Applying Neuroscience to Architecture

John P. Eberhard[1,*]
[1]Founding President and Board Member Emeritus the Academy of Neuroscience for Architecture, San Diego, CA 92101, USA
*Correspondence: jpeber@aol.com
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Architectural practice and neuroscience research use our brains and minds in much the same way. However, the link between neuroscience knowledge and architectural design—with rare exceptions—has yet to be made. The concept of linking these two fields is a challenge worth considering.

The design of places and spaces that provide a context for human experiences—architecture—has a long and often distinguished history. The conscious, frontal lobe processes of shaping this context are only partially understood by architects and have yet to surface on the roiling waters of neuroscience studies. Even less well understood is the role of architecture in shaping human experiences. Social and behavioral scientists have explored this terrain over the past 50 years, but the results of their work are shallow knowledge. They enable us to observe the fact that children in classrooms lit with natural daylight achieve higher test scores, but not why this happens.

More than 2000 years ago, a Roman architect, Marcus Vitruvius Pollio, was the author of *De architectura*, known today as *The Ten Books on Architecture*, a treatise written in Latin and Greek on architecture, dedicated to the emperor Augustus. This work is the only surviving major book on architecture from classical antiquity. Vitruvius is famous for asserting in this book that a structure must exhibit the three qualities of *firmitas*, *utilitas*, *venustas*—that is, it must be strong or durable, useful, and beautiful. It seems strange that 2000 years later this three-part requirement is still so little understood.

Most neuroscientists think of architecture as a profession concerned with aesthetic beauty—designs that please the observer through visual perception of the harmony, symmetry, and good proportions crafted by the designer. But, architecture is more than aesthetics. Well-designed buildings need to respond to the functional needs of the occupants, and users need to be provided with adequate lighting, well-modulated heating and cooling systems, structural soundness, and public safety provisions (i.e., entrances and exists, stairways, etc.). All of these attributes are now evaluated in physical science terms.

If we expand the horizon for neuroscience, it would eventually result in a new knowledge base for architecture. We would then know how the design of classrooms can support the cognitive activities of students, how the design of hospital rooms can enhance the recovery of patients, and how the design of offices and laboratories can facilitate interdisciplinary activities of neuroscientists, and so forth.

Understanding the Brain

Michael Gazzaniga began his essay in *Neuron* (Gazzaniga, 2008) by saying, "…scientists ask how the brain causes human beings to perceive, think, behave, reproduce, eat, drink, and all the rest. Enormous advances have been made toward this goal, and today, the excitement in the field is palpable."

After more than 15 years exploring ways in which these advances might be applied to architectural settings, I have come to believe that the key to understanding how our brains enable our minds to experience architectural settings is consciousness. There are a wide range of studies and opinions on what consciousness is. As early as 1912, William James said that consciousness is a process whose function is knowing.

While we gnaw away at understanding the elements of consciousness, we may produce some clarity that eventually enables us to incorporate human experiences of architectural settings directly into the neural networks of designers. This would be a multifaceted design process, built on a foundation of new knowledge and resulting in a much richer and more satisfactory context for our lives. Designers will be consciously able to understand what is, today, merely an empathetic guess.

In their book, Edelman and Tononi (2000) argue that a scientific approach to the still elusive concept of consciousness will gradually reveal that this mysterious process is knowable. They believe that we will eventually understand how consciousness arises from particular neural processes resulting from the interactions between our brain, our body, and the world. We would next be able to identify the key properties of conscious experiences and understand the role of qualia in neural terms and how to connect these scientific descriptions of consciousness to human knowledge and experiences. At that point, the way designers basically "think" about occupants experiencing the spaces they are designing will be changed. The details of how these processes change will only unfold once neuroscience research progresses to provide a deeper knowledge base than what is now available.

Johann Wolfgang von Goethe, the German poet whose works span the fields of poetry, drama, literature, theology, humanism, and science, said, "I call architecture frozen music." His statement was probably intended to convey how much of the emotional response he had to architectural settings was the equivalent of those he experienced with music. Most visitors to one of the great cathedrals of Europe are overwhelmed with the "beauty" of the interior setting on first entering the nave—in fact, cathedrals are designed with a narthex (entry way) that is small to prepare our minds for the awe inspiring experience that follows as we enter the nave. If an organ is also playing as we enter, this music will be included in the dispositional memory record we create. Visual, auditory, and emotional content are merged in our consciousness.

The sounds of the music being played will be included in the memory we recall on our next visit to a cathedral.

Dispositions are described by Damasio in his book *The Feeling of What Happens* (Damasio, 1999). He indicates that dispositions are records that are "dormant and implicit." These memory records that lie just below the surface of consciousness include our perception of the object (e.g., a cathedral), the sensory aspects of that object (such as color, shape, texture), as well as records of the motor adjustments that accompanied the gathering of the sensory signals and emotional reactions we had when perceiving the cathedral and hearing the music. When we return to a previous locale once recorded in a disposition (i.e., our next visit to a cathedral), we allow the disposition to make explicit the stored implicit information. We recall not just our sensory experience during the previous visit, but our past emotional reactions. According to Damasio, this is why we can be conscious of what we recall inside of our head as much as what we actually see, hear, or touch in real time. It's probably the "stuff" of which dreams are made. However, my experience would suggest that places in our dreams are often "embellished disposition"—that is, they are more elaborate than the actual place we once visited.

How the Brain and the Mind Relate to Architectural Settings

Research

In 1999, Nancy Kanwisher and her associates published an article in *Neuron* (Epstein et al., 1999) that established grounds for linking the brain to experiences with architecture. She called the place in the brain where this link is made the parahippocampal place area (PPA). The PPA is defined as the set of all contiguous voxels within the parahippocampal region that respond significantly more during viewing of scenes than during viewing of faces or objects. They found that PPA activity (1) is not affected by the subjects' familiarity with the place depicted, (2) does not increase when subjects experience a sense of motion through the scene, and (3) is greater when viewing novel versus repeated scenes. The authors had earlier reported that the PPA was significantly more active when subjects viewed complex scenes such as rooms with furniture, landscapes, and city streets than when they viewed photographs of objects, faces, house (elevations), or other kinds of visual stimuli. By place recognition, the authors mean the matching of current perceptual information to the memories of places that had been encountered in the past and stored in one's cognitive map. They do not use the term disposition, but it seems likely that what is stored in the PPA are the dispositions of past experiences of these buildings. This research is one of the few projects that clearly relates neuroscience to architectural knowledge.

A Case History of How Neuroscience Has Impacted Design

Neonatal intensive-care units (NICUs) in hospitals provide one of the best illustrations of how neuroscience knowledge has changed architectural design. This case is based on the work of Dr. Stanley Graven, at the Department of Community and Family Health, College of Public Health, University of South Florida.

Graven has said that the Book of Ecclesiastes points out that, "For everything there is a time and a season." There is a time in the course of an infant's development when each series of events is designed to occur. There is no benefit in early occurrence, although problems may arise due to late occurrences. Thus, it becomes important to design the environment and the care practice of the NICU to support and facilitate development and minimize interference. Most of the important events of development will occur without specific intervention if the *architectural setting* and the interactions between the infant and the caring adult are appropriate.

Neuroscience studies of the developing human fetus have identified three stages: (1) the most important neurodevelopment in the early stages of life include the basic structure of the brain, the development of the nerve tracks, the development of the sensory organs, and the basic connections and pathways; (2) the basic structure of the eyes and ears, with their pathways into central nuclei and then to the cortex—which is genetically driven but environmentally modified; and (3) new pathways, memory circuits, and the whole range of connections for the neurons in the cortex, made in response to stimuli. The second stage, which occurs early in the third trimester, finds the sensory auditory modalities (including responses to sound and vibration) appearing, followed by visual development. When an infant is born prematurely (especially if it occurs early in the third trimester—at 7 or 8 months), the sequencing of sensory development becomes an issue. Stimuli and use of systems that are out of sequence can create developmental problems, i.e., visual development should not normally begin until after the auditory modalities are in place. It's not that a premature infant will be deaf or blind, but they may be more likely to loose acuity. An impaired auditory system could prevent them from developing perfect pitch should they become musicians, and their visual system's poor development could even lead to macular degeneration in later life.

NICUs are historically designed to meet the functional requirements of doctors and nurses (as is true of the rest of the hospital), including abundant light to care for the babies and sound systems to let the staff be called for important assignments. Dr. Stanley Graven has studied the environmental impact of such designs on premature infants. His work suggests (Graven et al., 1992) that NICUs should be designed to facilitate development of the premature infant and minimize interference with their neuronal systems. These neuroscience studies are now beginning to influence architectural design decisions—a clear example of what can happen when direct links are made between neuroscience and architecture.

A Case History of How Design Impacts the Brain

Thorncrown Chapel (Figure 1) provides a rich illustration of how good design impacts our brains and minds. The chapel's history begins in 1971, when Jim Reed, a native of Pine Bluff, Arkansas, purchased land in Eureka Springs, Arkansas, to build his retirement home. Other people admired his location and would often stop at his property to gain a better view of the beautiful Ozark hills. One day while walking up the hill to his house, the idea came to him that he and his wife should build a glass chapel in the woods to give wayfarers a place to rest, reflect, and refresh themselves.

He asked his architect friend Fay Jones to design the chapel. Fay says,

Figure 1. Model of the Thorncrown Chapel Designed by Fay Jones, FAIA
A space that stimulates an emotional response in the brains of visitors.

I saw an opportunity here to create Architecture—with a capital "A." The distinction I am making is that all building isn't Architecture, just as all writing isn't literature or poetry, even though the spelling, grammar, and syntax might be correct. There is something in Architecture that touches people in a special way, and I hoped to do that with this chapel.

If you walk into this small chapel nestled in the Ozark mountains, you are likely struck with awe. It's only 24 feet wide, 60 feet long, and 45 feet tall. It would easily fit within one of the transepts of the National Cathedral in Washington, and yet it is larger than life. The American Institute of Architects chose it as the fourth most impressive design of the 20th century. Since July 10, 1980, when Thorncrown Chapel opened, over five million people have visited this little chapel on the hillside. Thorncrown has won numerous architectural awards.

The chapel is made with all organic materials to fit its natural setting. The building materials are primarily pressure-treated pine 2×4s, 2×6s, and 2×12s. The larger elements of the building, such as the trusses, were assembled on the floor and raised into place. Light, shadows, and reflections play a major role in Thorncrown's ambience. Because of the chapel's elaborate trusses and the surrounding trees, constantly changing patterns of light and shadows appear during the day. At night, reflections of the crosses in the lights appear to surround the entire building.

Our available knowledge of the brain and mind can provide some plausible hypotheses about the cognitive and emotional experiences associated with the Thorncrown Chapel:

- Our sense of awe is influenced, in part, by having space above our head that is not visible until we move our eyes (and probably our head) upward. Semir Zeki once suggested that raising our eyes upward to see a spire on a cathedral was transformative—it stirs some primal notions of something ethereal.
- The sensitivity of our suprachiasmatic nuclei (SCN) to light—driving the circadian rhythms—influences our alertness. The play of light and shadow may trigger the SCN to "play with alertness" in a way that we find stimulating.
- The hush of nature deep in the woods provides a "quiet" experience for our auditory cortex that could be soothing, which suggests that the sense of "quiet" experienced by urban dwellers may be more soothing (because of the ambient noise where they live) than the experience of rural dwellers.

Linkages with Potential Neuroscience Application

The Academy of Neuroscience for Architecture (ANFA) was created in 2003 to explore ways to link the research of neuroscience to the practice of architecture. After nine careers that included being dean of two schools of architecture and director of a number of research organizations, I was part of the team that created ANFA. I served as its first President before becoming an ANFA Fellow for two years. During these two years, a number of workshops were held to identify hypotheses derived from the functional requirements of healthcare facilities, elementary schools, correctional facilities, sacred places, facilities for the aging, and neuroscience laboratories. The workshops included architects with experience in designing the kind of facility under discussion, neuroscientists, behavioral scientists, and ANFA Board members. Some 70 to 80 hypotheses resulting from these workshops now await research efforts by doctoral and postdoctoral students.

The five areas studied in brain systems are:

- Sensation and Perception (how do we see, hear, smell, taste, etc.?)
- Learning and Memory (how do we store and recall our sensory experiences?)
- Decision making (how do we evaluate the potential consequences of our actions?)
- Emotion and affect (how do we become fearful or excited? or what makes us feel happy or sad?)
- Movement (how do we interact with our environment and navigate through it?)

These areas can serve as categories for the 70+ hypotheses developed by ANFA. In my book *Brain Landscape* (Eberhard, 2009), I discuss these hypotheses and their potential utilization in graduate research. For example:

- The brain is hard-wired to respond to proportions based on the golden mean (as illustrated by the architect Palladio)
- A distributed set of brain activities across the entire brain—including the cerebral cortex, the cerebellum, the basil ganglia, the amygdala,

and the midbrain—work together to yield a special sense of awe (as in Thorncrown Chapel)

- Facilities for the aging that allow residents to furnish rooms with their personal furniture provide support for episodic memory through links to their autobiographical past

Conclusion

Somewhere deep in the recesses of consciousness, the way we go about shaping designs and the way we conceive solutions to neuroscience hypotheses are similar and basic. These basic networks that distinguish humans from other species are a shared mystery. Architects know that by thinking creatively they can find three-dimensional solutions to human habitats—and sometimes do this so well that history books will record their achievement. Neuroscientists know that if they imaginatively utilize the scientific process to study the brain they can find new knowledge of value—and sometimes find new knowledge that is unique and so important that it deserves a Nobel Prize.

We spend more than 90% of our waking hours inside of buildings. It consequently seems appropriate to consider making a special effort to encourage doctoral and postdoctoral students in neuroscience programs to undertake research programs and projects related to hypotheses derived from the ANFA studies of architectural experiences. New sources of funding are likely to emerge for the support of interdisciplinary science in the next few years. Professors and research directors in neuroscience who read this essay are invited to explore this new horizon. By encouraging their students and graduate assistants to move into this new field, architecture would have a greater potential to improve the lives of generations yet to come.

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