a chair or a wall. But it is not enough to recognize one object at a time. To make sense of your environment you have to be able to relate many different objects and their spatial relationships. On the other hand, motor schemas provide the ability to carry out the actions that have been determined through the continued operation of the action-perception cycle. Note the plural—we seldom execute a single action, but rather a “coordinated control program” that coordinates the various motor schemas, modulating their activity as perceptual schemas update their representation of the current state of the actor’s interaction with the environment. However, rather than develop this notion of coordinated control program here (see, for example, Section 2.2 of Arbib 1989), let me focus on the perception of visual scenes. Re-
call René Magritte’s 1959 painting, Le château des Pyrénées (an image can be found at http://uploads0.wikipaintings.org/images/rene-magritte/the-castle-of-the-pyrenees-1959(1).jpg). If you look only at its top half, you get an immediate impression of a mountaintop with a castle on it. But when you see the whole picture, you are confounded—what had appeared to be a mountain is revealed to be an immense boulder suspended above (or crashing into?) the waves of the sea below. What is interesting here is that in general we live in a consistent world, so that our schemas (interacting states of activity in our brains) can “nudge” each other, changing the shapes they represent, redoing their parametric descriptions, so that between them they provide a coherent interpretation of the scene. Magritte’s art, as a surrealist, was to paint each part of the painting totally realistically. There is no way you can fail to see that there is an ocean at the bottom of his painting just as there is no way you can fail to see the bottom of the boulder above it; yet when you go to the top the view of the castle confounds the notion

Figure 5. The VISIONS paradigm for cooperative computation in visual scene analysis. Interpretation strategies are stored in schemas which are linked in a schema network in Long Term Memory (LTM). Under the guidance of these schemas, the intermediate representation is modified and interpreted by a network of schema instances which label regions of the image and link them to a 3D geometry in Short Term Memory (STM).
that what it sits atop is a boulder rather than a mountainside. He creates a form of cognitive dissonance. I use this example to illustrate the process whereby, as your eyes move around the scene you (in most cases) build up an integrated view. In general this will be a consistent view of what is out there, unless you are faced with Magritte, who deliberately wants to confuse you and by whom you deliberately wish to be confused. However, different people have different experiences, and these shape different perceptual schemas in the head, due in part to the diverse motor schemas—they themselves underpinning the skill set of the individual—with which they have been coupled in the action-perception cycle.

An early example of schema-based interpretation for visual scene analysis in the VISIONS system (Draper et al 1989, Hanson & Riseman 1978). Low-level processes take an image of an outdoor visual scene and extract an intermediate representation—including contours and surfaces tagged with features such as color, texture, shape, size and location. Perceptual schemas process different features of the intermediate representation to form confidence values for the presence of objects like houses, walls and trees. The knowledge required for interpretation is stored in LTM (long-term memory) as a network of schemas, while the state of interpretation of the particular scene unfolds in STM (short-term or working memory) as a network of schema instances (Figure 5). Note that this STM is not defined in terms of recency (as in very short term memory) but rather in terms of continuing relevance.

Interpretation of a novel scene starts with the data-driven instantiation of several schemas (e.g., a certain range of color and texture might cue an instance of the foliage schema for a certain region of the image). When a schema instance is activated, it is linked with an associated area of the image and an associated set of local variables. Each schema instance in STM has an associated confidence level which changes on the basis of interactions with other units in STM. The STM network makes context explicit: each object represents a context for further processing. Thus, once several schema instances are active, they may instantiate others in a “hypothesis-driven” way (e.g., recognizing what appears to be a roof will activate an instance of the house schema to seek confirming evidence in the region below that of the putative roof). Ensuing computation is based on the competition and cooperation of concurrently active schema instances. Once a number of schema
instances have been activated, the schema network is invoked to formulate hypotheses, set goals, and then iterate the process of adjusting the activity level of schemas linked to the image until a coherent scene interpretation of (part of) the scene is obtained.

This process is called cooperative computation. Rather than serial processing, the brain employs both competition and cooperation between schema instances as it moves towards some perceptual, motoric or communicative goal. Cooperation yields a pattern of “strengthened alliances” between mutually consistent schema instances that allows them to achieve high activity levels to constitute the overall solution of a problem. As a result of competition, instances which do not meet the evolving consensus lose activity, and thus are not part of this solution (though their continuing subthreshold activity may well affect later behavior). Successful instances of perceptual schemas become part of the current short-term model of the environment.

The issue of how the brain mediates such processes is brought into stark view by two forms of a neural condition called simultanagnosia, “lack of knowledge about things simultaneously in the environment.” In one case, resulting from a lesion in the dorsal part of the brain, unattended objects do not seem to be seen at all. The patient can look at one object and see what it is, but loses any awareness of other objects. As a result, they cannot locate the observed object with respect to any other object. When the lesion is ventral, the simultanagnosic may still have a sense of multiple objects, but when focusing on one object is unable to use the (previous) recognition of the other objects to make sense of the overall scene (Farah 1990). Such disorders makes us aware of the challenges of bridging between the phenomenological seamlessness of the world around us and the fine circuits in our brain that connect us to our sensations, our perceptions, our actions and our world. Neurological disorders give us a window into what happens when the parts and processes of the brain, or the cooperative computation that links them, become damaged. There are many different processes, and the job of neuroscience is not only to look at the high level correlations but to really tease apart more and more of those details.
A Case Study in Group Creativity: Choreography

Let me jump now to a particular case study in group creativity. If we are to continue the dialogue between architecture and neuroscience, it will be important to extract case studies of architects engaged in design. (I am sure there are many case studies in existence but I have not looked at them, yet.) As I said before, I do not think we can expect neuroscience to shed much insight into the autobiographical particulars in a specific case study, but we may begin to see that there are certain skills that are crucial to design and discern different styles. Certain people may make better use of visualization, others may rely on tactile images, while yet others people may skillfully imagine moving through the building and creating a three-dimensional pattern of interaction. However, in lieu of such studies, I am going to examine the design of a dance, in particular a case that involved group creativity: although the choreographer controlled the overall development, interactions with and between the dancers played a crucial role. The dance was created by Anna Smith as choreographer working with eight female dancers in Melbourne, Australia. In 2005, Kate Stevens gave a chronology of the creation the dance in the rather provocatively titled book *Thinking in four dimensions: Creativity and cognition in contemporary dance* (Stevens 2005). I offer a brief encapsulation of what it took to create that dance, in order to suggest how a careful case study of the creative process may offer clues for scholars who want to know what a human brain has to be to make such processes possible. Then you can ask the neuroscientists to tell you more about how those processes work in the brain, and you can ask more of the case-study to determine what happened in this particular instance.

When I am writing, I keep multiple drafts of a document which provide my record of this particular creative process. And many architects, when they are creating, will be making sketches, whether by hand or on the computer—and these provide a cumulative record of the various ins and outs of the design process. But a dance is evanescent. In the present case, a journal was kept with a record of what ideas were being explored in each particular week of the dance. This included photos of, say, a particular pose but even more important were videos of particular patterns of movement, creating a sort of external memory of the development. I am reminded of the work of Merlin Donald (Donald 1991) who has a theory of human evolution
based on mimesis, and for him the third and most crucial stage of development is the transition from reliance on memory structures in the head to external devices, whether through sketching, drawing, building sculptures or what have you. For this dance, this new dimension of technology (the video) helped produce a record in which patterns of movement were essential.

With much less constraint that for Peter Zumthor at Vals, the initial idea for the dance was to think about red and its relation to blood while having the dancers come up with various “through-lines,” ways of moving out through the body. And through the video record as well as through observations of each other, the group built up a motion vocabulary from which one could move out of the body toward this general idea of redness and blood. In the second week, they began to systematize these movements out from the body that they thought were important. In that same week, a turning point came when the choreographer asked each of the dancers to bring something red to rehearsal. One of them brought a bag of red kidney beans. Somehow the mixture of the feel, the sound, the texture and the pouring of the kidney beans became a central metaphor for the idea of blood and so that began to take control of the group’s imagination.

As the dance developed, the idea of pooling blood around a dancer provided a powerful image (Figure 6). Moreover, pouring the kidney beans out on the floor had an auditory component that was reminiscent of rain on a tin roof, inspiring the name Red Rain for the dance. Outlining the shape of the body with the beans, and then having the dancer move, formed various interesting outlines that added to the emerging motions of the dance.

In Weeks 1 and 2, the focus was on arterial blood, red blood. What about blue, venous blood? This question led, in Week 3, to the creation

Figure 6. Red kidney beans were used to outline the shape of a prone body. The line of the body left behind suggested traces written in blood. (Photos: Anna Smith.)
of large blue and red objects, symbolizing the two forms of blood, as props. And then the interaction of one dancer with those props yielded another beautiful, powerful image, the ‘nesting child,’ that became another building block for the dance. We see again this open-ended variation on what has been done before, but we also see this ‘ratcheting’ (Tennie et al 2009) where every now and again something will crystallize as a new component for the emerging design. Creativity exploits the prior schemas, places them in new contexts and assembles them in new ways to transform them into novel schemas which—together with external props and ‘narrative momentum’—provide aliment for further variation and development, building on what you know in order to vary it and discover something new. What one thing means at the beginning of a performance may mean something different later.

By Week 5, a lot of the through-lines had been created. But there was a worry about stasis and so the choreographer forced new variations on the existing themes by getting the dancers, much to their discomfort, to truncate their through-lines and learn new ones. In this way, a new set of bodily movements which were perhaps less natural but more evocative emerged. And so it goes on.... The through-lines which at first had been effortful, hard to master (because it was difficult to move the body in these unnatural ways) became automatized and therefore the design of the dance could move up a level to examine how to sequence and interrelate. And so, over the remaining weeks, the dance became complete (see Stevens 2005 for many more details). What may resonate with many architects is the frustration that the choreographer, Anna Smith, felt at times, not knowing what the shape of the final work would be because it was an emergent process rather than a pre-defined process. Creativity in composing this dance involved sequencing, melding and linking the parts of the work as well as the creation of the parts themselves.
In Conclusion
This takes us back to a final visit with Peter Zumthor. His essay, *A Way of Looking at Things*, led us to ponder a variety of words and phrases relevant to the design process and thus helped us begin to delineate some of the challenges for a neuroscience of the design process:

Images
Half-forgotten memories
Yet all is new
Construction is the art of making a meaningful whole out of many parts
I have to start with functional and technical requirements
Developing a whole out of innumerable details

We now have some sense of images and of how memories are built up and recorded (both internally and externally) as well as the search for something new all the time. In terms of construction, what is not emphasized in his quote, but what I have come back to several times, is that the whole is creating the parts at the same time that it is being created from the parts. Part and whole do not form an either/or. In general, we neither start with a whole and fill in the details, nor start with a known set of parts and merely assemble them. Rather there is a continual dialogue between the emerging selection and innovation of parts and the emerging concept of the whole. I have, among many other topics, touched briefly on the schema theory of visual perception to indicate how this mix of bottom-up and top-down is the essence of cooperative computation, which I hold to be the essential style of the brain. And the notion of dialogue is crucial—not only between parts of the brain, or between architect and sketchpad, but also between the many collaborators who may help shape the design, whether through a specific contribution to the emerging whole, or through informed critique. We begin to see, dimly, what enables the human brain to design new constructions, whether in our everyday life or the choreography of a dance or the development of a novel building.
NOTES

1 This article is based on a presentation given on June 3rd, 2013 in Helsinki as part of the Symposium “Architecture and Neuroscience,” the first in a series celebrating Tapio Wirkkala’s 100th birthday in 2015, and organized by Aalto University, Alvar Aalto Academy, Finnish Centre for Architecture, University of Helsinki and Tapio Wirkkala–Rut Bryk Foundation. My thanks to Juhani Pallasmaa and Esa Laaksonen for conceiving this event and bringing it to fruition.


3 An article based in part on this talk is to appear in a volume edited by Juhani Pallasmaa and Sarah Robinson and to be published by the MIT Press.

4 In this article, the word architecture will almost always be used in the sense of “the architecture of the built environment.” However, as we shall see briefly, neuroscientists use expressions like neural architecture or the architecture of the brain to describe the patterns whereby neurons and their connections are arranged in layers, columns and regions in the three-dimensional structure of a brain (Swanson 2011). A computer scientist will then use the term neuromorphic architecture for a computer which, unlike a conventional serial computer, has its components laid out in a fashion inspired in part [often a very small part] by the architecture of the brain.

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Architecture and Neuroscience


Architecture and Neuroscience
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Finnish architect, educator, and critic Juhani Pallasmaa, SAFA, Hon. FAIA, Int FRIBA, is a leading international figure in contemporary architecture, design, and art culture. His numerous books include Encounters 1 and 2 (2006 and 2012), Understanding Architecture (2012, in collaboration with Robert McCarter), The Embodied Image (2011), and The Thinking Hand (2009) and many others. Since 2008, he has served on the jury for the Pritzker Prize for Architecture.

Harry Francis Mallgrave
For more than 30 years Harry Francis Mallgrave has worked as an architect, editor, translator, teacher, and historian. In the last capacity he has authored more than a dozen books, and his current one, in the final stages of completion, is entitled Theory and Design in the Age of Biology: Reflections on the ‘Art’ of Building. Currently he is a professor of history and theory at Illinois Institute of Technology, which he is also the director of International Center for Sustainable New Cities.

Michael Arbib
Michael A. Arbib was a pioneer in the interdisciplinary study of computers and brains, and has long studied brain mechanisms underlying the visual control of action. For more than a decade he has devoted much energy to understanding the relevance of this work, and especially of mirror neurons, to the evolution of the language-ready brain. He is currently a Board Member of the Academy of Neuroscience for Architecture and University Professor and Director of the USC Brain Project at the University of Southern California.
About the TWRB Foundation

The Tapio Wirkkala – Rut Bryk Foundation was established in 2003 to carry on the legacy of the artist-designer couple Tapio Wirkkala and Rut Bryk. Both were enthusiastic designers and tireless experimenters who embraced new developments in technology and craft. Working across disciplines, they expanded the range of design possibilities through material and technical innovation.

Today the TWRB Foundation not only maintains the Wirkkala-Bryk archive to support research on the work of the designers, it also aims to maintain their spirit and passionate commitment to design education. In collaboration with universities and educational institutions around the world the foundation supports discussions, seminars, conferences, master classes and scholarly projects as well as publications, awards and scholarships related to design. In addition, it collaborates with museums and other institutions to produce exhibitions and publications on the work of Tapio and Rut.

As part of the centennial celebration of the couple, the TWRB foundation hosts a series of public events that consider design across a range of disciplinary boundaries. The Design Reader series documents these events and the ideas that they generate.

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