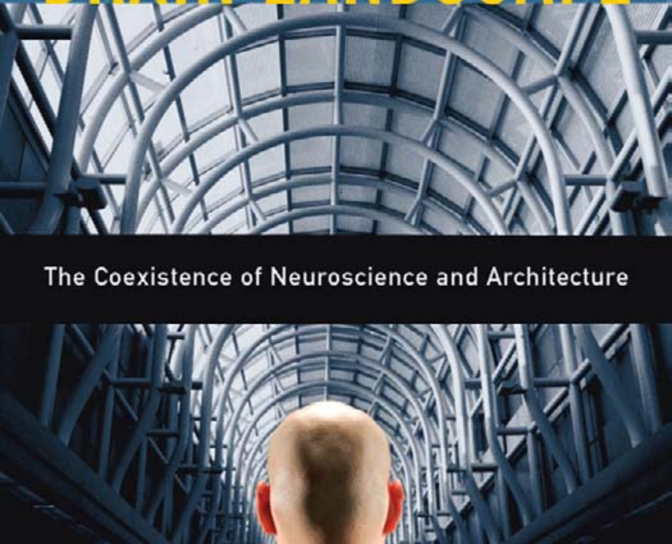
John Paul Eberhard

BRAIN LANDSCAPE

The Coexistence of Neuroscience and Architecture



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The Coexistance of Neuroscience and Architecture

JOHN PAUL EBERHARD

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The Academy of Neuroscience for Architecture
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Dedicated to Jonas Salk,
whose wisdom created the
opportunity for me to explore
neuroscience

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Acknowledgments

This book is the result of a number of events in my life that led to me becoming the only architectural member of the Society for Neuroscience. As indicated in the autobiographical material in Chapter 1, I was recruited by Norman Koonce and Syl Damianos in 1995 to become the director of discovery of the American Architectural Foundation in Washington, D.C. The idea had been stimulated by Jonas Salk's proposal to the foundation that someone in the architectural world should be looking at human experiences with architecture from a scientific viewpoint. This led me to many years of study of neuroscience research.

In 2003, the San Diego chapter of the American Institute of Architects (AIA) asked me to help them form the Academy of Neuroscience for Architects (ANFA). Alison Whitelaw was especially important in spearheading this effort.

In 2006, thanks to encouragement from Jim Cramer, CEO of Greenway Communications, his Ostberg Library of Design Management published my book *Architecture and the Brain*.

In the same year, Craig Panner, senior editor, Neuroscience and Neurology, for Oxford University Press, arranged a contract for me to write this book. I am grateful to Craig for his wisdom in seeing the value of a book like this to the neuroscience community, as well as the general public.

He has provided many hours of constructive editing to my manuscript as it has progressed from concept to content. My other two editors are my wife, Lois (who actually could be considered my coauthor), and my daughter, Barbara, who is a professional editor as well as marketing manager for a large corporation.

Sections of the book have been written by Fred (Rusty) Gage from the Salk Institute; Gordon Chong, current president of ANFA and a national leader in architecture; John Zeisel, a colleague and pioneer in the behavioral sciences; Bonnie Albert, a colleague from my years at the State University of New York at Buffalo, and an authority on Chinese architecture; and Melissa Farling, a colleague and research associate in ANFA (who assisted me in writing about professional practice). Tom Albright from the Salk Institute and Terry Phillips from National Institutes of Health have provided consulting services on technical aspects of some chapters. To all of these friends and colleagues, I owe a large debt of gratitude. Anything said correctly in my text is to their credit, and anything incorrect is due to my own limitations.

FOREWORD

From the Perspective of an Architect

GORDON CHONG

We know as architects that the ability to measure human response to environmental stimuli still requires more years of work. We are pleased that neuroscience is beginning to provide us with an understanding of how the brain controls all of our bodily activities and ultimately affects how we think, move, perceive, learn and remember.

Even before architecture was first recognized as a profession over 150 years ago, architects have been referred to as master builders, implying knowledge and leadership in multiple facets of the process of designing a building. In contemporary practice, there are five basic stages of architectural services, which allocate the architect's effort: schematic design (15%), design development (20%), construction documents (40%), bidding (5%), and constructions administration (20%). This framework strongly affects the process of how modern buildings are created. The modern architect focuses on the process of design: problem solving during design development, creating computer drawings during documentation, and delivery methods during construction administration. Approximately 85% of architectural services are oriented toward defining how a building should be built. The most recent primary advances in the profession have been in computer technology. Computer-aided design and building information modeling are major advances that have changed and improved the way architects deliver projects. However, they do not address the questions of what to design nor why we should design a given project.

Now, in the first decade of the 21st century, there is a great opportunity to achieve a better balance and integration between the issues of how architects design and what and why they should design. Profoundly critical issues, such as global warming, energy conservation, and the need for buildings that reduce our carbon footprint, begin to responsibly define how, what, and why we design buildings and other built environments. This is a welcome rebalancing of the role architects play to enhance the quality of our communities and the world.

Additionally, for new construction projects charged with meeting needs of health, rapid advances in scientific discovery are significantly influencing education, housing, and workplace environments. Given that a large majority of an individual's time is spent in built environments, the need for a greater understanding of human response to environmental stimuli inextricably links design to scientific research. The promise is that architects and scientists will collaborate more to determine what we build and why it will enhance the human experience.

Following the 20th-century advances in computer technology, the 21st century is heralded by many as the era of biological discovery.

Not coincidentally, technological advances such as functional magnetic resonance imaging and computational neuroscience have made possible greater understanding of the brain. As in any pioneering effort, there is a high level of excitement. However, neuroscientists are quick to caution that adequate knowledge is not yet available to substantively inform design decisions as evidence based.

Nonetheless, one cannot resist thinking "what if?" while pondering exciting new possibilities. Can we be predictive of human response? Can we use neuroscience to establish a framework for design decision making? In turn, can our environments enhance the quality of life linked to scientific outcomes, such as reduction of stress, reduction of chronic disease linked to stress, enhanced mental acuity, increased cognition, prolonged worker productivity, enhanced spiritual and emotional response, reduced episodes of depression, and even increased longevity? Those of us in the design profession strongly believe that thoughtfully informed and designed environments can contribute to these desirable scientific outcomes. Can we prove it? How will we know what, and even how much, we contribute?

To engage in this new frontier, architects will have the opportunity to expand their creative, intuitive approaches to design with an increased ability to collaborate with the sciences. This could well lead to a redefinition of how knowledge is gained and shared through a culture of research as well as design practice. This will not be easy to accomplish. As with all explorations, there will be missteps, inconclusive evidence, contradictory results, slower than desired progress, and of course, naysayers of change. Fortunately, we will also enjoy incremental advances, new client and marketplace demands, and academic advocacy that will encourage new interdisciplinary models of practice.

Publication of *Brain Landscape* by John P. Eberhard is a major step forward into this new frontier. As in his earlier book, *Architecture of the Brain*, Eberhard never relinquishes his role as an architect, a master builder. Rather, he has become more expansive in his vision and more integrative in his thinking as he masterminds a bridge between the seemingly separate professions of architecture and neuroscience.

Gordon Chong, FAIA, is the past president of the AIA as well as current president (2007) of ANFA

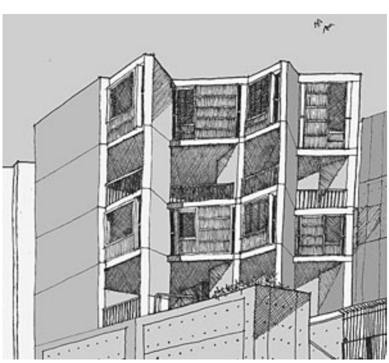
FOREWORD

From the Perspective of a Neuroscientist

FRED H. GAGE

John Eberhard has written a book to challenge neuroscientists to study how architecture affects the brain. His goal, though, is to open a dialogue between architects and neuroscientists, and this book will be at least as useful to the architects as it is to the neuroscientists. So this foreword is meant for the general audience that I expect this book to reach.

Neuroscience is the study of the brain, and neuroscientists believe that the brain is the organ that controls behavior. The brain is composed of areas that control vision, somatic sensory experiences, and motor output, as well as areas that help us navigate through novel environments.



A view of the Salk Institute.

The principal cell of the brain is a neuron, and there are something on the order of 100 billion neurons in the human brain, joined by 100 trillion connections. In addition to these neurons, the brain is made up of many different types of cells that interact with each other to allow us to perceive and think.

In the past, the dominant theory of adult brain function encouraged us to think of the brain as a fixed structure, an organ that in many ways is more like a computer than a biological structure. The brain, like other tissues, is generated based on a blueprint. Much as architects work with blueprints to build structures, our body and brain tissues are built on a blueprint, a genetic blueprint, beginning with DNA. Within every cell is the DNA complement that can make all the functional proteins that are required for that cell and the brain to function. Within every cell of the brain, this genetic material continues to make proteins and functions throughout life.

A major component of this early theory of brain function was that the changes that occur in the brain happen during development. Each of us develops from a single fertilized cell into a fully functional organism. That growth and development are predicated in our DNA blueprint. However, we also know that the development of the brain from early stages to a full-grown organ is dramatically influenced by environment. Thus, although the blueprint is active from birth, in defining the *basic elements* structure, the environment plays a very important role in the final product.

For many years, neuroscientists believed that once the mature postadolescent brain had been formed, it was fixed and immutable. One of our early neuroscience heroes, Ramon y Cajal, described it in this way: "Once development was ended, the fonts of growth and regeneration of axons and dendrites, which are the processes of our neurons, dried up irrevocably. In adult centers, the nerve paths are something fixed and immutable; everything may die, nothing may be regenerated."

This view of the fixed, immutable structure of the brain caused us to think about the brain as a computer. Recently, however, this dogma of the static nature of the brain has been challenged. It is now becoming clearer that the existing neurons are more "plastic" then previously believed. The connections between neurons can be increased or decreased based on experience, and even the total number of neurons can change in certain areas of the brain due to changes in experience and physical interaction with the environment. This change in brain structure in response to environmental changes is greatest during development, but surprisingly and remarkably, this environmentally induced structural plasticity continues throughout life in all mammals.

In summary, the brain controls our behavior, and genes control the blueprint for the design and structure of the brain, but the environment can modulate the function of genes and, ultimately, the structure of our brain. Changes in the environment change the brain and therefore can change our behavior.

What does all this information about neuroscience have to do with architecture? I contend that architectural design can change our brains and behavior. The structures in the environment—the houses we live in, the areas we play in, the buildings we work in—affect our brains and our brains affects our behavior. By designing the structures we live in, architects are affecting our brains. The different spaces in which we live and work are changing our brain structures and our behaviors, and this has been going on for a long time. John's book will open a dialogue between architects and neuroscientists to begin to determine how these different disciplines can work together to understand and improve the impact of space on the brain and our lives. This dialogue is a needed first step, and it will require participation of both neuroscientists and the architects; importantly, these two groups need a translator or they need to learn a new language to have this dialogue. This book should provide a foundation to assist both groups to speak together.

Fred H. Gage is professor and Vi and John Adler Chair for Research on Age-Related Neurodegenerative Diseases at the Laboratory of Genetics of the Salk Institute.

Preface

C. P. Snow in his well-known book *Two Cultures* says, "Constantly I felt that I was moving among two groups—comparable in intelligence, identical in race, not grossly different in social origin, earning about the same income, who had almost ceased to communicate at all. Who in this intellectual, moral, and psychological climate had practically nothing in common." He was speaking in broad terms about scientists and artists. In this book, I want to speak about a way of providing common cause between two specific and important groups: (1) the architectural community that creates designs for the buildings in which we spend more than 90% of our lives and (2) the neuroscience community that has focused on understanding how the brain and the mind have evolved to provide us with an ability to experience the world around us.

Both groups at their best provide us with beauty: one with a beauty expressed in physical terms that we perceive with our senses and use to shelter the activities of our lives; the other with the inner beauty of the mind and the beginnings of understanding how the mind comprehends and why the body experiences pain and pleasure. We need both. Each stands on the brink of understanding the other. The hope is that this book can stimulate intellectual links that will enrich us all.

As Professor Lord Porter said in his Second Athenaeum Lecture in London in 1998, "The scientist and the artist have much in common; both strive for originality through imagination; each tries to make a new statement and each hopes that the statement will be in some way acceptable to others. The fundamental difference between them is the type of statement that is made."

This difference is described by Nobel Laureate Herbert Simon in his book *The Sciences of the Artificial* (1996), "Historically and traditionally, it has been the task of the science disciplines to teach about natural things: how they are and how they work. It has been the task of engineering schools [read architecture] to teach about artificial things: how to make artifacts that have desired properties and how to design them."

In organizing possible intellectual links, I have chosen to use the term *framework* proposed by Francis Crick and Christof Koch (1997). A framework is not a detailed hypothesis or set of hypotheses; rather, it is a suggested point of view for an attack on a scientific problem, often suggesting testable hypotheses. A good framework, they suggest, is one that sounds reasonably plausible relative to available scientific data and turns out to be largely correct. (It is unlikely to be correct in all the details.) The framework often contains unstated (and unrecognized) assumptions, but this is unavoidable.

For general readers, this book provides an insight into ideas not previously contemplated. For the architectural community, I show exciting new possibilities for expanding our knowledge base by increasing the range of evidence-based design criteria. For the neuroscience community, I challenge scientists to begin exploring these new research horizons as a way of expanding future opportunities for newly minted doctorates and postdoctoral students.

Contents

BRAIN LANDSCAPE

Introduction

The goal of this book is to invite the neuroscience community to devote a portion of their research agenda to architectural hypotheses. These hypotheses are framed by questions of why the mind—with its organ, the brain—produces specific cognitive experiences for humans in the spaces and places designed for their use. Spaces include open areas such as parks, playgrounds, ceremonial plazas, and other landscape designs. Places include urban complexes, buildings, and especially interiors designed to serve some functional purpose.

As you walk into the Abbey Church in Bath, England (see Fig. I–1), your brain goes into overdrive. Not only does the shape and size of the space and the sparkling colors of the windows of stained glass behind the altar visually stimulate you, but all of your senses are formulating a sense of awe. The sounds of your footsteps on the hard pavement, the reverberation of music as an organ plays, the hushed voices of other visitors are being processed by your auditory cortex. We sense the rough texture of the stone before we actually touch it. We smell the musty odors of an old building and perhaps the remnants of recently burned incense. We assemble these sensory experiences in our brains and then filter them through our memories.

Figure I–1. Bath Abbey.

It is obvious that our brains and minds are interactive with the architectural settings in which we live, learn, worship, and work. The dramatic response of our sensory systems when visiting the Abbey Church are present in less dramatic form in 90 percent of our waking hours—the amount of time most of us spend inside of buildings.

However, we know very little about the ways and whys of our brain/mind interaction with architectural settings. The rapid development of neuroscience shows promise to begin assembling a body of knowledge around architecture and the mind. This book is intended to present the case for doing so and to suggest methods and models for going about creating such a new knowledge base.

THE HISTORICAL BASE FOR ARCHITECTURE IN PHYSICS

Little advances in physics were made during the Middle Ages. Although great medieval universities were founded in the 13th to the 15th centuries, these universities were places for scholarship in philosophy, literature, or the arts. There was little or no science based on experiments, even in the medical schools. There was a brief flowering of science in the 17th century, primarily based on the work of Sir Isaac Newton. However, from the time of Newton until the 19th century, little happened to advance physics.

In the 19th century, discoveries in electricity and thermodynamics were firmly established by experiments, and principles of these discoveries were incorporated in mathematical formulas. This enabled the engineering community of the 20th century to develop special areas of competence in electrical engineering, mechanical engineering, and environmental engineering.

It seems likely that just as 19th-century physics underlay the development of 20th-century engineering applications, so neuroscience (combined with genetics) will become the basis for new applied science tools in the 21st century. In the next few decades, it is likely that the fundamental aspects of neuroscience will become the domain of a new generation of applied social and behavioral scientists, engineers, and architects.

NEUROSCIENCE AND ARCHITECTURE: TWO NEW PARADIGMS

The concept of paradigms, first introduced by Thomas Kuhn (1970), is described here for both the architectural and neuroscience communities. An indication of the difficulty of introducing new knowledge into such communities is discussed. An example of a successful change in the design of neonatal care units based on knowledge from neuroscience is presented. This section concludes with comments on the likely path of paradigm shifts in the design professions.

Kuhn introduced the concept of paradigms. He says:

> Close historical investigation of a given specialty at a given time discloses a set of recurrent and quasi-standard illustrations of various theories in their conceptual, observational, and instrumental applications. These are the community's paradigms, revealed in its textbooks, lectures, and laboratory exercises. By studying them and by practicing with them, the members of the corresponding community learn their trade. (Kuhn, 1970)

The architectural and neuroscience communities are quite different communities whose paradigms are relatively clear. In the architectural community, the studio exercises of students, concentrated on designing buildings, become the central focus of their paradigm. With the exception of books on the history of architecture, textbooks in architectural schools are almost exclusively related to an engineering discipline whose basic tenets grew out of 19th-century physics. To become licensed to practice, a novice architect is tested for knowledge of structural design, lighting design, HVAC (heating, ventilating, and air conditioning), acoustics, and so forth. The core paradigm, however, is premised on creating *design solutions for buildings* that meet building codes and are constructible by skilled craftspeople. The profession awards prizes to designs (usually only shown to the judges in photographs) based on the changing value systems of one's peers. To be published in this community is to have photographs of buildings printed in professional journals accompanied by descriptions prepared by writers whose material is based on personal views, is lightly edited, but is not subject to the rigors of peer review. The architectural press, as well as the accolades of architectural fan clubs, change their allegiances every few years and encourage a striving for original design solutions.

The neuroscience community has sufficiently defined its paradigm through the classic medium of textbooks, lectures, and laboratory exercises required of students. The conceptual, observational, and instrumental applications of neuroscientists are organized around the brain, its genetic origins, developmental progress, network structure, chemical and biological activities, and so on. In rare excursions, these lab exercises will touch on aspects of the human experience, but generally the puzzles they address are ones that, when solved, advance our understanding of how to deal with disease.

The community of cognitive neuroscientists includes studies of how the behavior of animals (including humans) is caused by, modified, or prohibited by brain activity. To be published in these communities is to prepare a detailed, rigorous description of an experiment, how it was conducted, and what results were achieved. One's peers who are versed in the special language of the experiments review such publications. The articles are usually accompanied by detailed illustrations of the observations made with technologically sophisticated instruments.

Shared Paradigms and Developing Crisis

Kuhn suggests that communities who share a paradigm also share the belief that the kinds of problems they are prepared to address have solutions for which their skills are needed. They reinforce this belief by accepting only those problems into their community that they can solve. Problems that lie outside of their field of knowledge are considered to belong to another discipline or need to be rejected because they are too difficult. The result can be that the community is insolated from those important problems that are not reducible to their puzzle form and hence cannot be stated in conceptual terms they understand.

Kuhn proposes that a shift away from an existing paradigm occurs when a crisis develops. The crisis might be created when a discovery becomes known (e.g., x-rays) that no one had known about earlier. Or it might be produced by an anomaly—something about a puzzle being studied does not produce the results expected (e.g., Copernicus could not explain the motion of planets by using the existing paradigm of the time, namely, that the Earth was the stationary center of the universe). The difficulty with facing a crisis is that the decision to reject or modify an existing paradigm will not be made unless there is a new one to take its place. Those who hold the existing paradigm will take their time and be very cautious about comparing the new one with the old one before making the change. Historically, new paradigms have been adopted by another generation, leaving the practitioners of the old paradigm to retain their beliefs and methods for the balance of their careers.

Kuhn goes on to say:

> When a new paradigm begins to emerge, members of the existing community will be reluctant to embrace it unless convinced that two all-important conditions can be met. First, the new candidate must seem to resolve some

> outstanding and generally recognized problem that can be met in no other way. Second, the new paradigm must preserve a relatively large part of the concrete problem-solving ability that has accrued to science through its predecessors. (Kuhn, 1970)

The crisis in the architectural community is of two kinds. The first is a general dislike the public shares of the advanced design concepts of the architectural stars (those who are published as taste makers). For example, a letter to the editor of the *New York Times* (after their issue on architecture) says, "the whole architecture profession is ego gone wild. Here in Denver [where the author of the letter lives], Daniel Libeskind has given us a new art museum that looks, God forbid, like a collapsed skyscraper, jagged and inverted."

John Silber in his book *Architecture of the Absurd* (2007) argues that form meant to please one's self (or one's theoretician cronies) is architecturally irresponsible. He is displeased with "the heights of pretension and bogus philosophic and historical exposition."

A contributor to ArchVoices (a student Web page) wrote:

> One stated example of architectural leadership in the public realm is service on an architectural review board—with the goal of making it easier for architects to get modernist designs built in their communities. When our cities and countries are facing rapid ecological degradation and increasing inability to provide well-designed buildings and neighborhoods that are equally accessible to all people, is stylistic guidance truly the kind of leadership we need from design professionals?

The crisis in the neuroscience community is created by the existence of the enormous body of research emerging from the neuroscience community that is largely unknown to the architectural community—much like the existence of x-rays was unknown to the scientific community before Röntgen's discovery in 1895. There are two very different reasons the architectural and neuroscience communities have failed to bridge their intellectual gap.

The architectural community, although intellectually curious about new ideas such as neuroscience, is not prepared to give up the existing paradigm that serves them well in solving the kinds of problems they see as relevant. They do not "recognize problems that can be met in no other way." The architectural community also has their existing paradigm reinforced by clients (the source of income), code authorities (the source of law enforcement for correctly solved puzzles), and by the academic community (the source of new employees who can move comfortably into offices practicing the existing paradigm).

The neuroscience community, though intrigued by the possibility of interdisciplinary studies with architects, sees no possibility that a new paradigm would preserve a large part of their current problem-solving ability. Their field is so new that discoveries are being made every day, making it unnecessary for them to resort to a new way of working. Even novices entering the field (through graduate programs in universities) dare not entertain visions of a new paradigm for lack of assurance that careers paths will be open to them.

The Case of Dr. Stanley Graven and His Colleagues

Here we include an example of a new paradigm approach. The sensory systems of the human fetus develop in sequence. Four of them (called the somatosensory modalities), touch, pain, position, and temperature sensitivity, are the first to appear in the fetal life. These are followed very shortly by vestibular modalities—the sensory systems of the middle ear that detect motion. The third set of systems to develop and begin to function are the chemosensory systems of smell and taste. These are all well established with connections to the midbrain and basal ganglion in the second trimester of fetal life. The sensory auditory modalities, including responses to sound and vibration, appear early in the third trimester. After the critical stage for auditory development has past, it is followed by visual development. It is interesting to observe that at this point in development, the human fetus has no need for light or visual stimuli to have perfectly normal visual development.

When an infant is born prematurely, the sequencing of sensory development becomes an issue because stimuli and use of systems that are out of sequence can create developmental problems, for instance, visual development can begin before the auditory modalities are in place.

When stimuli are out of sequence or when their intensity is inappropriate for the stage of development, interference in the normal sensory development will be produced. The most common examples of sensory interference are the early introduction of visual stimuli before auditory patterns are learned and in place. Examples in animals have shown that the introduction of visual stimuli before auditory patterns are in place will interfere with both frequency discrimination and pattern recognition.

Architectural designs for neonatal care units are based on design criteria from doctors, nurses, and administrators. Architectural training provides the ability to solve the problem of designing a neonatal care unit by these criteria. It implicitly assumes that a concern with the development of the brain is the responsibility of another discipline—thus insulating the architect from a concern with fetal development. The architectural community has no conceptual or institutional tool provided by its paradigm of practice to include concerns based on an understanding of the brain.

Dr. Stanley Graven at the University of Florida several years ago began to address the problem of appropriate environments for neonatal care units. It was clear to him, based on his understanding of neuroscience, that noisy environments with announcements intended for doctors and nurses and loud air conditioning systems were placing demands on the auditory systems of premature infants before they were fully developed. Even worse, the lighting systems designed to ease the work of the medical staff, and sometimes daylight streaming through windows, was severely taxing the still-developing visual systems of premature infants. It was not that these infants would be deaf and blind; rather, they would lose acuity in these systems. Thus, a child born into these circumstances would not be able to develop perfect pitch if he or she became a musician. Children exposed prematurely to bright lights were likely to develop astigmatism and later in life would be candidates for macular degeneration.

By emphasizing the requirements for an environment responsive to premature infants and providing them with incubators tuned to their development stage, Graven managed to introduce dramatic changes in the design of neonatal care units.

A PROPOSAL FOR THE ARCHITECTURAL COMMUNITY

To cross the threshold from where we are to where we ought to be (or to evolve a new paradigm for architecture), major conceptual shifts must take place in how we understand human requirements. This will be a shift away from an exclusive emphasis on solving the puzzle of designing a building—its structural, mechanical, lighting, and spatial components—to studying how to accommodate human activities correlated with responses of the brain and the mind. In the future, architects will need an understanding of how to integrate knowledge of neural networks and their organization into the practice of architecture. This will include how attention and conscious awareness regulate and reconfigure the actions of the neurons in those networks affected by the built environment.

How Are Switches to New Paradigms Made?

Again, Kuhn provides the key concept here. When communities practicing in two different worlds see things from the vantage point of their long-established paradigms, they are not aware of viewing the same or related puzzles. Even when they are looking at the same issues, they cannot hope to communicate fully until one group or the other experiences a paradigm shift. It is also not likely that a transition between different paradigms can be made a step at a time, forced by the logic of common interests. What is required is a switch that occurs all at once, or not at all.

For example, when Copernicus announced in the 15th century that the Earth must be moving and not a stationary planet at the center of the universe, his detractors were not wrong—they had a different definition of what was meant by *Earth.* Within their paradigm, things worked well enough to suit them. They could not accommodate to the new concept of Copernicus by gradual accommodation, it was a whole new way of regarding the problems of physics and astronomy, one that necessarily changed the meaning of both *Earth* and *motion*.

The transition from one paradigm to a new one is a conversion experience that cannot be forced. Lifelong resistance, particularly by those whose productive careers have them committed to an existing paradigm, is not a violation of some standard of practice. Within their worldview, the existing paradigm enables them to solve all of the puzzles they consider to be important. A generation is often required to effect the change. Conversions to the new paradigm will occur a few at a time until, after the last holdouts have died, the whole professional community will again be practicing under a single, but now different paradigm.

This book is intended to help both the architectural and neuroscience communities think about the development of a knowledge base that will encourage a major paradigm transition in the architectural community.

A PERSONAL HISTORY

Many of the experiences in my life can explain the need I felt to produce this book, so I thought it would be appropriate to provide readers with a personal history. As you will see, it has been a complicated life, filled with many changing personal ideas of what is important in architecture, what needed to change, and how knowledge could be linked to professional practice. I hope you find it interesting to read as well as clarifying how I have arrived at this point in my life with a conviction that neuroscience research will likely produce a major shift in the architectural paradigm of education and practice.

How New Knowledge Changed My Architectural Ideas

When I was 5 years old, I met my first real architect. His name was Ralph Adams Cram, perhaps the most famous architect of Gothic structures during the first few decades of the 20th century. My father had managed to convince Cram to design a small church for our congregation in Louisville, Kentucky, even though Cram lived in Boston and had designed such significant projects as the West Point Academy and the Cathedral of St. John the Divine in New York City. Sitting in our living room and talking with Cram didn't seem like anything special to a 5-year old, but it influenced my life in many ways. One of the lasting impressions he made was to tell me a story about a personal experience of his. He said, "John Paul, what my family called me, if you think you want to be an architect remember you have to be prepared to have frustrating experiences as well as the exhilaration of designing. Last Sunday morning, while I was sleeping, my phone rang at five in the morning. The minister for a church in Nebraska that I had just designed was calling with what he considered an urgent question about where the toilet paper was kept. His new church was to be dedicated later that morning and he was checking to see if all was in order. He could not find the toilet paper. Consequently, he called me because, as his architect, he assumed I was responsible for every detail." That anecdote so impressed itself on my young mind that I never again saw architects as solely great form givers.

Entering the World of Architecture

During the years I was in high school, my father was tutoring me in Latin and Greek in preparation for entering the ministry. In my last year of high school (1945), just before I was scheduled to enter a preparatory school for Lutheran ministers, we had a visit from my maternal grandmother Schwolert. Diga, as I called her, asked me one day during dinner with our family why I was planning to be a minister. Her opinion was that anyone could become a minister, but if you were artistically gifted, God had other plans for you. I had shown some artistic ability, so Diga thought I should become an architect.

In November 1945, after graduation from high school, I was "drafted" into the U.S. Marines. After boot camp, I became the education officer for Parris Island (even though I was only a private). My responsibility was to help marines who were being discharged decide on alternative educational programs. This role gave me ample time to think about my own options. I ended up changing my mind about the ministry and agreeing with Diga. Because my father was also a great fan of architecture, he did not object to my decision. In 1947, after two years in the marines, I was selected by the navy to become a midshipman in their new Holloway Program, which included the opportunity to attend any university with a Naval Science Program.

I arrived at the Architecture School of the University of Illinois in 1948, just as the world of architectural education was in the midst of a revolution—what I would call today a shift to a new paradigm. I had no inkling of this revolution. I entered with the full intention of becoming a Gothic church architect like my hero, Ralph Adams Cram. I had never heard of Walter Gropius, who brought with him to Harvard the Bauhaus mandate to reject all historical styles and pursue modernism. Not until my junior year as an architecture student was my mind changed by these new ideas from Gropius sweeping through architectural education like a forest fire destroying all classical building design studies. Between my freshman and sophomore years, the Beaux Arts model of architectural education—one based on the rigorous study of classical design (with which I had begun my studies)—was completely eliminated. It was replaced with not fully formed but exciting notions of modern design to be generated by one's personal creativity, artistic inclinations, and the architectural design faculty's notions of good design. There was very little rigor left in such an educational paradigm. The general public, including clients, were left to accept such new design ideas or be considered Luddites holding back the advance of the new age. My ideas about architecture were changed, but there was little in the way of a knowledge base to support these new ideas.

Before I was 30, I served as the architect of record for more than 100 churches and parish halls (multipurpose first units for a new congregation). The primary reason for this remarkable number of clients was the result of a new venture that several of my classmates from Illinois and I began in 1952. When we graduated, we reasoned that our education and summer working experiences had given us a general understanding of how to prepare design and working drawings for a building (see Fig. I–2), but

Figure I–2. Design for A-frame chapel (design by John Eberhard).

we lacked any experience in actually constructing one. As a result, we formed a company we called Creative Buildings (in Urbana, Illinois) and began designing and building houses—primarily for university faculty members who were interested in contemporary design. Through a series of ventures, we moved into the business of panelized (prefabricating) buildings, including church buildings. By 1958, we had a manufacturing plant that employed 75 people and a large backlog of church clients. We had so many clients because a church building committee knew they could trust us to design, fabricate, and assemble a finished structure within a reasonable budget, something architects in traditional practice seldom did because they lacked sufficient experience to estimate construction costs. The American Institute of Architects did not condone this form of practice at the time, although it is accepted today.

Boston

In 1958, at the peak of Creative Buildings' venture into manufactured buildings, I began to have serious concerns about how poorly my architectural education had prepared me to deal with the business of architecture and how little value classes in learning to design original buildings one at a time had been for the design issues of prefabrication. The more I thought about these problems, the more I became convinced that I needed to go back to school and refresh my mind with new perspectives from fields other than architecture. I decided to take a year-long leave of absence from Creative Buildings and move my small family to the Boston area to explore graduate education. I first went to the architecture school at the

Massachusetts Institute of Technology (MIT), believing it to be best setting for expanding my mind. When I told Dean Belluschi I was interested in thinking about how one would approach design in an industrialized building industry, he was incredulous. Why would anyone want to study that problem, he asked, when architects were still not very good at designing buildings one at a time? Fortunately for me, one of the faculty members—Burnham Kelly, an attorney by profession who taught law courses for architectural students—told me I was in the right institution but the wrong school. He sent me to the School of Industrial Management at MIT to talk with his friend, Howard Johnson. Howard and I immediately bonded by some magical process that resulted in my becoming a Sloan fellow in his school (he became the dean of the school while I was studying there, and he later became the president of MIT).

While I was an architecture student at Illinois, I had discounted the notion that the so-called Ivy League schools in the East were superior educational settings. I was astounded to find the variety and depth of stimulating courses in the Sloan School—the new name given to the School of Industrial Management while I was there. My brain soaked up every educational experience, especially the great books course taught by Elting Morrison. Having had no exposure to great literature while I was at Illinois, I became truly educated for the first time. This included ideas acquired from reading such classics as the *Education of Henry Adams* and Alexis de Tocqueville's *Democracy in America*. Never in my wildest imagination while I was at Illinois would it have occurred to me to wonder how and why the United States became the longest-lived democracy in the world. My mind was being highly developed by such ideas.

Sheraton Hotels and MIT

When I completed my Sloan year at MIT in 1959, many aspects of my mental development had changed in a new and positive direction. I decided not to return to Creative Buildings in Urbana but to develop two new ventures in Boston. One, thanks to my friend Howard Johnson, who was now dean of the Sloan School, was to become a visiting faculty member at his school. I could not believe it when he first suggested I teach the great books course for Sloan fellows, but with the encouragement of Elting Morrison, who had mentored my thesis as well as taught the great books course, I agreed to try. It turned out I was good at this sort of intellectual challenge, and it was rewarding for me (and I hope for the Sloan fellows in my classes).

The second venture was to become the director of research for the Sheraton Hotel Corporation, based in Boston. During the preparation of my thesis at the Sloan School, I had determined that the newly emerging technology of electronic computation was going to have a major impact on the building industry—including architects. When Thomas Boylston Adams (a direct descendant of John and John Quincy Adams), a vice president of Sheraton, proposed that I work with the company to advance their use of new technologies, I jumped at the chance. He and others at Sheraton assumed that because I was a graduate of MIT I must know about computers. Because this was a technology I knew little about but wanted to learn as rapidly as possible, I dived into the subject with all my energy. One of the major outcomes of the 3 years I spent at Sheraton was the development (with the Statler Hotel School at Cornell University) of a computer-based system for checking in and out of hotels—now a common practice. As research director, I also developed a number of lesser inventions, but the largest result was internal to my own mind. I now knew how computers could become a major technological infrastructure for the design and construction of buildings. Integrating the thousands of bits of information needed in this process seemed as logical as what we had done with the data system of hotels. It has actually taken more than 40 years for the building industry to develop a serious application of this concept. Today it is called BIM (building information system) and is in the development stage across the construction industry—including the architectural profession.

One day Tom Adams, who was treasurer of the Academy of Arts and Sciences (AAS) in Boston (founded in 1779 by John Adams), asked me if I would undertake an architectural project on behalf of the academy. The AAS was housed on the first two floors of an elegant mansion called the Brandegee Estate. They had a client who wished to lease the third floor of the house for a top-secret project headed by Francis Schmidt of MIT. The Brandegee family was willing to allow this use if an architect would make sure that it was designed in keeping with the high quality of the rest of the mansion and done in a way that would allow the spaces to be restored to their former elegance once the project was over. I found out later that the project was devoted to a study of human memory, motivated by a concern that it might be possible for the Russians to use their Cybernetics Research Unit to involuntarily extract memories from captured spies. Schmidt's research team was called the Neuroscience Institute. They eventually moved their operations to Rockefeller University in New York City. Later, Gerald Edelman, who had become president of the institute, moved it to La Jolla, California, where it now flourishes. Little did I know at the time that I was a player in helping advance neuroscience.

Washington

One day in early 1963, my MIT officemate, Richard Morse, asked me if I had ever thought of going to work in Washington. I answered that I had often spoken to my class of Sloan fellows about my conviction that each of us owed a responsibility to perform a public service at some point in our careers. Morse then told me that Jerry Weisner, who had taken a leave of absence from MIT to become President Kennedy's science advisor, and Herbert Hollomon, who had headed research for GE and was now the assistant secretary of Commerce for Science and Technology, were starting a new federal program called Civilian Industrial Technology (CIT). CIT was intended to stimulate "backward" industries (which they defined as industries with little or no research) to invest in research and development. One of those industries was going to be the building industry, and they wanted me to come to Washington to help them. President Kennedy was a hero to me, so I couldn't resist the chance to work in his administration—even if it meant my family would suffer from the reduced income available for civil servants. When I met Herb Hollomon, it was clear we were going to be good teammates, even when we lost Kennedy and inherited Lyndon Johnson.

During my first week working in Hollomon's office, he introduced me to another one of his young recruits—Don Schön. Don was 4 years younger than I (I was only 36), a graduate from Harvard with a doctorate in philosophy. He had worked for the previous 5 years with Arthur D. Little (a major consulting firm based in Cambridge, Massachusetts). Don was to become the director of the State Technical Services program. After Johnson became president, Hollomon reorganized the science and technology side of the Department of Commerce, which reported to him. This reorganization included:

- the Patent Office;
- the Weather Bureau and Coast and Geodetic Service and other units of the Commerce Department were merged to form NOAA; and
- the National Bureau of Standards along with the State Technical Services program, which were merged and reorganized into three institutes—on the model of the National Institutes of Health.

To our surprise, Don was made the director of the Institute for Applied Technology (IAT), and I was made his deputy. IAT included 800 people who worked in divisions as diverse as Building and Fire Research, Computer Technology (which had developed SEAC, the first fully functional stored-program computer in 1950), the Technical Analysis Division (using advanced computational methods to model national economic issues such as whether the United States should invest in the development of the Concorde), and the Clearinghouse for Federal Scientific and Technological Information (which published all nonclassified reports by federal agencies).

After 2 years of working together, Don decided to leave Washington and move back to the Boston area to start a consulting firm he called OSTI (Organization for Social and Technological Innovation). Hollomon made me the director of IAT, and in a ceremony in the Rose Garden (see Fig. I–3), Lyndon Johnson promoted me to a GS-18—the highest rank for a civil servant. This made me, at the age of 40, the equivalent of a two-star general and the highest-ranking architect in the government. I was not put into this position because I was an architect—it was because I had shown myself to be a competent manager of complex research organizations.

Figure I–3. John Eberhard in the Rose Garden with President Lyndon B. Johnson.

Buffalo

Having learned more than I ever thought I needed to know about how the federal government worked, I decided it was time to leave when Richard Nixon was elected president in 1968. IAT had shown me the value of linking research on advanced concepts to real-world demonstrations; the issue was what to do next to continue my personal development. An opportunity I couldn't resist presented itself when Martin Meyerson, president of the State University of New York at Buffalo (SUNY-Buffalo), invited me to start a new school of architecture at his university. He arranged for my new school to report to three provosts: Engineering, Fine Arts, and Social Science. I decided to have this school focus on an interdisciplinary graduate program, which would have as its purpose educating a new generation of architects who could organize and manage research projects—as contrasted to designing buildings. We formed a nonprofit organization outside the university called BOSTI—the Buffalo OSTI related to my friend Don Schön's research organization in Boston. During the next 5 years, our team of graduate students participated in more than 50 projects—all of which were funded through BOSTI by outside organizations. We used the money we earned to support our graduate students and supplement faculty salaries. While the Architectural Accrediting Board did not see fit to accredit our graduate program (they had no basis for evaluating a nondesign curriculum), our graduates nonetheless all went on to interesting careers, most in the building industry.

Washington Again

After the Vietnam War demonstrations on our campus, the New York State legislature began to drastically reduce the budget for SUNY-Buffalo. One result of these cuts was that Meyerson resigned as president and moved to greener pastures at the University of Pennsylvania. Not long after, I was given an opportunity to return to Washington, where I actually preferred to live and work. The opportunity was the result of a grant given to the American Institute of Architects (AIA) by the Ford Foundation to study energy conservation in buildings. In 1973, the nation was entering an energy crisis, and the Ford Foundation decided to publish a report on the nature of this crisis and what could be done about it. Bill Slayton, executive vice president of the AIA, created a nonprofit corporation he called the AIA Research Corporation (AIARC) to receive the $50,000 grant. He needed someone who knew something about managing research to organize this new corporation and find other projects to support its independent status. When he found out I was interested in returning to Washington, he recruited me for the post.

Over the next 5 years, AIARC undertook a large number of projects ranging from energy conservation (including solar energy and wind energy) to new design concepts for libraries. By 1978, there were more than 60 people on our staff, and we had a budget of almost $10 million. This was by far the largest research organization in the architectural world, but the elected officers of the AIA lacked the imagination to see what its research agenda had to do with architecture (as they defined it). In an unfortunate series of events, I resigned as president of the AIARC and it eventually dissolved. I learned an important lesson—it is not easy, in fact almost impossible, to introduce new knowledge into a large institutional setting that is seen by its leaders as already well suited to its goals.

A New Opportunity

It was not long before Dr. Edward Epremian of the National Academy of Sciences (NAS) approached me to talk about becoming the executive director of the Building Research Advisory Board (BRAB) of the National Research Council (NRC)—the NRC was the operational arm of the NAS, providing advice to government agencies. BRAB had been established ostensibly to provide advice to the 16 agencies that designed and built facilities for government purposes. In fact, however, it was a behind-the-scenes lobbying organization for building industry groups as diverse as the Masonry Institute and the National Association of Home Builders. I indicated I would take the job if we could change the name (to signal the end of the old regime) and create a new board of directors. After I provided Dr. Frank Press (president of NAS) with background information on the actual activities of BRAB, he agreed to change the name to the Advisory Board on the Built Environment (ABBE) and form a new board under the leadership of Phillip Hammer—an eminent building industry economist.

For the next 5 years, I served as the director of ABBE undertaking various advisory projects for government agencies. One of our major projects was for the U.S. State Department after the tragic 1983 bombing of the U.S. embassy in Beirut. Immediately after the bombing, Congress appropriated $1 million that was specified for the State Department to use in obtaining a design for an "embassy of the future" that would be resistant to terrorist attacks. The assistant secretary of State called me to his office and asked if I had any advice on how to obtain such a design. When I indicated it would not be wise to ask architects to design such a project without first having clear design criteria to evaluate their work, he agreed and gave us the funds to undertake the development of these criteria. We assembled a team of nine specialists on a range of subjects from the psychology of terrorism to blast-resistant structural design. The team report was immediately classified secret and still serves as a resource for the Office of Foreign Buildings in the State Department. This project was an example of how reframing a research question can produce more satisfactory results.

Carnegie Mellon University (CMU)

In 1989, shortly after I thought I had retired, I was recruited as the head of the Department of Architecture at CMU. The doctoral program within the architecture department there concentrated on either computer-aided design or building systems—both areas of my past research interest. These two developing knowledge bases for the architectural profession were in their early stages. Doctoral students at CMU, with their faculty advisors, were helping advance the state of the art in both areas. An organizational unit called the Advanced Building Systems Integration Consortium (ABSIC) had been created as a vehicle for supporting research in building systems design. The PhD program in computer-aided design had also created an institutional unit for organizing their research and gathering funds for student support. Both institutional settings worked well for organizing interdisciplinary research and could serve as models for future neuroscience and architecture degree programs.

The American Architectural Foundation

In 1995, after I had once again "retired," I was approached by Syl Damianos, chairman of the board, and Norman Koonce, president, of the American Architectural Foundation (AAF; a not-for-profit affiliate of the AIA) who asked if I would take on a new assignment. Jonas Salk, who had founded the Salk Institute, had told them of his personal experiences in trying to find a cure for polio in the 1950s. He said he had reached a point where he was "stuck" intellectually and needed to take a brief sabbatical. He did so by retreating for several weeks to the Abbey at Assisi, Italy (see Fig. I–4). He said the architectural setting of the abbey was so stimulating to his imagination that he created the concept for what became the Salk vaccine as well as how to produce it. Dr. Salk proposed that the AAF

Figure I–4. Abbey at Assisi.

mount a research effort to better understand how architectural settings influence human experience. Just as he had found the architecture of the Abbey at Assisi stimulating, so he believed the human mind (and its instrument, the brain) reacted continuously to architectural settings. Syl and Norman asked me how I would like to return to Washington and work on this challenge. I said I was interested in returning to Washington, but indicated I had no idea about how to approach this issue. They proposed that I be given the title "director of Discovery" with the assignment of finding the appropriate research.

My Discovery of Neuroscience

I embarked on my discovery period by reading and talking with a wide range of people. In this early stage, I collected anecdotes of people who had experienced an architectural setting that for them was memorable. A number of these anecdotes are used in chapters in this book.

In 1996, Norman and I went to visit Dr. Fred (Rusty) Gage at the Salk Institute because Norman had heard a radio broadcast in which Rusty described his experiments with mice who produced new neurons in their brains when they were placed in stimulating environments. We visited his laboratory and told him of our interest in learning if his research would enable the AIA to say architectural designs (which provided simulating environments for people) would enable humans to produce new neurons. Rusty was quick to make it clear that his research had been done with mice and could not be assumed to prove anything about humans. But he encouraged further exploration of the relationship of neuroscience and architecture.

While we were in La Jolla, we accepted Dr. Gerald Edelman's invitation to visit his Neuroscience Institute. He thought we would admire the architectural design of the institute. He was not willing to comment on ways neuroscience might assist architects in understanding how the brain and mind experienced architectural settings, but he gave us a copy of his book *Bright Air, Brilliant Fire: On the Matter of the Mind.* My reading of his book, which I found tough going because I did not yet know the language of neuroscience, was so stimulating that I immediately decided my journey of discovery had borne fruit. Here was a body of knowledge of vast importance, little known by those of us who were architects, which seemed likely to change our understanding of how classroom design affects the cognitive processes of children, how the design of hospital rooms could impact the recovery rate of patients, how working environments likely impact the productivity of white-collar workers, how sacred spaces instill a sense of awe in those who worship there, and much more. It was clear to me then, and even clearer now, that I needed to spend the rest of my life learning as much as possible about this rapidly expanding field of knowledge. For example, I wanted to know the following:

- Whether the genetic structure of our brains provides humans with an innate sense of "good" proportion.
- In what way does the development process in the brains of young children impact their cognitive abilities between 6 and 12 years of age (the first to sixth grade)?
- Is the function of mirror neurons in the brains of adults who are witnessing a dance performance affected by the distance between their seat and the stage?
- When humans move from one cultural context to another are dispositions (as per Damasio) recorded by previous architectural experiences used when experiencing similar buildings in the new context?

- How do our emotional memories of past experiences with an architectural setting affect the perception of current experiences?

I was fortunate in 2005 to become a member of the Society for Neuroscience. I am the only architecturally educated member of the more than 35,000 members of the society.

It seems to me highly likely that neuroscience has much to contribute to the practice of architecture. This book introduces and brings together my own understanding of neuroscience based on the research of others and attempts to use this understanding to challenge the field to explore architecture as a new frontier.

CHAPTER ONE

Three Approaches to Consciousness

The human brain is what makes humans capable of painting the Sistine Chapel, designing airplanes and transistors, skating, reading, and playing Chopin. It is a truly astonishing and magnificent kind of "wonder-tissue," as the philosopher Dennett jokingly put it. Whatever self-esteem justly derives from our accomplishments does so because of the brain, not in spite of it.

—CHURCHLAND (2002)

The goal of science is not to open the door to everlasting wisdom, but to set a limit on everlasting error.

—BERTOLT BRECHT, *GALILEO*

Architects have designed many of the places where we live, work, study, and worship. Some places have been converted from previous uses, for example, a warehouse converted into loft apartments. Others are only temporary places, such as a place used for a wedding. There are usually design criteria for places intended for a functional purpose—schoolrooms, patient bedrooms, and offices. Owners, elected officials, government agencies, and others formulate these design criteria and designers follow them—making their stylistic choices. Social and behavioral research over the past few decades has provided an understanding of how people respond to design attributes. Although this research provides an understanding of how humans respond, it does not explain why we have such responses. Neuroscience research could provide a knowledge base with clear evidence of why the occupants of spaces and places are affected by the design of these spaces and places. For example, it is only after we know how a child's brain responds to daylight that we can understand why they might have better grades and attendance in a well-lit school.

THE STATUS OF ARCHITECTURAL PRACTICE

Architecture is currently in an unstable state. The following are my observations of why this has happened.

In the 1930s, the Bauhaus in Germany began a rebellion that swept across the world of architecture like a forest fire. This rebellion has been incorporated in the paradigm now underlying architectural education and practice. Modernism (to use one of the names given this movement) sought to serve the needs of society's common people, as opposed to the princes of the church, the state, and big business. In doing so, the movement was against historicism, ornament, and the overblown forms of the classical period. However, critics like Nathan Glazer (2007) argue that modernism in architecture has abandoned its early intentions and hopes. He says that when architects compete with each other in imposing forms on museums and concert halls and residential towers that bear no resemblance to their functions, the movement in its larger sense is dead.

It also seems fair to say that most members of the general public who have not been educated to the modernist paradigm do not like the architectural designs of the architectural elite. Thomas Kuhn (1970) suggests in his classic treatise that paradigmatic shifts are produced when the existing paradigms do not produce satisfactory results. Clients, who provide the commissions for architects, pursue various strategies to force a more financially competitive climate for architectural services. In the United States, the architectural profession has so far managed to insulate itself from competition for services by shielding practices with a licensing process managed by state governments. The original concept behind granting an exclusive license to call oneself an architect was because architects provide services to protect the health, safety, and welfare of the public. This is shaky ground because many states are reviewing their registration laws and are raising questions of whether architects should be granted this protection.

The third reason is based on a developing change in building technology at the end of the 19th century when steel structures, elevators, interior plumbing, electrical lighting, central heating, the telephone, and automobiles were invented, creating a massive change in the infrastructure of cities and buildings (see Appendix 3). As these inventions have become integrated into the fabric of buildings and cities, they have been accompanied by changes in land uses that have produced dense, high-rise urban centers that are crowded, unsafe, and polluted. If one accepts the notion that necessity is the mother of invention, it seems likely that these urban conditions in the developed world will soon generate new innovations. So far, the only changes to emerge are those introduced in the communications systems of cities (rather than in the physical fabric), namely, the Internet and cell phones. There are a few new ideas emerging for the physical surround of places in buildings. The idea is to have systems that are dynamically adaptive to changes in occupation and use—that is, the interior elements are not static solutions (see Appendix 3). However, these ideas are still in the experimental stage.

I propose that a new knowledge base from neuroscience be developed that will enable designers to respond to cognitive experiences of spaces and places and allow architects to combine these design concepts with adaptive technology for the fabric of cities and buildings. This will bring about a major shift in the paradigms of architectural education and practice.

First, I want to introduce the subject of consciousness.

CONSCIOUSNESS

Consciousness is the "binding" context for understanding how we experience architecture. It is considered the hard issue of neuroscience. The commonsense notion of consciousness is well enough understood without the advantage of a scientific explanation. It seems obvious that we need to be conscious to have an experience, even if that experience is one we are reliving through dreams or memories. The dictionary definition is simply, "the upper level of mental life of which the person is aware as contrasted with unconscious processes."

Potential scientific explanations of consciousness discussed in the section that follows are those of Gerald Edelman and Giulio Tononi, Antonio Damasio, and the late Francis Crick with his associate, Christopher Koch.

Before going to these discussions, here are some other examples of attempts to explain consciousness. For René Descartes and William James more than two centuries later, to be conscious was synonymous with "to think." Descartes's famous statement, "I think, therefore I am," was a direct recognition of the centrality of consciousness to both ontology (what is) and epistemology (what and how we know).

Some philosophers deny any ontological or epistemic validity to consciousness; they insist that there is literally nothing else beyond the functioning of brain circuits, or at least nothing else that needs to be explained.

These philosophers have suggested that once we understand the workings of the brain sufficiently well, the concept of consciousness will evaporate.

The mind–body problem is made to disappear by denying or explaining away the consciousness side of it.

Others propose that although consciousness is generated by physical events in the brain, it is not reduced to them but emerges from them, just as the properties of water emerge from the chemical combination of two hydrogen atoms and one oxygen atom but are not directly reducible to the properties of hydrogen or oxygen alone.

Models of the functions associated with consciousness have been formulated in many ways—including metaphors borrowed from computer science that talk about a central executive system or an operating system. Some of these intuitions may point in the right direction, and others may be misleading even though they are appealing.

Colin McGinn (1999) says that explaining consciousness has stubbornly resisted our best efforts. The mystery persists; he thinks we should admit that we cannot solve it. We still have no idea of how "the water of the physical brain is turned into the wine of consciousness." McGinn doesn't exactly mean that human beings are just too stupid. Instead, he introduces the idea of *cognitive closure*, that is, the operations the human mind can carry out are incapable in principle of taking us to a proper appreciation of what consciousness is and how it works. It's as if, on a chessboard, you were limited to diagonal moves: you could go all over the board but never link the black and white squares. That wouldn't mean that one color was magic or immaterial. Equally, from God's point of view, there's probably no mystery about consciousness at all—it may well be a pretty simple affair when you understand it—but we can no more take the God's-eye point of view than a dog could adopt a human understanding of physics.

The Mind

Though less controversial than the ideas surrounding consciousness, any discussion of the mind will raise questions with which some members of the neuroscience community are not comfortable. They see the concept of mind as proposing something metaphysical or nonphysical outside the biological reality of the brain. Descartes's notion of dualism is how they view any attempt to consider the mind as a phenomenon. I prefer to use the commonsense notion of mind. Most people speak easily of "mind the gap" (a sign in all London Underground stations) or "I don't mind (doing something)" or "I think I am losing my mind." The simple definition is: "the element or complex of elements in an individual that feels, perceives, thinks, wills, and especially reasons."

A Universe of Consciousness

A detailed approach that seems to me to be the most complete development of a theory of how our rich experience of the subjective arises from the experience of a physical event is proposed by Edelman and Tononi (2000). Take, for example, how we consciously form our experiences when we visit the National Cathedral in Washington, D.C. (see Fig. 1–2). We know intuitively that our conscious experience depends on the complex yet delicate activity within our brains. We also know that if our brain is damaged, we may lose this ability to form an experience. The total experience of all of the events in our life exists for each of us only as a part of consciousness and ends for us when our life is over.

Edelman and Tononi argue that a scientific approach to consciousness will gradually reveal that this mysterious process is knowable—it will be possible to develop testable theories and well-designed experiences.

Figure 1–2. Washington National Cathedral.

They believe that eventually they will be able to answer such questions as (1) how does consciousness arise from particular neural processes that are the result of interactions between our brain, our body, and the world? (2) What are the key properties of conscious experiences? (3) How can we understand the different subjective states—so-called qualia (see later discussion)—in neural terms? and (4) How do we connect these scientific descriptions of consciousness to the human knowledge and experience? Edelman and Tononi believe that higher brain functions underlie consciousness and are not just activities within the brain, but instead rely on our interactions with other people, events, and places in the world. They take the position that consciousness is a process and therefore can be studied by scientific methods.

Primary Consciousness

Edelman and Tononi introduce three concepts at this point: (1) primary consciousness, (2) the remembered present, and (3) higher-order consciousness. Each of these concepts is discussed. They are not easy to understand immediately, but they are worth the effort.

To illustrate, I return to my example of the Washington National Cathedral: within milliseconds after you enter the cathedral, interactions occur in your brain that connect memory systems (of past visits or visits to similar places) with the perceptual categorization formed by the images now being sent to your visual cortex. This connection establishes what Edelman and Tononi call *primary consciousness*. The neuronal groups activated by your experience thus construct a scene of the objects you are seeing, hearing, touching, and perhaps smelling that are distributed across the networks linking the thalamus and the cortex—the thalamocortical system.

Which objects and/or which sensory systems you give particular attention to depends on your personal "value system"—a system established during past events that seemed important to the brain, such as a loud noise, a flash of light, a sudden pain, or a major emotional response to a place. When an event of this kind happens, it brings about the widespread release in the brain of neuromodulators that are able to influence neural activity as well as neural plasticity, that is, to make changes in the synaptic connections of groups of neurons that will be "remembered"—or which place a *value* on the importance such events have for you. The short-term memory involved in helping establish the primary consciousness experience has the function of incorporating memories from past categorization in a kind of bootstrapping operation with those of the present. This operation constructs a conscious scene in the brain that can be thought of as a "remembered present." Your past visits to the National Cathedral (or a similar place) are linked to the perceptual experience you are having at this instant. You have used this process to construct a relationship between the past and the present that is unique to you—no one else will have memories that are identical to yours, and no one else will have established value systems that are the same as yours. This ability leads to consciousness and explains why it has been preserved during eons of evolutionary development.

The mechanism by which our brain provides continuity in our lives—linking memories to present perceptions and using our unique value system to assign priorities—is what Edelman and Tononi call *higher-order consciousness*. Humans added this ability to their primary consciousness when they acquired language, because they had the needed mechanism to think about the past, contemplate the future, and be aware of being aware of the present.

Neuroanatomy of the Brain

There are three major arrangements in the complex topology of the brain that Edelman and Tononi propose should be understood to take understanding of how the brain functions to a global level.

The first is a three-dimensional mesh known as the thalamocortical system. The thalamus is central to this system. The brain has hundreds of functionally distinct areas in the cortex, each containing tens of thousands of neuronal groups that respond to various stimuli, ranging from those that make vision possible to those that cause the heart to beat faster when we are frightened. These groups are then linked to a huge "meshwork" with connections through the thalamus and back again to the cortex. This meshwork forms a system while each neuronal group maintains its local functional specificity.

The second topological arrangement can be thought of as a set of parallel chains that move in only one direction from the cortex to a set of appendages. These appendages (discussed in more detail in Appendix 2) include the cerebellum, the basal ganglia, and the hippocampus. These system connections to the appendages seem well suited to the execution of a wide range of complicated routines from motor neurons to cognitive neurons. Each of these networks, from the appendages back to the cortex, is isolated from the others, making it possible for speed and precision in the execution of the routines.

The third topological arrangement is like a large fan whose connections are formed by nuclei that project widely to huge portions of the brain, perhaps to all of it. The locus coeruleus (an area of the brainstem with many neurons), which is part of this fan and made up of thousands of neurons, appears to fire whenever something seems important to the brain. This fan arrangement forms the value systems discussed earlier.

Categorization

The brain and associated nervous system provide humans with an ability to categorize the different signals being perceived by visual, auditory, and other sensory systems. Somehow this ability divides perceptions into coherent classes, even though there is no prearranged code for doing so—something special to a person's consciousness that is still unmatched by computers. Neuroscience does not yet understand how this categorization is done, even though it is clearly being done. Edelman and Tononi believe it arises through the selection of certain distributed patterns of neural activity as the brain (and mind) interacts with our bodies and the outside world.

The concept of reentry in the brain is a key to how widely dispersed neurons are connected and become the basis for the integration of perceptual and motor processes. This integration provides our ability to discriminate an object or event from a background filled with other objects and events. Metaphorically, reentry might be thought of as a string quartet with each player connected to the other players by fine threads so that the tension in the threads conveys movements rapidly. Even without a conductor, each player improvises around the themes he or she hears, as well as cues from the architectural space in which they are sitting. This integration makes it possible for the quartet to produce coherent music that is more than the sum of its parts—just as the brain will use reentry to integrate a variety of perceptions and their associated memories into a coherent pattern that is greater than any one of the perceptions.

The Content of Experience

The current understanding of the brain indicates that the cerebral cortex is responsible for the content of our experiences. For example, the area of cortex devoted to voxels used in face recognition or the recognition of buildings provides content for perceptions of faces or buildings. If this area of the brain is damaged, this ability is lost. Likewise, our ability to perceive color is lost if the so-called fusiform and lingual gyri areas are damaged.

The brain regions where activity generates conscious experiences are widely distributed but remain locally specific, that is, activity in the visual cortex will be activated by perceptions of images via signals from the retina but will also link with other regions of the brain to form the total content of an experience. How our brain does this is still being studied.

The Problem of Qualia

There may be no more difficult problem facing those who study consciousness than the problem of how humans produce the subjective experience (qualia) associated with color, warmth, pain, or a loud sound. Sensing the color red, for example, requires the integrated activity of all the groups of neurons constituting the dynamic core of the brain that respond to red in some way. The brain has to discriminate red from among the billions of other states within the same reference space.

Edelman and Tononi take the following position: First, to experience qualia, one must have a body and a brain that support neural processes of the kind discussed earlier. Second, each conscious experience represents a different quale whether it is primarily a sensation, an image, a thought, or even a mood. Third, each quale corresponds to a different state of the dynamic core among billions of alternative states. The discrimination made among these billions of alternatives by any single quale gives it a unique property. Fourth, the earliest qualia develop in the brain of an embryo—a multimodal, body-centered discrimination carried out by the proprioceptive (see Appendix 2), kinesthetic, and autonomic systems of the infant's brain—particularly in the brainstem—and constitute the basis of the most primitive self. These qualia are the reference source for all future qualia.

Bringing It All Together

Consciousness is more than activating a large number of neurons; something else is needed to turn all of these activities into a conscious experience—a scene. Edelman and Tononi indicate that what is required is that the distributed groups of neurons across the brain must engage in strong and rapid *reentrant* interactions. At the same time, the activity patterns of these rapidly interacting neuronal groups must be constantly changing and adequately differentiated from each other.

They conclude their book (2000) by saying that future research may or may not support their current speculations, and they wish to make it clear that certain conscious experiences may not be able to be studied scientifically. The example they use is poetry, but they might also have included certain kinds of experiences with architectural settings. What they say is that such conscious activity rests on too many unique historical patterns, many ambiguous references, and incomparable samples. Each individual's conscious experiences are based on his or her special cultural context and unique memories.

Even with these reservations about poetry and other fragile conscious activity, I hope the work of Edelman and Tononi will encourage future research by bright, young doctoral students who wish to build intellectual bridges between neuroscience and architecture.

THE FEELING OF WHAT HAPPENS

Another view of consciousness and how it may be understood is provided by Antonio Damasio (1999). He suggests there are two components: "core consciousness," our moment-to-moment attention in the act of knowing something; and "extended consciousness," which begins with core consciousness and then incorporates memory and other faculties of the brain to produce autobiographical knowledge.

An Architectural Example

If you think about an altar (see Fig. 1–3), you can tell me what an altar is, and you can provide a reasonable definition of what it can be used for. There is not a single place in your brain where you will find the word *altar* followed by a neat dictionary definition. There are a number of records in the brain that correspond to different aspects of our past interactions with altars: their shape, the typical movements with which we use them, the result of doing this, and the word for altar that we use in whatever

Figure 1–3. The altar in St. Peter's Cathedral, Rome.

language we know. These records are dormant, implicit, and based on neural sites located in separate places in the brain. Appreciating the shape of an altar by feeling it is different than experiencing it visually. When you are asked to think about an altar, all these records are made explicit and are integrated so that they appear as a seamless memory.

You are not thinking of these sensations in words or, as Damasio says, using the mask of language. Our brain uses a nonverbal language at the instant in time when we have framed an experience for our "proto-self" (see following discussion). At the same time, the brain generates an automatic verbal version of this experience. We can't stop this process of converting the nonverbal track in our mind into words and sentences.

Core Consciousness

Core consciousness is the result of the brain generating a nonverbal representation of how our personal state is affected by our processing of an event—such as seeing the altar. This process enhances the image of the altar sufficiently to make it stand out from other objects in our immediate environment and to make our brain pay attention right here and right now. Remembering the object or event later can also produce this process.

In its normal operation, core consciousness is the process of developing a neural and mental pattern that brings together, at about the same instant in time, the pattern for the object, the pattern for the self, and the pattern for the relationship between the two. For this to happen, a large number of sites in the brain need to be working in close cooperation. These unfolding patterns give us a sense of "belonging" and are represented by what Damasio calls the *proto-self*—a coherent collection of neural patterns that map, moment by moment, the state of the physical structure of this person. We are not conscious of this proto-self. It has no powers of perception and holds no knowledge; it is simply a reference point at each place in the brain where it is located.

Damasio's hypothesis is that two component mechanisms are active at the same time: (1) the generation of the nonverbal but imaged account of you and an object (e.g., the altar) in a relationship—a way that your "self" has a sense of knowing the experience you are having, and (2) the enhancement of the images of the object to draw your attention.

Consciousness depends on the internal construction and exhibition of new knowledge concerning an interaction between you and an object. You—as a physical entity in the world—are mapped in your brain as well as the structures that regulate your life and continuously signal your internal state. The object with which you are interacting is also mapped in your brain based on the sensory and motor structures it activates. These maps—the "you" map and the sensory and motor maps—are recorded in neural patterns in your brain ready to become images. These sensory and motor structure maps cause changes in these maps of your physical entity and internal state. Second-order maps are then created to represent the relationship between you and the object. These second-order maps (which are always changing) can also become temporary mental images. In summary, these maps in the brain, because they relate our bodies to mental images that describe relationships with objects and events, are what Damasio calls feelings.

Consciousness begins as a feeling of what is happening to us when we see, hear, or touch an object. Such feelings mark those images we are experiencing as ours and allow us to say that we are seeing or hearing or touching.

Extended Consciousness

Extended consciousness is a prodigious function and, when fully operational, is the glory of being human. Whereas core consciousness is the indispensable foundation for extended consciousness, it exists only in the moment-to-moment activities of the brain. Extended consciousness goes both backward to the past and forward to the future. It includes everything that is core consciousness, but it is bigger and better and grows with our lifetime of experiences. It allows you to access a large landscape of your experiences. Damasio calls the self from whom you view this landscape the *autobiographical self*.

Autobiographical memories are things or events that the brain recalls and relates to the current experiences one pulse at a time. The many experiences stored in memory by core consciousness (by a nonconscious process) are now available to us because we can reactivate them in a manner that generates "a sense of self-knowing."

Working memory, the ability to hold active the many objects and events of the moment over a substantial period of time, lasts from seconds to minutes, and can be extended to hours. This contrasts with core memory that lasts only for an instant in time. It is in working memory that thoughts, ideas, plans, and the capacity to be aware of many objects and events simultaneously occur.

We should now add to the mix within the brain a sense of our autobiographical self—that unique set of memories about our past, that is, where we were born, when we visited Rome, and so on. These memories provide us with a sense of our past and the historical continuity of ourselves. The interlocking of core and extended consciousness, of proto- and autobiographical selves, once fully realized, produces consciousness. Damasio eloquently suggests that this consciousness allows us to know sorrow or joy, suffering or pleasure, to sense embarrassment or pride, to grieve for lost love or lost life. He suggests that consciousness is the key to a life examined for better and for worse, our beginner's permit into knowing all about hunger, thirst, sex, tears, laughter, the flow of images we call thought, our feelings, our stories, our beliefs, music, and poetry.

THE PROBLEM OF CONSCIOUSNESS

Crick and Koch (1997) were interested in how best to attack the problem of consciousness scientifically. They proposed to explain mental events as being caused by the firing of large sets of neurons. They felt it was not productive to worry too much over aspects of the problem that cannot be solved scientifically or, more precisely, cannot be solved solely by using existing scientific ideas. Radically new concepts may be needed. They suggested that the best approach is to press the experimental attack until we are confronted with dilemmas that call for new ways of thinking.

There are many possible approaches to the problem of consciousness. Crick and Koch selected the visual system because humans are very visual animals and because so much experimental and theoretical work has already been done in this area. Visual theorists agree that the problem of visual consciousness is ill-posed—that is, additional constraints are needed to solve the problem. Although the main function of the visual system is to perceive objects and events in the world around us, the information available to our eyes is not sufficient by itself to provide the brain with its unique interpretation of the visual world. The brain must use past experience (either its own or that of our distant ancestors, which is embedded in our genes) to help interpret the information light brings into our eyes.

Visual theorists also would agree that seeing is a constructive process, one in which the brain has to carry out complex activities to decide which interpretation to adopt from input that is ambiguous. The concept of computation implies that the brain acts to form a symbolic representation of the visual world with a mapping of certain aspects of that world onto elements in the brain.

What we are aware of at any moment is not a simple matter. Crick and Koch have suggested that there may be a very transient form of fleeting awareness that represents only rather simple features and does not require an attentional mechanism. From this brief awareness, the brain constructs a viewer-centered representation—what we see vividly and clearly—that does require attention. This in turn probably leads to three-dimensional object representations (such as a building) and thence to more cognitive ones. Representations corresponding to vivid consciousness are likely to have special properties.

A different part of the brain—the hippocampal system—is involved in one-shot, or episodic, memories. Over weeks and months, the hippocampal system passes memories on to the neocortex. This system is placed so that it receives inputs from, and projects to, many parts of the brain. Thus, one might suspect that the hippocampal system is the essential seat of consciousness. This is not the case: evidence from studies of patients with damaged brains shows that this system is not essential for visual awareness, although naturally a patient lacking one is severely handicapped in everyday life because he or she cannot remember anything that took place more than a minute or so in the past.

Crick and Koch's Concept of Categorization

In broad terms, the neocortex probably acts in two ways. By building on crude and somewhat redundant wiring produced by our genes and embryonic processes, the neocortex draws on visual and other experience to slowly rewire itself to create categories to which it can respond. A new category is not fully created in the neocortex after exposure to only a single example, although some small modifications of the neural connections may be made.

The second function of the neocortex (at least the visual part of it) is to respond extremely rapidly to incoming signals. To do so, it uses the categories it has learned and tries to find the combinations of active neurons that, on the basis of its past experience, are most likely to represent the relevant objects and events in the visual world at that moment. The formation of such *coalitions* of active neurons may also be influenced by biases coming from other parts of the brain: for example, signals telling it what best to attend to or high-level expectations about the nature of the stimulus.

If visual awareness at any moment corresponds to sets of neurons firing, then the obvious question is: where are these neurons located in the brain, and in what way are they firing? Visual awareness is highly unlikely to occupy all the neurons in the neocortex that are firing above their background rate at a particular moment. We would expect that theoretically at least some of these neurons would be involved in doing computations—trying to arrive at the best coalitions—whereas others would express the results of these computations, in other words, what we see.

Attention and Awareness

The major problem is to find what activity in the brain corresponds directly to visual awareness. It has been speculated that each cortical area produces awareness of only those visual features that are "columnar" or arranged in the stack or column of neurons perpendicular to the cortical surface. Thus, the primary visual cortex could code for orientation while area MT would code for motion. So far, experimentalists have not found one particular region in the brain where all the information needed for visual awareness appears to come together.

Crick and Koch wondered whether the pyramidal neurons in layer 5 of the neocortex, especially the larger ones, might play the role of synthesizing the content of visual awareness. They also wondered if there are some particular types of neurons, distributed over the visual neocortex, whose firing directly symbolizes the content of visual awareness. One very simplistic hypothesis is that the activities in the upper layers of the cortex are largely unconscious ones, whereas the activities in the lower layers (layers 5 and 6) mostly correlate with consciousness. These are the only cortical neurons that project right out of the cortical system (that is, not to the neocortex, the thalamus, or the claustrum). If visual awareness represents the results of neural computations in the cortex, one might expect that what the cortex sends elsewhere would symbolize those results. Moreover, the neurons in layer 5 show a rather unusual propensity to fire in bursts. The idea that layer 5 neurons may directly symbolize visual awareness is attractive, but it still is too early to tell whether there is anything to it.

Crick and Koch believed that once we have mastered the secret of this simple form of awareness, we may be close to understanding a central mystery of human life: how the physical events occurring in our brains while we think and act in the world relate to our subjective sensations—that is, how the brain relates to the mind.

Further Developments by Koch

The October 2007 issue of *Scientific American* reported a discussion between Christof Koch and Susan Greenfield (a professor of pharmacology at the University of Oxford, director of the Royal Institution of Great Britain, and a member of the House of Lords in the British Parliament) on the subject of "How Does Consciousness Happen?" They agreed in general that there is not a single problem of consciousness but many different notions—from being self-conscious to what should be considered the content of consciousness.

Koch argued that neuroscience needs a new theory, based on physical measurements, that predicts what it means to be conscious—from fruit flies to Alzheimer's patients. The theory should include specific hypotheses that can be tested with today's technology that can toggle layer 5 pyramid cells on and off until the exact set of neurons being affected is identified. Neurons are part of large networks, and these networks can generate consciousness. Koch's basic argument is that qualitative (not quantitative) differences in neuronal activity give rise to consciousness.

He differs with Greenfield on this topic because she believes sheer numbers of neurons produce consciousness, and he believes consciousness is caused by the informational complexity that the neurons represent. Koch says each specific percept requires a specific network of neurons, and for full consciousness a coalition of neurons must encompass both sensory representation at the back of the cortex and frontal structures involved in memory, planning, and language. These patterns represent the accumulated information learned over a lifetime, as well as that of one's ancestors, whose information is represented in genes.

Greenfield argues that either you are conscious or you are not and that in Koch's lab subjects are conscious throughout experiments performed on their neurons; therefore, it is not consciousness itself that is being manipulated but the *content* of that consciousness. Her assumption is that there is no intrinsic, magical quality in any particular brain region or set of neurons that accounts for consciousness but a special *process* within the brain. It is not generated by a qualitatively distinct property of the brain but by quantitative increases in the holistic functioning of the brain. Greenfield sums up this process concept by saying that consciousness grows as the brain grows.

A Role for the Claustrum

One of the proposals that Koch developed with Crick to explain how consciousness works is based on their studies of the claustrum—a sheet-like structure within the cortex (see Fig. 1–4). In their search for the best neuronal correlates of consciousness—the brain activity that matches up with specific consciousness experiences—they looked at the claustrum. The neurons in this structure receive input from almost all regions of the cortex and project back to almost all as well. Koch suggests that the

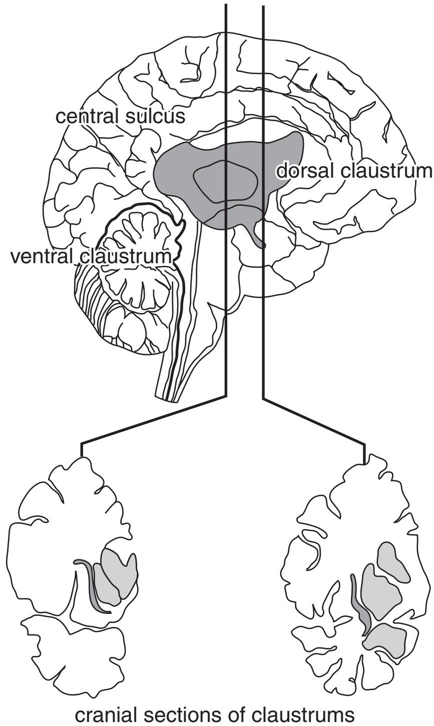


Figure 1–4. An illustration of claustrum.

claustrum may be perfectly situated to bind the activity of the sensory cortices into a single, coherent percept.

Although Koch has not proposed a theory for the role of the claustrum in consciousness, it was a considerable interest to his friend Crick toward the end of his life.

CONCLUSION

This chapter is not easy to understand because consciousness is an elusive subject. I hope that introducing the several different approaches for conceptualizing what consciousness might be, and how it is dependent on the brain, will give the reader a glimpse of what consciousness is or could be.

I am personally convinced that our perceptual experiences of architecture are not going to be completely understood until they can be explained within the context of consciousness. The neuroscience community is moving in that direction and will likely provide results in the future.

CHAPTER TWO

Neuroscience and the Design of Educational Places

Research undertaken by neuroscientists around the world is beginning to provide new insights into the influence of the various qualities of schools on learning experiences. Schools designed with an understanding of how children's brains and minds respond to the attributes of spaces and places can lead to enhanced learning. Such research is adding to the architectural knowledge base an understanding of how daylight, acoustics, air quality, and views of nature deeply affect the cognitive processes of children.

Figure 2–1. One-room school, Bear Creek School (c. 1870), Iowa.

Children learn lessons from the school building in which they are being educated. They may not be aware of these lessons, but their core consciousness is providing experiences that illustrate the importance of this education to their parents and their community. It will also cause them to be anxious because they are in an environment different from their homes, filled with others of the same age, with an authority figure called the teacher, and with an architectural setting foreign to their home experience. Later, many are likely to experience the trauma of moving from elementary school to middle school where all of the "big kids" will pose a threat to their egos and sense of security, and where a new school building challenges them to adapt to a new physical environment. Schools that are modern in their design are likely to seem unfamiliar to children if they live in a traditional house in an ethnic neighborhood.

For these reasons and more, it is worth exploring the evolution of architectural concepts for schools over the past 100 years, as well as the progression of educators' ideas about the role of the physical classroom in education. We also examine neuroscience studies related to hypotheses based on observations of children in schools. Having discussed the design of schools—especially classrooms—and the understanding we have of children's learning patterns, development processes, and responses to sensory perceptions, we will explore in greater depth these perceptions and pose potential hypotheses.

DESIGN CRITERIA FOR SCHOOLS

School administrators and their architects have developed a number of guiding principles that seem appropriate as design criteria for all schools.

- Places with a variety of different shapes, color, light, size, and so on, should be provided.

- Interior color and textures should be rich and stimulating.

> *Hypotheses 2–1*
>
> Children who are 5 or 6 years old respond differently to colors than adults do because their perceptions are different.

Comment: Adult designers may be inserting their intuition about children's preferences. In addition to emotional associations, factors that affect color perception include the observer's age, mood, and mental health. People who share distinct personal traits often share color perceptions and preferences.

Color matters in our innate perceptions. For example, blues and greens are generally regarded as restful. There are many associations with red as an attention-commanding color—red lights, red flags, and so on. Perceived color is based on the relative activity of ganglion cells whose receptive field centers receive input from red, green, and blue cones. It appears that the ganglion cells provide a stream of information to the brain that is involved in the spatial comparison of three opposing processes: light versus dark, red versus green, and blue versus yellow (Bear, Connors, & Paradiso, 2001).

Additional criteria from school administrators and architects:

- Places for group learning—alcoves, breakout spaces—should be made available.
- Places should be perceived to be safe as well as actually safe.
- Places should foster self-identification and personalization, including opportunities to express territorial behaviors.
- The school should be an active participant in community affairs.

We explore how such principles can guide hypothesis formulation.

HISTORY OF EDUCATIONAL ARCHITECTURE

Introduction

The history of the American schoolhouse reflects the history of education and its social, economic, and political context. The architectural form, aesthetics, symbolism, and layout of school buildings has been influenced by the evolution of educational philosophy and goals, curricular objectives, instructional methods, and the cultural background and value systems of the schools' governing boards.

The history of educational architecture follows three general periods of American social, economic, and political history: the agrarian period (1650–1880), the urbanization period (1880–1940), and the modern period (1940–present).

The architecture of the small, one-room country school building was an appropriate design response that served the basic educational and social needs of small rural communities for well over 200 years, beginning in the colonial period of the United States.

As the social challenges presented by the Industrial Revolution grew in the mid- and late 19th century, the need for educating larger groups in urban centers became a necessity. The common school movement and large, multistory classroom buildings provided the necessary educational and architectural response at that time.

After World War II, societal changes brought on by the Baby Boom created a need for school construction never seen before. Along with innovations in educational delivery suggested by the progressive movement, lead principally by John Dewey, school architecture soon responded with more child-scaled, flexible, and open environmental settings.

Educational Architecture in the Agrarian Period

Early U.S. society consisted of village settlements where land was cultivated for agricultural purposes. Land was the primary basis for the economy, life, culture, family structure, and politics. Life was based on the social support of the village settlement pattern of semi-isolated communities. Houses were typically grouped around a central public meeting space containing public structures, such as the church and sometimes a school.

Even though the written word was available, literacy was rare—most people were illiterate and relied on others to read aloud the material of benefit to the whole community. The need for literacy in the village focused almost entirely on the perceived need for an exposure to Christian morality and the teachings of the Bible. The Sunday school movement in the early 19th century was one of several precursors to the common school.

When settlers arrived in New England, they began almost immediately to establish Latin grammar schools and colleges. The most formal structure involved the academy and university. Harvard College was established in 1636, and the College of William and Mary followed in 1693. State-mandated public education and schools did not exist prior to the 19th century.

In the New England colonies, the first schools were set up in either private homes or churches. Home schooling and informal education was common in colonial America. Unmarried or widowed older women often held classes in their own homes, whereas wealthy parents hired tutors to come into the home to instruct their sons in the classics. As the population increased in the colonies, subscription schools evolved, with support for these schools coming from subscriptions, tuition, land rental fees, and taxes. In 1647, the government of Massachusetts Bay was the first to enact a statute providing for the establishment of a school system requiring the provision of school buildings.

By the middle of the 19th century, the one-room schoolhouse had become a familiar object in rural areas (see Figure 2–1). The school included all ages due to the relatively small size of the community. One teacher presided over instruction that emphasized recitation and direct supervision. Learning was by rote and self-paced, depending on the student's developmental level. One-room schools often had very simple furnishings, poor ventilation; they relied on oil lamps for light and wood-burning stoves for heat. Schoolhouses in urban areas were variations on the theme of the country schoolhouse, often containing two, four, or six self-contained rooms, frequently with their own entrances.

Along with the church, the school was the social center of community, where town meetings, voting, fundraisers, and celebrations of all kinds took place. In essence, the entire community, not just school-age children, was served by the school building. The school housed the activities that integrated people into their community. To this day; communities are identified by their school.

Andrew Guildford (1984) examines the one-room schoolhouse and the memories of this important part of the American past through sections on the country school legacy, country school architecture, and country school preservation. More than 400 photographs evocatively portray the architectural and historical significance of this distinctive building type. The section on country school architecture provides a review of little red schoolhouses and others.

The Urban Growth Period (1880–1940)

Figure 2–2 shows a typical classroom of the early 20th century. It is, in fact, a classroom in the two-room parochial school I attended from the first to eighth grades—Concordia Lutheran School in Louisville, Kentucky. There were two rooms like this. Each room housed four grades of five to eight children each.

Figure 2–2. Interior of Concordia Lutheran School. Rome.

The desks were fastened to the floor, and each child had a private space for storing books, writing material, and "treasures." A piano in one corner of each room (which meant the teacher had be able to play it) was used to accompany opening ceremonies with the singing of a hymn. Pictures of Jesus, George Washington, and Abraham Lincoln adorned the walls, and an American flag hung from the ceiling. There were many large windows, filling an entire wall. The room had more than enough natural light to compensate for the poor quality of the artificial lighting available in the 1920s. Schools across America followed this pattern well into the middle of the 20th century.

Toward the end of the 19th century, a large number of key inventions emerged to change the character and infrastructure of urban areas (see Appendix 3). Steel structural systems, indoor plumbing, electricity, central heating, elevators, the automobile, and the telephone collectively changed cities into densely populated places. With urban density, the opportunity to build larger schools began to emerge.

The Crow Island School (see Fig. 2–3) opened its doors in 1940 and was an outgrowth of a plan by Winnetka, Illinois, businessmen to create a public school whose philosophy and facility would rival its private school counterpart. Carleton Washbourne, the school superintendent, envisioned a child-centered learning environment. The result was an elementary school with three classroom wings arranged around common spaces

Figure 2–3. Crow Island School.

that included a playroom, stage, art room, and library. The classrooms were organized along horizontal corridors.

The L-shaped layout used for the Crow Island classrooms was special (see Fig. 2–4). The wings are not of equal size, and each was designed as two spaces. The smaller, narrower wing is the workroom with a sink, counters with windows above them, a washroom, and a drinking fountain.

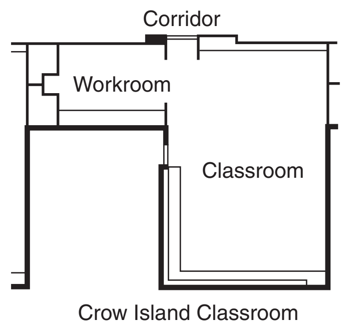


Figure 2–4. Partial floor plan of Crow Island classroom.

This room was the space where the students worked on specific projects. In addition, this room may have been designed for either individual or one-to-one activities. The wider and longer wing was the classroom area. This space was designed with a bay window to define a large group meeting area. The space was flexible and provided with age-appropriate furniture so that it could be arranged in a variety of small group activities.

The Crow Island School set an architectural precedent because of how the physical environment was created to support learning. The participatory process in which the architects met with the staff and students was invaluable in creating this setting.

Hypothesis 2–2

A child provided with a space that is appropriately scaled to his or her size will have an adjusted sense of time and space that leads to reduced stress, greater feelings of security, and increased competence.

Comments: It would be useful to know when and how children acquire spatial-linguistic categories, when and how they acquire the ability to negotiate frames of reference, and when and how they acquire organizational strategies to structure their verbal descriptions of space (Newscombe & Huttenlocher, 2000).

The Modern Period of Education and Architecture (1940–Present)

Not until late in the 20th century did school design become more daring. Most school boards, the client for new schools in their geographic area, were not prepared to be very adventuresome as far as design was concerned. School buildings that were reasonably simple in design—and especially low in cost—were the rule. The formula for a typical school became so standard that some architects were reported to simply take the plans they had developed for one school and put a new title on the drawings for another school.

About 1980, a new era of modern schools emerged. It's not clear whether school boards began to understand that the design of schools spoke to the children about community values, or whether a more aggressive design profession was able to convince their clients to become more progressive.

The next few pages illustrate schools that are part of this new wave of progressive design. Architectural journals are filled with photographs of them. It is unlikely that any architect or school board would design a school today that was colonial or gothic in character unless it was an addition to an existing school originally designed in one of those styles. School boards considered to be progressive in their building programs do not consider historic style to be appropriate—and, most important, they know that modern is usually less expensive.

What is missing from this progressive movement is a knowledge base providing clear evidence of the impact of the design principles on the cognitive activities of children. Behavioral science research provides a good deal of information about how children respond to colors, light, or the size of the space. However these studies are limited to describing *how* children respond to architectural features, but not *why* they respond. To understand why children respond the way that they do requires studies that include exploring brain patterns and genetics. The hypotheses included in this chapter indicate some of the ways neuroscientists could now be exploring children's brain responses and classroom design.

WAYFINDING

An example of exploring why children's brains respond to spatial arrangements is provided by the concept of wayfinding. *Wayfinding* means using the physical environment to navigate from one location to another, including from home to school or playground to school. Another example is remembering how to find the washroom or the principal's office.

Wayfinding concerns include accommodating special conditions of those with disabilities, such as visual and aural impairment and physical impairment, including use of wheelchairs, mental retardation, and so on.

Some children learn best by visual/spatial clues, and others learn best by auditory clues. There are clearly children who are skilled at finding their way and others who have constant problems.

Children's ability to navigate in large, complex environments generally improves over time. Newscombe and Huttenlocher (2000) outline several features of wayfinding development in children:

- Young children probably lack an objective frame of reference, because their experience in the world has been limited.
- Young children can construct spatial representations but will have difficulty integrating them when a common frame of reference is not available. They will have to infer spatial relationships.
- Young children are less likely to have the ability to use landmark selection strategies and route examination to help navigate unfamiliar areas.
- Children acquire new strategies and refine existing ones to produce an improvement in their wayfinding and navigation skills through age 12.

Hypothesis 2–3

Landmarks designed around images familiar to children (e.g., animal pictures) can assist in route knowledge (knowledge of the sequence of landmarks that must be followed to reach a goal).

Comment: Wayfinding skills are based on previous experiences that have been committed to either implicit or explicit memories. Such memories include landmarks, symbols, color clues, and so on. What happens in children's brains to enable them to develop such skills?

Alexander Dawson Lower School

This school (see Fig. 2–5) accommodates 120 students in kindergarten through grade four. Every classroom has a combination of high translucent clerestories and low tinted-glass windows (see Fig. 2–6). The two opposite light sources provide well-balanced illumination throughout the day. The exact size of the windows and their locations are optimized to avoid overheating from sunlight while maximizing daylight. The clerestories are sloped inward to reduce contrast within the room and increase visual comfort without the use of electric lighting most days.

Figure 2–5. Alexander Dawson Lower School, Boulder, Colorado, Hutton Ford Architects (1998) (photo by Greg Hursley).

Hypothesis 2–4

A child's brain responds to natural daylight (compared to artificial light) in a manner that enhances learning.

Comments: A research project in which a subject must pay attention to one stimulus and ignore the others is a way of determining what the brain pays attention to. Comparisons can then be made between the responses in brain hemispheres to an attended and an unattended stimulus. The harder students have to work to attend to something, the more they have to suppress unattended stimuli. To focus on speech in a crowded room, students need to ignore other stimuli. It's the same thing in the visual system. Motion is automatically distracting. For basic visual tasks, performance will deteriorate throughout the day (this is common sense). But if a small change is introduced, the performance goes almost back to where it was in the beginning. It isn't the result of general boredom or fatigue; it's something in the visual system. Lisa Heschong's (2001) firm showed—using behavioral studies in California schools—that increased daylight tended to increase awareness and raise test scores for students.

Figure 2–6. Interior, Alexander Dawson Lower School (photo by Greg Hursley).

Crozier Middle School

This middle school campus (see Fig. 2–7) covers 104,000 square feet and accommodates 1,300 students in a state-of-the-art learning facility. The design incorporates the need for safety and accessibility and

Figure 2–7. Crozier Middle School, Inglewood Unified School District, California; Dougherty + Dougherty Architects LLP (photo by Greg Hursley).

complements the scale and aesthetic of the nearby civic center. The new facilities include an administration building and library, a gymnasium, and a theater in addition to the two-story classroom building.

The new campus also includes much-needed open space for playing fields and outdoor basketball courts. The goal of the architects and school administrators was to lead, instruct, and empower students toward success in school and in life. The new school site has been the only campus in the school system to meet enrollment projections, and test scores have increased more than 40%.

THE LEARNING BRAIN

A discussion of brain processes and learning by Blakemore and Frith (2005) points out how little neuroscience research has contributed so far in providing guidance to educators.

The brain is a machine that allows all forms of learning to take place—from baby squirrels learning how to crack nuts, birds learning to fly, children learning to ride a bike and memorizing multiplication tables, to adults learning a new language or mastering how to program a video recorder. The brain is also the natural mechanism that places limits on learning. It determines what can be learned, how much, and how fast.

Scientists know a considerable amount about learning—how brain cells develop before and after birth; how babies learn to see, hear, talk, and walk; how infants acquire a sense of morality and social understanding; and how the adult brain is able to continue learning and growing. What is amazing is how few links exist between brain research and the policy and practice of education. Despite major advances in our understanding of the brain and learning, neuroscientific research has not yet found significant applications of this knowledge in the theory or practice of education.

Thinking about the educational implications of genetics research will be a hugely important task for the future. Blakemore and Frith believe this jump can be made more easily when we understand the links between brain and behavior.

Cognition means anything that happens in the mental domain, which includes thinking, memory, attention, learning, mental attitudes, and emotions. When the authors refer to *cognition* or *mind*, they do not mean to separate them from the brain. The brain and mind have to be explained together.

To fully understand human cognitive functioning, we must understand how children code the locations of things, navigate around their world, and represent and mentally manipulate spatial information. Without at least tolerably close correspondence between internal representations and the actual physical world, children would not be able to find what they need, avoid what they fear, or imagine and construct tools that they use.

THE DEVELOPING BRAIN

At birth, the brain seems to be equipped with some information about what a face should look like. Newborn babies prefer to look at drawings of whole faces rather than drawings of faces whose features have been "scrambled." Within a few days of birth, a baby learns to recognize his or her mother's face—a baby will look at a picture of its mother's face longer than at a picture of a stranger's face. A baby also can discriminate between his or her mother's face and those of other animals. This remarkable early ability to recognize faces is probably controlled by brain pathways different than those involving later, more sophisticated face recognition. It probably evolved because it produces an automatic attachment for newborns to the people they see most often.

After 6 months, babies' abilities to perceive tiny differences in the speech patterns of their own language or discriminate between faces of other species (as contrasted to other humans) are fine-tuned—bringing a loss in early discrimination abilities. But this cost is well worth it because it results in the brain's amazing speed and accuracy when it comes to recognizing other people and what they are saying. Skills acquired after the loss of this early sensitive period are subtly different and probably rely on different strategies and brain pathways than if they had been acquired during the earlier sensitive period.

Different Types of Learning and Memory

One of the contributions to education that neuroscience is capable of making is illuminating the nature of learning itself. There is probably no single, all-purpose type of learning for everything. In terms of the brain structures involved, learning mathematics differs from learning to read, which differs from learning to play the piano. Each memory system relies on a different brain system and develops at a slightly different time. Remembering *who* you are differs from remembering *where* you are.

Episodic memories of particular events or episodes in one's life—for example, the first day at school or a more recent birthday—are processed in different brain areas from semantic memories of names, numbers, dates, and facts. These two types of memory are distinct from procedural memory for skills like tying shoelaces and walking. These types of memory are processed separately in the brain, and they can exist in isolation from one another. Learning can be implicit or explicit. That is, we are sometimes be unaware that we are learning, and on other occasions, we are acutely aware.

Teaching often involves making implicit or procedural knowledge explicit. Teachers have to explain how to read, how to paint, and how to play the violin. Knowing how or when to make rules explicit is likely to be an important determinant of effective teaching. When can explicit teaching replace implicit learning? Is a degree of prior implicit learning always helpful? Possibly, a reciprocal dialectic between implicit learning and explicit teaching supports learning most efficiently.

These are all questions that could be explored to help the teaching process, but it would also be useful to provide some questions (or frameworks) related to the manner in which the attributes of classrooms impact a child's brain (at various stages in development) and cognitive processes. For example, is natural daylight supportive of cognitive processes? Can the shape of a classroom impact a child's attention span? Will soft floor surfaces contribute to better acoustics that produce a feeling of calm for young children, and enhance their ability to pay attention? If so, why is this the case—in neuroscienctific terms?

THE CLASSROOM AND THE COGNITIVE PROCESS

A number of observations in the literature comment on how classrooms affect cognitive processes. For example, it seems clear that children with deficient sensory integration, or those who cannot hear or see well in certain environments or under certain conditions, can be greatly delayed in their reading ability—which is the key to successful learning.

It has also been shown that two brain areas (the anterior cingulated and the lateral prefrontal cortex) demonstrate robust differences between good and poor readers in reading visual words (Rueda et al., 2004). One of these regions is active in listening to speech and is located near brain areas involved in processing sound. This area is specifically engaged by tasks that require thinking about the sounds of words—phonology, as in deciding whether two letter strings rhyme. This region maybe be critical in early reading experiences, when children learn to systematically associate the sight and sounds of words. The other region is responsible for active cognition and planning.

Poor performances on standardized tests and other assessment modules are often associated with underdeveloped cognitive abilities and underdeveloped sensory integration—in which case the students have a hard time learning how to learn (Ornstein & Thompson, 1991).Classrooms are often filled with deterrents that hamper a child's ability to listen and learn. The acoustical environment in classrooms can evidently be one such deterrent. Excessive background noise and reverberation can affect the achievement and educational performance of children with sensorineural hearing loss (SNHL) and those with normal hearing sensitivity who have other auditory learning difficulties, as well as elementary schoolchildren with no verbal or hearing disabilities (Knecht et al., 2002).

Auditory Design Issues

Speaking and listening are the primary communications modes in most educational settings. Therefore, noise levels and reverberation times of these learning spaces should be such that speech produced by teachers, students, and others is intelligible. Unfortunately, many learning spaces have excessive noise (inside or outside the room) and poor reverberation times (the time it takes for a sound to be reflected by room surfaces).

Although there is little published neuroscience research evidence relating cognitive processes to the acoustical properties of architectural spaces, the acoustical characteristics of a classroom do have a significant affect on the cognitive processes of children with normal hearing—and especially on those of children with a hearing impairment. Ambient noise (background sounds), including external noise (e.g., from passing traffic), adds to the difficulties of poor acoustics. The type of background noise (music, mechanical equipment, other activities in adjacent spaces) is an important consideration in a noisy environment. Children who speak English as a second language have a special acuity problem in understanding words and separating sounds spoken by a teacher.

Hypothesis 2–5

Background sounds (such as traffic noise or sounds from other classrooms) impede reading skills.

Comments: This hypothesis should be tested with children of different ages, genders, cultures, and socioeconomic status. All students and teachers are negatively affected by noise and reverberation. However, young students, English language learners, and anyone with hearing, language, or learning problems may be at a greater disadvantage. The acoustical properties of classrooms are often the forgotten variables in ensuring students' academic success, particularly for students with unique communications or educational needs (ASHA, 2005).

Educational research suggests that the acoustical profile of a learning environment can significantly improve learning. One approach might be to "tune" a classroom to enhance the teacher's voice or the students' voices.

COGNITIVE NEUROSCIENCE AND CLASSROOM DESIGN

The life and behavior of neurons are dictated partially by genetics and partially by the environment. The body generally goes through an excessive amount of cell proliferation (especially during the first 3 years of life) and selective cell death. Life experiences are known to have physiological effects on the brain at the level of the cell.

Neuroscience research results suggest that the brains of children between the ages of 6 and 12 are still going through major developmental changes. The majority of changes in the brain begin 28 days after conception (in the embryo) and continue through about 5 years of age. Dr. Joan Stiles, director of the Center for Human Development at the University of California San Diego, says:

> Brain development is a complex and protracted process. Both biology and experience play critical roles in shaping the final organization of the brain. Development is more than a simple unfolding of a predetermined genetic plan. While genes are critically important for brain development, the development process is also adaptive. It is the interaction of biological systems

with each other and with input from the world that ultimately determines brain organization and function.

Because the cognitive processes of the brain (those that form the basis for learning) are particularly sensitive to the capacity of neuronal circuits, it is reasonable to assume that cognitive abilities change substantially between the ages of 6 and 12.

In a UCLA Brain Development brief (Halfon, Shulman, & Hochstein, 2001), a number of important points related to brain development were presented.

- A newborn has about the same number of neurons as an adult, but only 25% of its brain volume has developed. Infant's brain cells are connected by some 50 trillion synapses.
- By age 3, the synapse number on average is 1,000 trillion. Beginning at age 3 the synapses are selectively eliminated. At age 15, there are 500 trillion synapses left, a number currently thought to remain steady thereafter.
- Functions like heart rate are relatively hardwired at birth, whereas higher functions related to learning and memory are sculpted and modified by experience—however, the exact network of connections changes over time.
- Synapse survival is use-dependent. External stimuli and synaptic firing under the influence of new types of stimuli lead to synapse formation and neuronal survival.
- It is believed that brain regions become connected with others and form functional pathways in a hierarchical fashion, enabling increasingly complex behavior.

Sharp boundaries in developmental periods are called critical periods where growth and pruning most likely occur. In these periods, children could be more vulnerable to environmental influence, which probably can cause experience-expectant development and experience-dependent development. In experience-expectant development, the brain responds to stimuli, such as light and sound, that are expected to influence development.

A child's brain is constantly adapting to new demands placed on it from the external world. In neuroscience terms, the brain is "plastic," that is, dynamically changed by events and stimuli and by requirements to be more efficient. This plasticity has different critical periods (related to age) during which the capacity of an area of the brain is changed to meet new conditions. A critical period often requires a development process that cannot be rushed by circumstances. For example, the process of providing directions to others has to wait until a child is approximately 7 years old. At this point, his or her brains has developed sufficiently to know whether other people can understand the directions being given.

There is a spurt between the ages of 6 and 12 in the areas of the brain that are specialized for language. This rapid growth appears to slowly come to an end before the age of 12. This could therefore be considered a critical period for learning languages.

Cognitive psychologists and neuroscientists are intrigued with how cognitive capacities change with age. Their research has shown that regions of the brain associated with the primary function of movement (an activity that requires a response from the motor cortex in collaboration with other brain appendices) are the first to mature. The functional areas associated with complicated integrative functions are the last to mature. Some functions of the brain cannot be performed until those functions with which they integrate have matured.

In the developing brain, complex/integrative task regions develop after the primary functions (e.g., vision and hearing) are in place. Eventually those regions containing association areas for integrating information from several sensory modalities are created. Consequently a child's age (and maturity) determine the performance of complex brain functions (Thompson et al., 2000).

Results suggest that the neural systems processing spatial information are specified early in development. Changes in performance on spatial tasks with development in normal children therefore appear to reflect maturation and increased organization of both the left and right hemispheres (N. Akshoomoff, Stiles, & Wulfeck, 2006).

Visual Design Issues

A child's visual functions at close range, particularly good stereoacuity, are significantly correlated to academic performance. Lighting varies throughout the modern classrooms. Inconsistency of light in the environment can cause poorer performance on certain tasks. The brain processes light information to visually represent the environment and also to detect changes in ambient light level. The latter information induces non–image-forming responses and exerts powerful effects on physiology, such as synchronization of the circadian rhythm and suppression of melatonin.

The quality and characteristics of natural light and artificial light affect the brain's ability to process information about the environment through the visual systems. Light is known to acutely modulate alertness (hence the ability to pay attention). Perception based on the visual system varies with the age of the child and the types of distraction in the environment.

Some of the variables related to a child's age discussed in the previous pages are summarized in Figure 2–8.

The middle two lines graph the changes in weight and height of boys and girls between 5 and 12 years of age, something easily recognized by teachers and parents. Not generally known by teachers and parents are the data displayed in the top two lines. These show the rates of glucose consumption by the occipital and temporal cortexes of children's brains as they age from 5 to 12. These areas are used for vision and hearing. Note the rapid increase in consumption in the early years and then a leveling off after age 8 or 9. This coincides with the ability to hear and learn a new language.

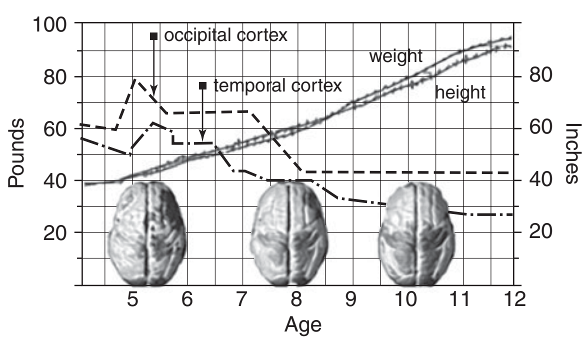


Figure 2–8. Brain growth variables.

The three views of the brain shown at the bottom of the figure display results of scans that were made of the brains of healthy children as they matured, showing changes in gray matter density as the brain develops. These scans published in the proceedings of the National Academy of Sciences (Gogtay et al., 2004) found that the first areas to mature (e.g., extreme front and back of the brain) are those with the most basic functions, such as processing the senses and movement.

CHAPTER THREE

Vision and Light in Architectural Settings

> *Although many of characteristics of quality lighting conditions are known, it is a difficult area to define precisely. Research continues in an effort to uncover knowledge of how people see and what kind of lighting conditions are most desirable for every situation.*
>
> —ARCHITECTURAL GRAPHIC STANDARDS

VISUAL NEUROSCIENCE OF ARCHITECTURAL DESIGN

In this chapter, we discuss the perceptual response to buildings by the visual system. To do so, there is a technical discussion of vision and the role of the retina. (Appendix 2 deals with other sensory mechanisms.)

Figure 3–1. Winchester Cathedral north transept.

THE HUMAN EXPRESSION OF SYMMETRY: ART AND NEUROSCIENCE

The concepts of symmetry, harmony and proportion are attributes of objects that are broadly processed by the visual system. Christopher W. Tyler (2000) says that symmetry is an important visual property for humans because it can be useful in discriminating living organisms from inanimate objects by identifying face orientation and direction of attention. He suggests that humans see symmetry as an important principle in objects we design—from buildings to Persian rugs.

St. Peter's Basilica in Rome (see Fig. 3–2) is a magnificent example of symmetry. Humans can detect symmetry within about 0.05 second over all regions of the retina. This stimulus duration is too brief for a process based on serial eye movements or attentional comparison to be completed. This implies that human symmetry processing is a global, hard-wired activity of the brain.

Tyler further indicates that his initial evaluation of cortical processing of symmetry established that symmetry/random alternation is a sufficient stimulus for significant activation, visible via functional magnetic resonance imaging (fMRI), in a little understood region of the occipital lobe in and around the middle occipital gyrus. It can be hoped that Tyler and

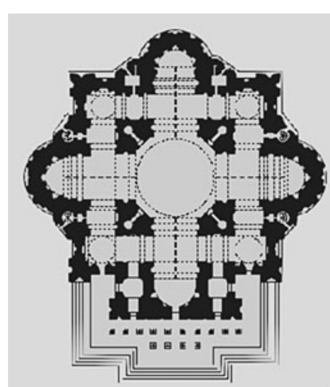


Figure 3–2. Floor plan of St. Peter's Basilica, Rome.

others will continue to explore how the brain processes symmetry in buildings.

HARMONY, SYMMETRY, AND PROPORTION IN ARCHITECTURE

Harmony is understood to mean a consistent, orderly, or pleasing arrangement of parts. There is considerable evidence that the golden mean (see Fig. 3–3) is recognized and used in a large number of human designs—both consciously and intuitively. The golden mean is a numerical relationship in which the ratio of the long side to the short side of the golden section is always within the range of 1.618 to 1.

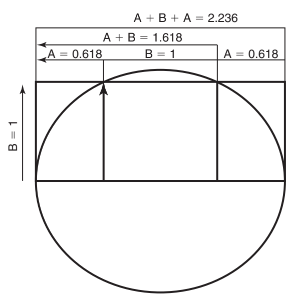


Figure 3–3. Golden mean proportions.

The classic volute of an Ionic capital (see Fig. 3–4) on the left is generated using the golden mean. The two on the right used the same geometric rules provided by Palladio, but not with a progression from the golden mean. Human brains seem most responsive to the classic one.

> *Hypothesis 3–1*
>
> The brain is hard-wired to respond to proportions based on the golden mean.

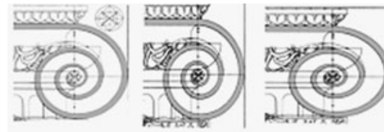


Figure 3–4. Ionic volutes.

Although the preference shown for the Ionic volute seems reasonable, that's likely based on the fact that as observers, we have the same hard-wired preferences. What would be useful to know is why this is apparently true. Neuroscience experiments validating this hypothesis would need to explore this question.

TRACERY PATTERNS IN GOTHIC WINDOWS

Figure 3–5 is a drawing of a typical rose window similar to those in windows of Gothic churches. All the harmonious relationships of the tracery (stone settings for stained glass) design are generated by the golden mean and are symmetrical both horizontally and vertically. It seems likely that we respond positively to the harmonies in this design because we are hard-wired for the golden mean.

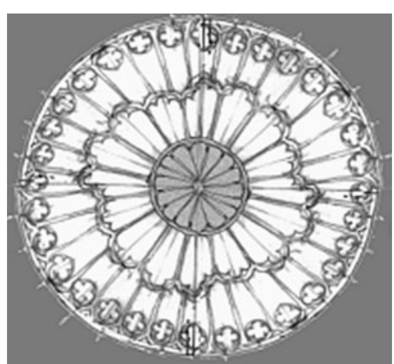


Figure 3–5. Gothic traceries.

Vitruvius

Vitruvius (b. circa 70 B.C.) was a Roman architect-engineer and author of the celebrated treatise *De Architectura.* Throughout the revival period of the Renaissance, the classical period of the Baroque, and the neoclassical period, he was the prime authority on rules for architecture. His famous dictum that all buildings should meet the tests of "commodity, firmness and delight" is still important today. I propose that in addition to the vast amount of research neuroscientists devote to studies of disease, they should look at the positive aspect of human responses incorporated in the concept of delight. This ancient Roman wall in Madrid (Fig. 3–6) is a clear expression of three-part harmony embodied in the main arches with an overlay of counterpoint design elements above them.

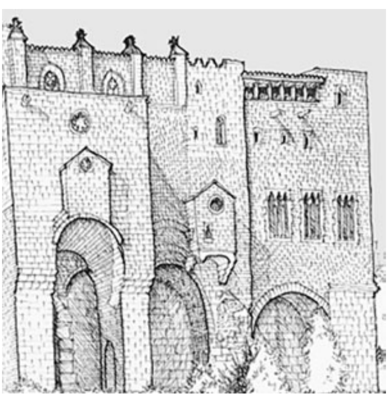


Figure 3–6. Roman wall in Madrid.

Alberti

In 1443, Alberti was inspired by one of his patrons to restore the classic text of Vitruvius. As a result he produced a whole new work called the *Ten Books on Architecture*. These books became the bible for all Renaissance architects. This design theory grounded the stylistic principles of Vitruvius in a fully developed aesthetic theory of proportion and harmony (see Fig. 3–7). The facade of his 1472 design for Saint Andrea in Mantua was organized around his rules of the "rhythmic bay" (repetition of the proportions of the five design elements). Alberti, unlike his fellow

Figure 3–7. Alberti proportions.

architects in the Renaissance, was a brilliant theorist, historian, scientist, and humanist, and he left an important body of essays, plays, poems, and letters. His 10 books of architecture emphasized the intellectual requirements for the practice of architecture—the mastery of geometry, mathematics, philosophy, and the Classics.

Palladio

Palladio was born in 1508 in Venice and is generally regarded as the greatest architect of 16th-century Italy. The harmony of his window design (Fig. 3–8) is derived from the proportions of the golden mean. Today this window design—called Palladian—is popular in homes.

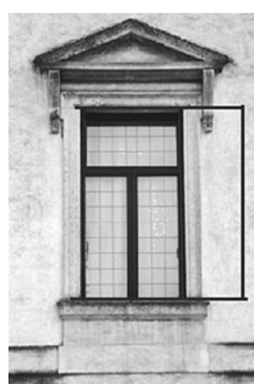


Figure 3–8. Palladio proportions.

Conclusions

All of these examples from history seem to clearly indicate an inherent response of the human brain to symmetry as well as harmony and proportions related to the golden mean. Organizations such as the Smith-Kettlewell Eye Research Institute at the California Pacific Medical Center in San Francisco have undertaken research on how the human visual cortex processes visual symmetry. Tyler (2000) said:

> Symmetry is an example of a cue that plays a profound role in object properties and requires long-range integration of object features across parts of the image. The reason for the perceptual salience of symmetry is unknown, but it can be argued that symmetry is a useful cue for discriminating living organisms from inanimate objects. That it is an important visual cue to humans is evident in the recurrence of symmetric patterns and designs throughout human history in the constructed environment from architecture and art to furniture and transportation.

The work of this institute has not yet included studies using architectural images, but I hope they might soon include architecture in their portfolio.

Later in this chapter, I discuss three other approaches to vision that seem to suggest ways that visual images of architectural settings are processed in the brain. It may be productive to link the work on voxels in the parahippocampal place area (PPA), described next, to a study of how we respond to symmetry and harmony in the design of buildings.

VOXELS IN THE BRAIN THAT EXPRESS BUILDINGS

In a series of experiments, Epstein and Kanwisher et al. (1999) demonstrated that the PPA responds more strongly to spaces and places than to other kinds of visual stimuli—that is, the PPA is significantly more active when subjects viewed complex scenes, such as rooms, landscapes, and city streets, than when they viewed photographs of objects, faces, and other kinds of visual stimuli.

The voxels that are active in the PPA are in the lingual sulcus (shown in Fig. 3–9) running almost parallel to the voxels used for face recognition—fusiform face area (FFA). The PPA activity is greater when a person is viewing a novel place or space, as contrasted to a repeated view. PPA recognition activity is apparently not affected by how familiar a person is with place being viewed, nor does it seem to increase when a person experiences a sense of motion through the space. The evidence provided by the research indicates that the PPA does not get image information from memories; it is not involved in the process of wayfinding, and it does not participate in monitoring a person's movement through the local environment. The PPA, however, does seem to be the place where we encode new perceptual information about the appearance of layout of places and spaces.

Other studies have shown that the formation of the voxels used for place and face recognition is formed over a long period of development in the brain. It appears that more neurons are gradually encoded as the result of accumulated experience. Eventually, we reach an adult stage that is proficient in the processes of both face and place recognition.

Hypothesis 3–2

Recognition of architectural features is impaired when ambient lighting conditions are below a certain threshold.

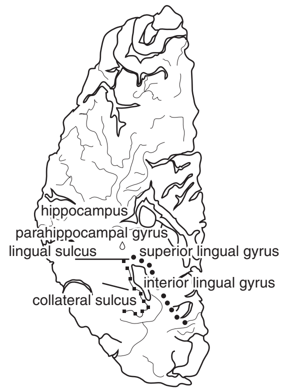


Figure 3–9. Lingual sulcus.

Comment: The amount of illumination is measured in *lux* (amount of illumination)). A threshold level has some basis in the visual system of the brain. What that might be and why it responds in this manner would be useful to know. Future research in how our brains recognize places and spaces in architectural settings should consider the role of light in providing the needed visual stimuli.

VISION

Goodale (2000) has identified the following general pattern for vision as shown in Figure 3–10. There are two broad streams of projections for the visual information entering from the eye—the ventral stream and the dorsal stream. The ventral stream's transformations focus on the lasting characteristics of objects and their relationship to each other, for example, size, shape, color, and brightness. This permits long-term perceptual representations—a knowledge base about the world. The dorsal stream's transformations provide moment-to-moment information about the location and disposition of objects, enabling the visual control of skilled

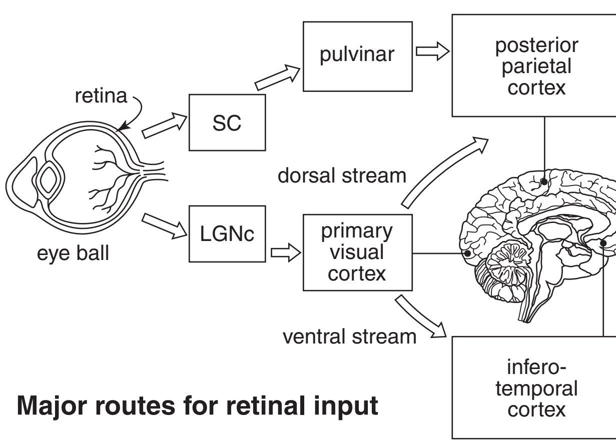


Figure 3–10. Visual process.

actions (like making drawings). These transformations are not stored but are new for each use.

Hypothesis 3–3

The transformations of the ventral stream focus on size, shape, color, and so on of an architectural setting provides long-term perceptual knowledge that enables humans to recognize specific buildings, for example, the U.S. Capitol in Washington, D.C.

Comment: Though research by Goodale and others has identified the general patterns of visual perception, to the best of my knowledge this has not included the relationship of these patterns to specific buildings.

The Visual System

The remarkable human visual system (see Fig. 3–11) needs the light reflected from the objects to let us know where they are in our environment (even when they are as small as an ant on a blade of grass or as distant as the moon). Our visual system needs to make it possible to use the object's shape, size, and color to help in recognizing it. The system needs

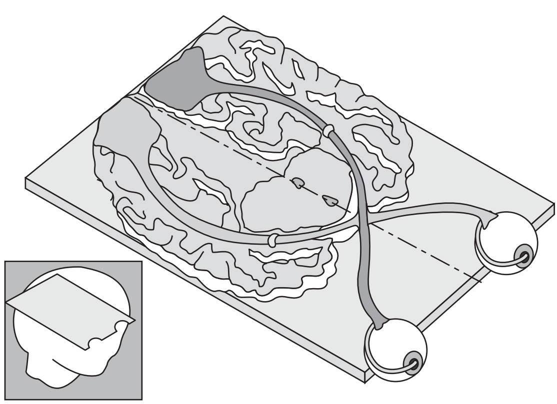


Figure 3–11. Visual section through brain.

to make it possible to "freeze frame" a moving object so it is not just a blur. The visual system needs to do all of this under a wide range of lighting conditions.

Most projects by students in architectural schools are judged by the visual perception of their teachers, and you will recall that architectural awards are based on photographs of buildings. The photographs provide an architectural jury with images (visual perceptions) that are intended to provide a sensory experience of a building without actually visiting it. The profession should be learning from neuroscience that perception is totally integrated across all of the senses. Concentrating on visual images alone is like falling in love with the photograph of a person without ever meeting him or her.

The Basics of the Visual System

Nearly half of the brain's cerebral cortex is used to process visual signals, more than any other sensory system. The eyes are the input component of the visual system, but the eyes do not see anything until the visual cortex of the brain is stimulated by signals from the retinas. These signals are processed by the ganglions associated with the retinas and then transmitted to the back of the brain (the visual cortex, see Fig. 3–12) via the optic nerve. Once signals from the optic nerve have stimulated the various sectors of the visual cortex, the perceived image is assembled in the primary area of the visual cortex (known as the V1 area). *Perception* of an object does not occur until the mind assembles the necessary memories associated with such objects. *Recognition* does not occur until the mind

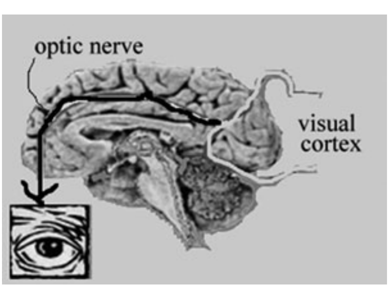


Figure 3–12. Visual cortex linked to eye.

locates a memory that gives meaning to what is being perceived. As an example, a child might perceive the letter A as a simple pattern of lines, but does not recognize it as a part of the alphabet or know what to call it until she has learned her alphabet and stored this knowledge in memory.

Visual images begin with a stream of photons that strikes the retina of each eye. A thin layer of neurons and glial cells line the inside surface of the eyeball. This layer captures and transduces the photons into changes in voltage. The *rods* that perform this function translate these messages as black, white, or shades of gray. *Cones* are sensitive to wavelengths of light; one type responds especially to the long (or red) wavelengths, others to the medium (or green) wavelengths, and the third type to short (or blue) wavelengths (see Fig. 3–13). A small network of neurons in the retina starts analyzing these signals and converts the cones' firing rate. These signals, processed by the ganglion cell layer (just behind the retina), are the sole pathway from the retina to the rest of the nervous system. The resulting cell activity signals the brain centers to move the eyes and focus the foveas

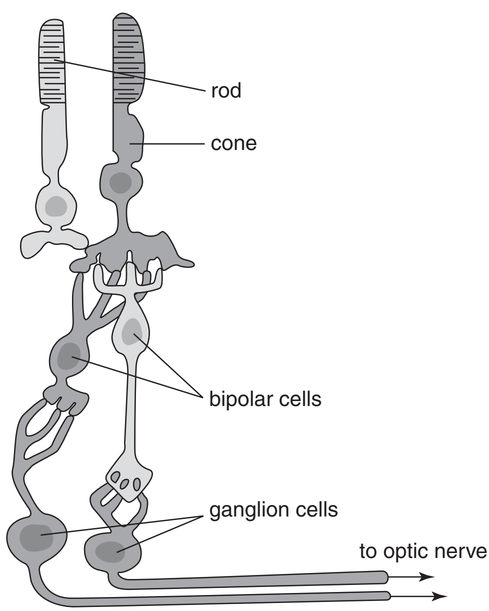


Figure 3–13. Rods and cones of retina.

(the small, central regions of the retina used to discern details) on the target to examine its details.

From this point on, the visual signals are transmitted along the optic nerve to the back of the head and are then subdivided into multiple pathways. Most of the signals from the left eye go to the right side of the visual cortex, and those from the right eye go to the left side of the visual cortex. Each of these separate pathways is a parallel process that allows analysis and feedback to be done more quickly than if it was carried out sequentially.

The six specialized areas of the visual cortex are shown in Figure 3–14 and listed here.

- V1: The primary area, where all of the inputs are assembled.
- V2: Produces stereo vision (an image in each hemisphere made up of pixels—like newspaper photographs).
- V3: Depth and distance are added (a kind of topographic process).
- V4: Color is overlaid (but not exclusively in this area).
- V5: Motion is "frozen" for a split second for recognition to take place.
- V6: Designates the specific position of object being viewed.

The outputs from regions V1 to V6 provide inputs to various regions of the brain. For example, the parietal areas deal mainly with *where* objects

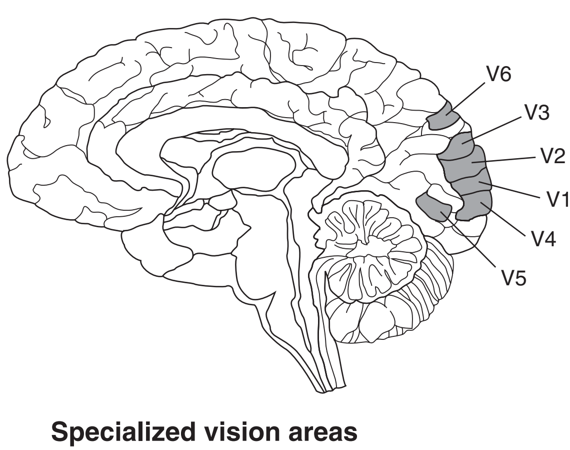


Figure 3–14. Specialized vision areas of cortex.

are in space, and the temporal cortical areas analyze the form of the objects to provide information on *what* is being seen.

Neuroscientists call the assembly of these separate bits of information a "binding" process. A functional activity in the thalamus (see discussion of the thalamus in Appendix 2) sweeps the brain at 700 times per second looking for neurons that are oscillating at 40 hertz. When these are found, they are bound together in some way that is not entirely understood. However, only one image is seen, including its color, and it will be in focus (with the aid of glasses for some people)—one of the many spectacular abilities of the brain.

LIGHTING DESIGN IN ARCHITECTURAL SETTINGS

"Although many of the characteristics of quality seeing conditions are known, it is a difficult area to define precisely. Research continues in an effort to *uncover knowledge of how people see* and what kind of lighting conditions are most desirable for every situation" (Ramsey & Sleeper, 1988). This statement is found in the lighting design section of *Architectural Graphic Standard.* The emphasized statement indicates a recognized need for more research on how human vision works to better design lighting conditions. The material provided by *Architectural Graphic Standards* includes a table that can be used to determine appropriate illuminance values for various types of activities and another that indicates the color appearance perceived for various lamps.

Architects normally use lighting consultants (or lighting engineers) for any project that is reasonably complex. Consultants are often members of the Illuminating Engineering Society (IES). Because architects will have had a course in lighting design during their school years, they will often design lighting for relatively simple settings themselves.

Lighting Conditions

Lighting conditions range from lighting to perform work (including reading, assembling parts, etc.)—commonly referred to as task lighting—to light used to reveal the spatial volume, plans, ornaments, and colors of architectural spaces. Light is also used in buildings to draw attention to points of interest and assist people in finding their way. Especially important in many places today is providing a sense of security by providing sufficient light to make objects or people visible.

Hypothesis 3–4

Raw information (e.g., words on a printed page) will not be processed beyond the visual cortex unless the lux (see following pages) measure is above a certain level.

Comment: When performing a visual task, the light that reaches our eyes and is therefore laden with the raw information for our mind is usually reflected light—that is, light reflected off the details of the task (typed letters), the immediate background (paper), and the surround (desk top and room). In this context, *light* is defined as electromagnetic radiation that can be detected by the human eye.

Vision, the Brain, and the Mind

Our responses to architecture—the assembled attributes of a space—will be largely unconscious. For example, the quality of light in the space will be registered not only by the lumens (a measure of the amount of light; used in calculations regarding artificial lighting) that send signals via the retina to the visual cortex, but also by the response of our body's homeostatic system. Our perception of how bright (in lumens) the light is cannot be controlled by any act of willpower on our part. How our body responds to too much light or too little light depends on age and our circumstances at the time. If you are trying to read the small print on the label of a medicine bottle, you will need more light than if you are sitting quietly listening to music and reading. How we respond psychologically to light is a complicated phenomenon only partially understood. For a small child who is afraid of the dark, light is comforting by its presence alone.

For an adult in a working environment, the amount of ambient light is important, but so is task lighting that shines on your work surface; the availability of daylight is likely to be important to you psychologically.

Hypothesis 3–5

The visual system's attention span—especially the visual field in the peripheral area—is restricted by the size of a window's opening.

Comment: The visual system's PPA has been shown to respond strongly to buildings, landscapes, and city street scenes. Often these stimuli are viewed through windows, where the content of the "view" is constrained by the size of the opening.

The Problem of Glare

Although there is general enthusiasm in the architectural community for large windows that allow natural light into spaces used by people and provide views out from those spaces, there is reason to be cautious. There has been a good deal of research in the past few decades on the problem of discomfort glare. This is caused by too much light from windows falling on working surfaces that are not well lit.

There are two solutions available to architects: (1) Use reduced transmission glass in an appropriately artificially illuminated environment. (2) Increase the level of artificial light to reduce the luminous contrast. The second solution has an added caution from the research community. They argue that there is no evidence of either a psychological or physiological need for natural light in the daytime work environment. They point out that daylight cannot be "seen" and that only conjecture supports the contention that the human eye can differentiate natural light's magnitude.

The design of buildings today also requires attention to reducing energy consumption. This can pose a problem when there are conflicts between adjusting brightness levels and still providing a satisfactory solution in terms of energy use.

Hypothesis 3–6

The cognitive activity of the brains of children working at desks in an environment of discomfort glare is impaired from those in nonglare environments.

Comment: This hypothesis is likely to be proven incorrect; either because children's visual systems adapt easily to glare conditions or because stress on the visual system does not translate into reduced cognitive ability. It would be of value to the architectural and education communities have evidence of this kind.

Every experience we have is the result of activities of our brain, mind, and consciousness. Consequently, every experience is unique to an individual—to our genetic inheritance, our lifelong accumulation of memories (both conscious and subconscious), and our place in the world. Other people can influence, for good or bad, the character of the architectural setting in which we have an experience, but they cannot change our personal perceptions or the autobiographical history we bring to the event—at least not in the short term.

The brain is constantly changing. Its raw material is information from the senses—vision, hearing, smell, touch, taste, and proprioception. From this information the brain creates a perception of what lies outside. However, these ideas are not truly useful until they are invested with meaning. The meanings we attach to perceptions transform mere patterns of light into buildings we can use, people we can love, or music we can enjoy. Our visual system is the most active of these information-processing systems.

How the brain perceives is the result of how it has evolved (and consequently the kind of vision we have available). The design of the brain is not the most perfect design conceivable, nor is it merely good enough to get by. It is the product of a historical sequence of changes, each one of which represented, at best, the better of the alternatives (mutations).

A neuroscientist studying the structure of the brain and its processes is like a computer engineer analyzing a system's performance when the programs used to activate the computer have been lost. Our brains seem to work in well-organized, logical ways, but we don't have the blueprints for this design. Natural selection cobbled together the equivalent of a machine code for a computer by favoring mutations that modified successive generations of the brain to behave in ways appropriate to our survival—including our visual system.

OTHER COMMENTS ON PERCEPTION, VISION, AND THE DESIGN OF OBJECTS

There are three sources for dealing with vision and perception I have found useful. These publications are related to design, the images produced by design, and how the brain forms perceptions.

Rita Carter (1998), in *Mapping the Mind*, has a special observation regarding perception. We construct a perception of the external world that is different—because our brains are unique, no two people have exactly the same number of motion cells, red-sensitive cones, or cells that are sensitive to straight lines. An individual's view is formed both by his or her genes and by how his or her brain has been molded by experience. Even though the raw data in the external world are the same, perceptions vary. There is no definite picture of "what's out there," only a construction in our heads triggered by the external elements we are best equipped to register.

Musicians, for example, have been found to have, on average, 25% more auditory cortex, used for musical processing, than do other people. The greatest amount of extra "music" area is found in those who started to play earliest.

Hypothesis 3–7

Architects who have graduated after at least 5 years of study and who have passed the national architectural examination for a license have 25% more of their visual cortex used for processing building images than other people.

Comment: As discussed earlier, the work done by Epstein and Kanwisher et al. (1999) has shown a strong response to images of building by the voxels in the PPA. To the extent there is a parallel with how musicians' experience has been found to increase the amount of the auditory cortex, it would be useful to know if the extensive experience of architects increases the amount of the visual cortex.

There is a hypothesis that people who are deprived in infancy of the sight of one particular visual element—horizontal lines, say—are bad at or even incapable of discerning them in adulthood because the cells that would normally detect this visual component fail to develop. So far, there is little evidence in humans, although studies of people raised in the special light of rural India have a bias in their color vision.

Donald D. Hoffman, a professor of cognitive science, philosophy, and computer science at the University of California, Irvine suggests (Hoffman, 1998):

> "Just as scientists intelligently construct useful theories based on experimental evidence, so your visual system intelligently constructs useful visual worlds based on images at the eyes."

Hoffman proposes that there is a basic element of human intelligence shaping our experiences, using roughly 50% of the brain, but not generally known—visual intelligence. Our eyes actively construct every aspect of the visual experience—from the colors of a stained glass window to the dark spaces of a cathedral's narthex. Hoffman argues that we construct a special grammar of vision. As with grammar in language, visual grammar is a set of rules that govern perception of a line, of color, form, depth, and motion.

We use this visual intelligence to explore architectural places in their settings or to do somewhat the same thing by producing images with computers (virtual reality). Figure 3–15 is a famous demonstration of how the visual system dictates to the brain things that are not real. Although they may be clear to you, these triangles (devised in 1955 by G. Kanizsa) are invisible to a photometer (which measures light), and there is no

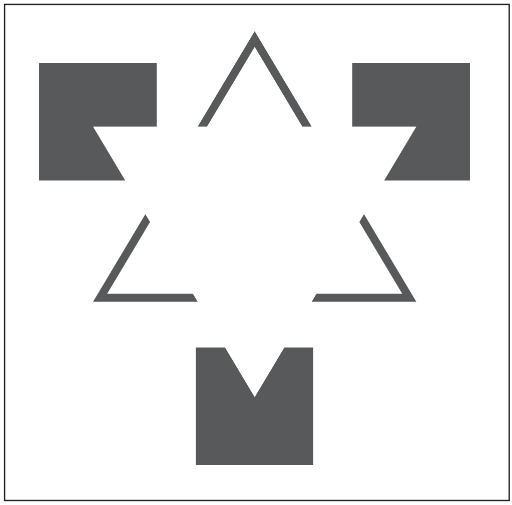


Figure 3–15. Kanizsa diagram.

change in the brightness of the paper inside and outside the triangles. Your rules of visual grammar lead you to construct these triangles, even as your reasoning brain knows they are not real. Therefore, subjective figures, like the triangles, are not just a trick of our perceptual system, but are the way we see all the images in the world around us.

Semir Zeki, professor of Neurobiology at the University College London, has still another approach. He suggests in *Inner Vision* (Zeki, 1999) that artists' work and the science of vision may seem distantly related, but really are not. Leonardo da Vinci wrote that of all the colors, the most pleasing are the ones that constitute opponents; he was stating a physical truth about the visual brain. However, this fact was verified only 40 years ago through the discovery of opponency—by which cells in the visual system that are excited by red are inhibited by green, those excited by yellow are inhibited by blue, and those excited by white are inhibited by black. Zeki describes in compelling detail how different areas of the brain respond to elements of the visual arts, such as color, form, line, and motion, and argues that our experience of art (and by implication architecture) relates strongly to how the brain works.

Zeki's book is more about how the brain responds to aesthetics than it is about art as such. He believes the function of art and the function of the visual brain are more or less the same—in fact, he believes that the aims of art constitute an extension of the functions of the brain. It is even more difficult to say much about how and where the aesthetic experience (like an architectural design) arises from the work, or about the neurology underlying the emotional experience that an architectural design arouses.

CHAPTER FOUR

Memorials, Sacred Places, and Memory

Any experience a human has is processed within the brain—not in one's "aching heart," not in the "pit of one's stomach," not in the "music of the spheres," nor in an audible "cry of anguish." All of these metaphors are useful for poets to convey a semblance of the emotions being experienced by a conscious being, but they are not the *experience* of a sacred place or a memorial to those who have died. Neuroscience has scarcely touched the subject of how we experience architectural settings—especially those that are sacred.

EMOTIONS AND BEHAVIOR IN ARCHITECTURAL SETTINGS

> *Architecture moves us. It can comfort us or intimidate us; it can enlighten us or mystify us; it can bring joy or tear at our hearts. Architecture moves us by touching three layers of memory. Through primal space it can touch our deepest emotional core; evoking shadow memories of the womb, the cave, the forest, and light. It can recall memories of culture, or our place in the historical world. Personal memories add overlays of subjective meanings, as buildings are associated with events in our lives.*
>
> —CHRISTOPHER EGAN, ARCHITECT, SAN ANTONIO

Figure 4–1. Darmstadt church. This is the interior of a Lutheran church in Darmstadt, Indiana, for which I served as architect in 1956.

Many architectural settings are designed to evoke emotional responses from those who visit or occupy them, but only rarely does a setting clearly affect everyone who experiences it. The great cathedrals of Europe have an impact of awe on those who visit them, especially the first time. Other places of worship around the world, used by a wide variety of religious groups, can also inspire a sense of reverence in the casual visitor as well as the faithful—not always, but sometimes.

However, it seems that often in the design of memorials to those who have died, the architectural setting can evoke those deep responses Egan so eloquently describes. This chapter explores a number of memorials and then looks at some of the neuroscience literature on emotions and behavior. It concludes with frameworks for considering how neuroscience explorations might further help us understand why we have such responses to evocative architectural places.

A FRAMEWORK FOR ARCHITECTURAL EMOTIONS

For people who have visited an architectural setting—such as the U.S. Holocaust Memorial Museum in Washington, D.C.—that has provided them with strong emotional responses, it is likely that simply showing them images of that setting will reconstruct their nonconscious emotional experiences and allow them to verbally express their thoughts. Their emotional responses may range from fear to joy. Identifying where in the brain these emotions are being generated (by MRI scanning) and then hearing about the feelings the subject is experiencing can set the stage for the next round of studies.

In the second stage—having identified where in the brain emotions responsive to an architectural settings are located—it would be possible to test hypotheses such as whether the Gothic design of churches evokes a stronger emotional response than does that of modern or contemporary designs. Or, one could test whether subjects with positive emotional responses to buildings retained in their dispositional memories will have negative responses (as exhibited by activation of the amygdala) to building designs that are significantly different; for instance, strong emotional responses to schools (by people who are over 50) attended as a child may trigger negative responses to more modern schools. Both hypotheses could help architects understand the response of building committee members to their design ideas and raise questions that may point to a compatible solution.

In the second stage, more fundamental issues of architectural experiences could explore whether dark interiors in restaurants can produce emotional responses (at a subconscious level) related to fear that will conflict with the intention of designers to provide a relaxed setting. In much the same way, it might be possible to test whether bright colors on the interior of classrooms produce emotional responses in children that are recognized as anxiety.

Primary and Secondary Emotions

Antonio Damasio (1994) has said that feelings are critical to sensing the biological variations produced by experiences. These feelings enable us to sense the states of our body that are painful or pleasurable—producing such emotions as bliss, longing, mercy, and so on.

Our understanding of how our brains produce emotions responsive to art and architecture will not devalue the emotional experiences or the importance of their role in our lives. The mind needs the input of the body's states for its base. These states include mental phenomena that can be fully understood only in the context of our interactions with art and architecture. This is true even if it is our mind that creates the art and architecture in the first place. The body state provides basic images for representation in the brain, and the body's experience with art and architecture embellishes these representations. The creation of a new art object or architectural setting is based on neuronal activities within a brain, provided that brain has been and is currently interacting with its body.

In conclusion, Damasio provides a summary by saying we come into the world with automatic survival mechanisms, such as a physiological kit to regulate metabolism. As we emerge from the child development stage, we add socially permissible strategies through education and acculturation. The total assembly enhances survival, improves the quality of how we survive, and becomes the basis for constructing the self. This self, when it interacts with a given culture, produces something unique to humans—a moral point of view that sometimes can transcend the immediate selfish interest of our species and produce art and architecture to enrich the lives of all who come into contact with it.

Damasio goes on to discuss primary and secondary emotions. Those more or less automatic responses we have to things we fear are primary. We are wired at birth to fear large animals, flying eagles, snakes in motion, the sound of an animal growling, or pains indicating a heart attack. Each of these fears are processed by components of the limbic system, especially the amygdala.

These primary emotions produce changes in our bodies over which we have little or no control—such as blushing, doubling up in pain, or showing fear on our face. Anyone who observes us under these conditions can see that we are experiencing an emotion (or what Damasio also calls an expressed feeling).

Once we begin to form a primary emotion, there is likely to follow a secondary emotion (see Fig. 4–2) that reflects our cognitive interaction with the object that has produced the primary emotion. In fact, we can generate secondary emotions just by remembering an event that produced a primary emotion—such as the first time you walked into the vast open space of a church. If we are responding to an experience we are having in real time, for example, walking into the Washington National Cathedral (see Fig. 4–3) for the first time, we call forth from memory a record of other cathedral experiences we have had. Damasio calls these records

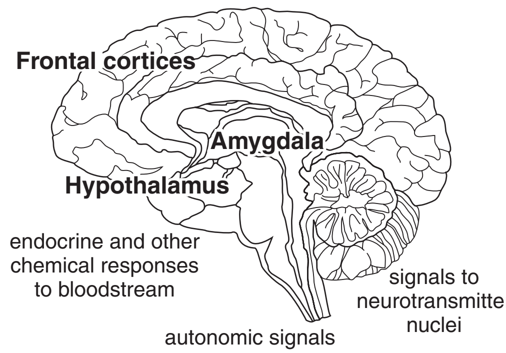


Figure 4–2. Secondary emotions chart.

"dispositions." They come with memories of all of the sensory experiences we had with these cathedrals and include the emotions we experienced when visiting them.

The process is cognitive—mental images organized in a thought process—concerning such aspects as your previous experiences with cathedrals in general or with the Washington National Cathedral in particular. Such cognitive evaluations might include personal relationships or other situations. They are derived from and guided by dispositions held in memory.

Networks in the prefrontal cortex automatically and involuntarily respond to signals arising from the processing of these images. The prefrontal cortex response comes from the dispositional representations that

Figure 4–3. Washington National Cathedral.

"remember" how certain past experiences have been paired with emotional responses.

Even though the relations between the type of situation and an emotion are similar among individuals, a person's unique, personal experience customizes the process. The prefrontal acquired dispositional representations needed for secondary emotions are separate from the innate dispositional representations needed for primary emotions—even though the secondary emotions need the primary emotions to express themselves.

MEMORIALS IN WASHINGTON, D.C.

Architects consult and work with many other professionals and use their expertise to design memorials. I propose that the neuroscience research community participate in these important issues by organizing and conducting studies of how and why humans respond to various attributes of memorials and concepts of appropriate honor.

Washington, D.C. provides the largest collection of memorials in the United States. The National Mall, extending from the Capitol to the Lincoln Memorial, is in its design a unique national memorial space. Located within it are a number of architecturally designed areas dedicated to the memory of an important person or event in the life of this nation. The essential plan was created in 1902 by architects Burnham, McKim, and Olmstead, who were part of the McMillan Commission's charge to create a plan for the park system of the District of Columbia.

Whenever new memorials and museums are proposed for the National Mall space, there is a conflict over their design. The classicism that Burnham, McKim, and Olmstead took for granted when they made their proposals has long been superseded by so-called modernism and its variants. These controversies always raise questions: What will the new memorial look like? What other designs were considered? How effectively can the proposed design serve as a national memorial? The answers to these questions are largely matters of judgment and are often settled by appointing a committee to render a collective opinion.

The U.S. Holocaust Memorial Museum

In 1986, James Ingo Freed, an architectural partner in the firm of Pei Cobb Freed & Partners in New York, began the most difficult commission of his life—the design of a memorial to the millions who perished in the Holocaust of World War II. In 1939, when Freed was a boy of 9 living in Essen, Germany, World War II was just beginning. The Third Reich's 6-year reign of terror soon implemented its ghastly instruments of destruction and genocide. Freed and his parents were fortunate enough to escape to the United States. He could not forget how fortunate he had been. When he visited Auschwitz later, in preparing for his design of the Holocaust Memorial Museum (see Fig. 4–4), he says, "I began to feel some strong emotions. If I had not left Germany when I did, I would have been one of those who perished here."

In his design, Freed struggled to rekindle his memories of Auschwitz. Instead of reconstructing a memory of the atrocities, he wanted to create a building with spaces that would resonate memories that were primal in character. The form, movement, sounds, and materials of the spaces had to be, in part, the same as the death camps, but not so much as to appear to be a theme park. He wanted the visitor to leave with a feeling of imbalance, irresolution, incompleteness. Architect Arthur Rosenblatt, who served as a consultant to the Holocaust Memorial Council and who had recommended the choice of Freed to be their architect, says, "Not many buildings are evocative of emotions. Where the Holocaust Museum is unique is that it subliminally releases an emotional narrative." The building as such does not convey this narrative, because from a distance

Figure 4–4. U.S. Holocaust Memorial Museum.

it looks like any other limestone federal building around the National Mall.

Don Oldenburg has written:

> It is the interior spaces where the visitor begins a procession that draws them into an architectural sphere of gravity that is unique.
>
> Tourists who pass through the doors into this interior have faces that are somber with anticipation. Two entrance gates funnel crowds into the Hall of Witness. From several stories above, sunlight passes through the vast skylights and intersects with diagonal steel beams to cast eerie shadows across the large, crowded floor. People wait their turns to enter the elevators that lead upstairs to the permanent exhibition. Each visitor is given an ID card from an actual Holocaust victim to take with them on their journey. They are herded into small elevator chambers behind ominous, heavy metal doors that clang close behind them.
>
> The fourth floor where the exhibition begins is dark, the walls and ceiling are muted black that seems to absorb the dim light of the exhibits. One wall-sized photograph is immediately overwhelming: the gruesome scene American GIs witnessed when liberating the concentration camps with countless starved and distorted bodies tossed in piles. The floor plan requires the visitors to shuffle slowly in ill-defined lines. Glass-cased displays on both sides bounce back reflections at irregular angles creating the feeling of deception. Crowds of visitors are forced toward a glass-enclosed footbridge whose walls are etched with names of 5,000 cities, towns and Jewish communities of Eastern Europe destroyed by the Nazis.
>
> Light dims beyond the bridge with each new space changing from low to high, crowded to open, captive to released, darkness to light, the architectural forms seem to bear their own witness to the process of mass murder. And, then suddenly, the museum is about life, about lives. A gallery room displays striking black and white photographs of pre-camp Jewish life.
>
> It leads into the stunning, three-story tower of the Shtetl Collection of photographs, hundreds of them taken over 50 years of people and their town, all wiped from the face of the Earth. The visitor sees row after row of faces some 30 or 40 feet above them. These are the smiling, loving, playful, kind faces that reappear in other photographs as skin-drawn skulls and twisted cadavers.
>
> As one rounds the next corner there are stairs that lead down to a floor where a sign announces: "Final Solution." Visitors cram together again. The

Figure 4–5. Holocaust Memorial Tower.

ceiling seems lower. Footsteps pound across the wooden bridge ahead that leads through a death camp gate and past dreary remnants of the Warsaw ghetto.

A gloomy train boxcar used to deliver Jews to death camps and the segment of concentration camp barracks beyond it deliver similar messages of death—a model of the gas chambers where thousands of victims were stripped of their clothing and dignity, then pressed into "the showers" to die. Another narrower hallway passes by thousands of musty shoes taken from the death camp victims. Most visitors at the end of this journey finally read the identification card they received when they entered. They find that their assumed person perished in one of the camps.

Figure 4–6. Holocaust Museum Hall of Remembrance.

Finally there is the Hall of Remembrance, a six-sided, minimalist, open space that provides calm after the storm. Its light streams from above, and hundreds of lit candles flicker in memory of the 6 million Jews and millions of others persecuted and killed. This is a catacomb of contemplation, the ending that invites reflection. Light penetrates deep within this spiritual space.

Modern and Classical Architecture of Places on the National Mall

Nathan Glazer, (Glazer, 2007) has written about the design issues surrounding memorials. He introduces the subject of monuments by saying:

> A successful monument incorporates symbolic meanings, without embarrassment, as its origin, and it can carry new meanings attributed to it over time without any necessary diminishment. The human figure, the obelisk, the pyramid, the column, ancient forms all, inevitably can carry many meanings, and continue to do so while aesthetic tastes, elite and popular, change.

Glazer proposes that modernism begins by placing an emphasis on the functional aspects of architecture. Its advocates suggest that it reflects a new social aim: priests and princes no longer dominate us, we abhor war and hope for eternal peace. The early practitioners of modernism intended to design better dwellings, schools, and factories—not grander palaces and tombs. Glazer suggests:

> How, then, can the desire for celebration and memorialization be satisfied by modernism? . . . The dilemma of modernism in dealing with the monument is that while it begins, at least in architecture, with the idea it will accommodate the needs and uses of ordinary men and women, economically and directly, it has undergone an evolution and development in which the architect and artist become creators of the new and astonishing. They do not find it easy to celebrate the common ideals and emotions of a community. It is more likely that they celebrate themselves.

He points out that modernism as advocated by artists and architects is based on a rejection of community views and the celebration of the new and rebellious. How, then, can advocates of this style also believe their personal views are representative of the average person in the street's notions of appropriate memorials?

At the time of the McMillan Commission for developing the National Mall, there was only one monument in that space—the Washington Monument (see Fig. 4–7). This is the most prominent monument in the nation's capital. It is among the world's tallest stone structures, standing 555 feet high, and is made of marble, granite, and sandstone. Robert Mills, a prominent American architect of the 1840s, was the original designer. The completed monument was dedicated on February 21, 1885 and officially opened to the public on October 9, 1888.

The proportions of the Washington Monument were determined by a study of the ancient obelisks of Egypt. More then 5,000 years ago, Egyptians followed the same design criteria—their height was 10 times the width, and the top was a pyramid with sides that sloped at 60 degrees. When I have shown people alternative shapes of obelisks, they always pick out the one with the same proportions as the actual monument.

Hypothesis 4–1

Humans are hard-wired to respond to the proportions of an obelisk.

Figure 4–7. Washington Monument.

Figure 4–8. Lincoln Memorial.

Henry Bacon designed the Lincoln Memorial (Fig. 4–8) after ancient Greek temples. It stands 190 feet long, 119 feet wide, and almost 100 feet high. The north and south side chambers contain carved inscriptions of Lincoln's second Inaugural Address and the Gettysburg Address. Daniel Chester French sculpted the statue of Lincoln, which is just over 19 feet high and weighs 175 tons. Construction began in 1914, and the memorial was opened to the public in 1922.

Just about everyone who has ever visited the Lincoln Memorial has experienced the sense of something special. It's not just the design of the place, or the way that Lincoln's statue dominates by its presence, or the prospect of the National Mall stretching beyond the view from the entrance, but something larger. Somehow the combination of these features—especially at night—clearly sends a message that this is a space sacred to the nation. This seems to be true even for visitors from other countries.

Hypothesis 4–2

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. (Even though the qualia associated with "awe" are elusive, we all seem to know what it means.)

The General Ulysses S. Grant Memorial (see Fig. 4–9), designed by Henry Merwin Shrady, consists of three separate groups of sculpture. Grant sitting on his horse, Cincinnati, was dedicated on the 100th anniversary of Grant's

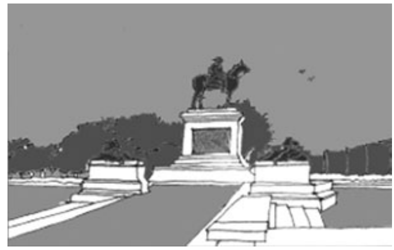


Figure 4–9. Ulysses S. Grant Memorial.

birth, April 27, 1922. Statues of fighting Union artillery on one side and a cavalry group on the other side flank Grant's equestrian statue.

After World War I, many people had memories filled with dispositions related to the military. In the 1920s, there were many people with sufficient recall of stories told them about the Civil War to whom Grant was a hero. Today, it is less likely that General Grant, as a person, stirs many memories. However, a memorial of this scale adds to the ambience of Washington, D.C., as the nation's capitol.

Hypothesis 4–3

When subjected to images of Civil War military figures, people under 50 years old show no emotional response.

The Thomas Jefferson Memorial (see Fig. 4–10), by architect John Russell Pope, was completed in 1943 after a long battle over its design. Some commissioners appointed to build the memorial wanted it to be modern in its design, whereas others (who eventually won) wanted it to

Figure 4–10. Jefferson Memorial.

be classic. The walls are engraved with passages from Jefferson's writing, including, "I have sworn upon the altar of God eternal hostility against every form of tyranny over the mind of man."

An informal survey of visitors to both the Lincoln Memorial and the Jefferson Memorial showed that the sense of awe experienced in the Lincoln Memorial is not repeated in the Jefferson Memorial. I do not believe this is because Lincoln is more popular (although he clearly is), but because the architectural setting is different.

Hypothesis 4–4

Subjects who view architectural settings with light and dark areas (in virtual reality displays) register higher emotional responses than when shown architectural settings with only well-lit areas.

In 1982, a major departure from classical memorials was initiated by the winning design for the Vietnam Veterans Memorial by a young student sculptor, Maya Lin. Her design was surrounded by controversy when it was first shown to the public. The design community was enthusiastic in their support, and the veterans community was initially unanimous in their objections. Today is is the most popular memorial on the National Mall—with almost 3 million visitors each year. The following is a well-written tribute by Jack Perlmutter (1977).

Figure 4–11. Vietnam Veterans Memorial.

We come to the black wall of the Vietnam Veterans' Memorial that sweeps the grounds of the Mall in our nation's capital and grow silent, for the wall creates its own overwhelming experience. Walking the wall is a participatory ritual, engulfing the visitor with the power of war and the loss of 58,000 Americans who died in answer to their country's call in a disputed war.

- They speak out to us through the architecture of this place.
- They speak to a family who leaves a spray of red roses.
- They speak to a schoolgirl who touches a white-etched name and senses the sadness.
- They speak to a stranger who pauses.
- They speak to one who has located a friend's place in a ghostly march of the names of the now-eternal heroes.

Entering the path through peaceful parkland, the visitor's head is well above the ground. The names of the dead begin to emerge in slow, disturbing rows at ground level, as if rising out of the earth. The names mount geometrically in ever-greater columns as the visitor descends beneath the horizon. The wave of stone rises with force and the architectural mass of the entire earth behind it. The visitor is half-entombed. The sense of helplessness and grief is overpowering. Slowly, the visitor begins to rise again, but the names still continue. Even as the heart hopes for an end, each name still reports that another life has been given. At the end of the walk, again in full open light, there is exhaustion and finally closure. The peaceful light now almost itself speaks to the visitor, whispering that the old wounds of bitterness have been healed, watered by our tears.

Hypothesis 4–5

When subjects are shown images of the Vietnam Veterans Memorial and have the passage by Perlmutter read to them, they have much more of an emotional response than when viewing the memorial alone. (Reading the passage might be considered a form of priming.)

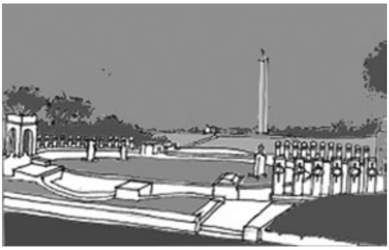


Figure 4–12. National World War II Memorial.

In April 2004, the National World War II Memorial (Fig. 4–12), designed by architect Friedrich St. Florian, was opened to the public. It honors the 16 million who served in the armed forces of the United States, especially the more than 400,000 who died. Its more classic design was the center of another controversy between those who favor modern design and those who prefer classical styles. Advocates claim that it is a balance of these styles.

"Harmony" is understood to mean a consistent, orderly, or pleasing arrangement of parts. There is reason to believe we are hard-wired to respond to harmonious arrangements in music, art, and architecture.

Hypothesis 4–6

Harmony in architectural designs elicits more positive brain responses than those that are clearly nonharmonious.

There are a number of new memorials still in the planning stages. One of the most prominent locations will belong to the Martin Luther King, Jr. National Memorial (Fig. 4–13). The central opening through its arc is on the axis of the Jefferson and Lincoln Memorials. The ROMA Design

Figure 4–13. Dr. Martin Luther King, Jr. National Memorial.

Group of San Francisco created the design. It is scheduled to begin construction in 2008 and open in 2009.

Most events are stored in memory for only a short time, but special events form vivid memories that stay with us for the rest of our lives. For many people, especially those in the African American community who are over 40 years old, the assassination of Dr. King in 1968 is a vivid memory. The proposed memorial will celebrate the life of this inspirational leader.

Since the location of this memorial is intended to evoke an association of Dr. King with the greatness of Lincoln and Jefferson, the question is raised whether such associations can be evoked by visual sensations alone.

Hypothesis 4–7

When the eyes, in a series of jerky movements, are provided with images of well-known persons, there is a recall mechanism in working memory for each image in sequence or a retention of more than one image in working memory.

SACRED PLACES

We now consider several examples of sacred places in China, the United States, and the Islamic world. Over several centuries, each culture has accumulated different architectural designs for settings considered appropriate for sacred places.

China's Sacred Architecture

The book *China's Sacred Sites* (Shunxun & Foit-Albert, 2007) explores the philosophical tenets of the ancient Chinese so beautifully articulated in splendid and unique architecture. China is a long way from the monuments on the National Mall in Washington, D.C., but it is part of the

Figure 4–14. Chinese temple (photograph by Nan Shunxun).

emotional heritage of all humans. The Chinese have an ancient belief system they call *feng shui*. Each monastery, pagoda, temple (see Fig. 4–14), and convent is notable for the way in which it communes with what might appear to be a particularly inhospitable environment. Some buildings are like jewels perched on the tips of rugged, wind-blown mountains. Others are strung along cliff faces or seem to meld into nearly inaccessible ravines or incorporate natural outcroppings as roofs, stairs, gates, and entranceways. The concepts of dragon, water, wind, and orientation in feng shui are ways to search for a balanced, intermediate, and moderate environment, forming an affectionate organic whole and reflecting the value of being in harmony with nature on a larger scale, as a national consciousness and way of living.

Water

Architectural compositions, varying from a single room to an entire city were assembled into a unified and harmonious whole. Like mountains, rivers embody the spirit of the Tao and are therefore extremely important components in traditional Chinese architecture. Mountains and water act as symbols of sublime character. Where one is stable, the other is in motion; one is high, the other low; one is clear, the other dark; one is bold and firm, the other soft and gentle. Out of the balancing and harmonizing

Figure 4–15. Chinese water garden (photograph by Beverly Foit-Albert).

of these dualities arises the principles of feng shui, *shui* (water), is of vital importance to a site.

Whether mirroring a lakeside pavilion or providing the accompanying sounds to the drums and bells of a Buddhist temple, water creates the yin quality of a site (Fig. 4–15). The concepts of bold and gentle, form and formless, active and serene arouse the viewer. Whether rising and falling, or resting in a serene pool, water coaxes our senses into stillness wherein serenity is born.

Cave

Another of nature's aspects used in Chinese sacred architecture is the cave. Caves in the clefts of mountains or the ledges of high cliffs are dark, mysterious, introversive spaces that embody yin. Taoists and Buddhists often constructed their temples in caves (Fig. 4–16), where spiritual

Figure 4–16. Chinese cave temple (photograph by Nan Shunxun).

practices could be conducted in seclusion. One stunning example is the Avalokiteshvara Cave, a vertical gap 330 feet high at North Mount Yandang, which encloses a nine-story Buddhist temple.

Harmony

With the philosophy of yin and yang and the constant, flowing presence of chi throughout Heaven, Earth, and humans, ancient Chinese sacred architecture embodies a message of accord and balance. The ancient Chinese faced challenging geological and climatic conditions and had limited material possessions. They relied on nature's harmony and the support of yin and yang.

The Courtyard

Perhaps the most vivid symbol of the concept of yin and yang is the courtyard. The courtyard of a house is like a well. Looking up, one sees and senses the yang of the sky; looking down, one sees and senses the yin of the Earth. Both forces meet and merge in the courtyard. This image carries with it a sense of nature, connection to the individual environment of a place, and a feeling of comfort.

The traditional courtyard house, in addition to being a shelter, is an intermediate communication between human and nature. The concept of the courtyard house originated from the search for harmony in the living environment. The courtyard forms an intermediate space that is suitable for living, outdoor housework, family gatherings, recreation, children's play, and the maintenance of health for the aged. Relying on intimately scaled enclosures formed by the surrounding walls, buildings, and eaves, courtyard spaces are sheltered from harsh wind and too much sun, thereby providing an environment that can be warm in winter, cool and shady in summer, quiet, safe, private, and psychologically easy to control. All courtyard houses reflect the search for a moderate place suitable for specific geographical and climatic conditions. The courtyard house has been the material expression of the Chinese way of life, using the open void within an enclosure as a piece of Heaven and Earth. No matter what happens outside, the yard is quiet, simple, and unadorned, leaving space for nature to perform.

The Garden

Another extraordinary example of intermediate harmony is the Chinese garden (Fig. 4–17). In the Western world, buildings are mostly individual, enclosed objects on the Earth, whereas gardens are more like nature itself. But in China, gardens are part of the building, and buildings are part of the garden.

The narrow, slightly darkened corridor of a garden entry illustrates the subtle difference of yin and yang and gradually becomes more intense. Through the corridor, a small opening with plants appears, softening the strong divide between the dark, narrow entrance and the bright, pond-filled garden. Approaching the pond, one winds through small courtyards with rock gardens of tall, thin rocks balanced on their narrow ends. The rocks have variegated surfaces with holes to provide views that contrast yin and yang.

The entrance to the central feature, the pond, is an open hall with columns that frame the view of the pond. Small buildings are sited around the pond. Some are set over water, with three open sides; some rest on retaining walls; others are set back from the water's edge. Openings in the walls of the buildings form living paintings of the scenes beyond. Bridges and paths meander so as to give the observer a variety of views. Natural colors are used for buildings in the garden, minimizing interference with views of the landscape.

Figure 4–17. Chinese garden (photograph by Beverly Foit-Albert).

Poetic Conclusion

When you look up from the courtyard of the heart and imbibe the secrets of the universe, full of light and dark, sound and silence, the light of the stars in the black fullness of space, you become as large as the universe. There, communication between humans and Earth and the heavens is complete, and words fail to be formed. Listen, then, to the sound of water and wind, then unfocus and listen to the nonsound that surrounds it and hear that nonsound expand infinitely. This is the sound of silence. The yin within the yang, the yang within the yin, continuous interplay and eternal cycling and circling. This is the silent music of ancient architecture.

The Mosque

Still another type of sacred architecture is found in the mosque in many locations in the Middle East. The Blue Mosque (Fig. 4–18) in Istanbul (called that because of the blue tiles adorning the walls of its interior) is an especially handsome example. Officially known as the Sultan Ahmed Mosque, it is the national mosque of Turkey. The mosque was built between 1609 and 1616. Like many other mosques, it also houses a tomb of the founder, a school, and a hospice. The design is the culmination of two centuries of Ottoman mosque development. It is the last great mosque of the classical period. The architect has ably synthesized the ideas of his master Sinan (a great architect of the Ottoman Empire), aiming for overwhelming size, majesty, and splendor.

Figure 4–18. The Blue Mosque.

Sacred Spaces for Christian Worship

The concept of sacred as applied to architectural settings can be elusive. Some definitions include places where people go to worship, or spaces associated with formal religions, or practice of religious rituals. Other definitions would broaden the concept to include places dedicated to the memory of an important individual within a community (e.g., the Lincoln Memorial). It seems useful to make a distinction between *spiritual* places and *sacred* spaces. A spiritual place is one that has been designated for some religious purpose. In this case, the place is spiritual by definition and is not dependent on the experience of the visitor. A sacred space can be defined as any space (including spiritual places) that evokes special transcendent feelings within the visitor—a connection with something larger and deeper than our self.

The North Christian Church in Columbus, Indiana (Fig. 4–19), creates a special experience for each person who visits there. The spire makes it clear from a distance that one is approaching a spiritual place—this building is all about breaking the bonds with the Earth. It sits within an sensitively landscaped field, with its roof/spire floating above it, an effect heightened by the roof's deep shadow line. The landscape is very regular and structured so that one proceeds to the main entry along a single path from the parking area. The design is orchestrated in such a way that the

Figure 4–19. North Christian Church (photograph by Eve Edelstein).

exterior does not reveal the nature of the interior architectural setting. On entry to the building, one comes into the lobby and then moves downstairs before coming back up to the worship area. Thus, even though the form of the building and its symbolism make it clear that this is a spiritual place, not until the visitor is inside the space of the sanctuary is a feeling of being sacred impressed on the brain.

At North Christian Church, architect Eero Saarinen brings us into the sacred inner sanctum by first inviting us to descend into the Earth, below grade level, then slip under a levitating roof, and finally come into the sanctuary as if rising from a tomb. We arrive at the very heart of this sacred space with seating radiating around it. The underside of the roof seems to slide past the supporting walls and float above us. How does our visual system form the concept of the roof "floating" above us?

Hypothesis 4–8

A dark surface above our visual plain (the area generated from our eye level by peripheral vision), when intersected by a dark vertical plain that approaches but does not touch the overheard plain, induces a sense that the overhead plain is floating above us.

How does the sequence of brain activations as one proceeds from the narthex to the nave in a place of worship bring about a feeling of awe?

Hypothesis 4–9

The perceptual awareness of a small space (the narthex), as recorded in the frontal cortex, is stimulated by moving into a suddenly much larger space (the nave). This stimulation produces a sense of expansion (or awe).

Is this a primer for a feeling of sacred? Is it possible that space can evoke a spiritual feeling resulting from the mystery of surprise on arrival?

Hypothesis 4–10

In a virtual reality environment, subjects will react to an image that surprises them by registering a reaction in the amygdala. This reaction can be considered one of fear or mystery.

Most people walking into North Christian Church universally experience a sense of something, whether or not they're approaching the church for an act of worship. Most have a transcendent feeling of being in a sacred place of shelter, regardless of their religious convictions.

At this point we might ask, how does the web of consciousness spread across our existence, experienced by so many people with so many concepts of the divine, indicate that they are present in a sacred place? How can we measure this experience? These are questions that could be explored by the neuroscience community.

NEUROSCIENCE ISSUES THAT COULD BE EXAMINED

Newberg, D'Aquili, and Rause (2001)(have asked: Are we "hard-wired" for God? The term "hard-wired" suggests that we were purposefully designed that way. Neuroscience cannot answer the question of purposeful design. However, it is known that the brain has two primary functions, considered from either a biological or evolutionary perspective—self-maintenance and self-transcendence. The brain performs both of these functions throughout our lives. Religion also hopes to perform these two functions. From the brain's perspective, Newberg and colleagues suggest that religion is a wonderful tool because it helps the brain perform its primary functions.

In Newberg et al.'s investigations, changes were measured in the brain's blood flow, which correlates with brain activity. For example, they compared the brain activity of people performing Buddhist meditation with what their brains do at rest. Their studies, as well as those of other investigators, have shown that meditation increases activity in the front part of the brain. This increased frontal activity is found not only during meditation but also during any attention-focusing task. As meditation involves focusing attention, it makes sense that this attention area of the brain is activated.

Testing the Effect of Dispositions

It may be possible to test hypotheses, such as whether Gothic design of churches evokes a stronger emotional response than does modern or contemporary designs. However, this is likely to be related to the early experiences of the person being tested. Subjects with positive emotional responses to buildings retained in their dispositional memories will probably have negative responses (as exhibited by activation of the amygdala) to building designs that are significantly different than their dispositions. Thus, one is likely to have a strong emotional response to churches they have worshiped in as a child and negative responses to "modern" churches.

Vision and a Sense of Awe

Movements of the body closely guided by vision have their own pathways in the brain. Occipital visual areas send axon fibers to the pons and from there to the cerebellum. Also, just in front of the visual cortex in the parietal lobe are neurons organizing certain types of eye movement. These neurons are at rest during steady gaze, and become active when we turn our eyes to look at something. The movements constitute a high level of motor behavior, shown by the activation of these neurons when we attempt to satisfy an appetite (for food, drink, or sex) by using our limbs and hands.

In much the same way, when eye movements are purposefully directed upward (e.g., to view a spire on top of a church) there may be an area of the brain activated that is also associated with experiencing awe. A related question would be whether this area of the brain is only activated when one "looks up."

Can Architecture Express a Doctrine?

The designed environment of a church needs to be very accommodating. It has to express, define, accommodate, enrich, and enhance the doctrine and the worship practices therein.

The question to be addressed as a result of these remarks is whether the concepts of "expressing a doctrine" or "enriching a doctrine" or "accommodating a doctrine" are testable by neuroscience. A doctrine is a belief that has been learned; perhaps one aspect of belief could be isolated for test purposes—for example, Jesus died on a cross. Inquiry methods traditionally used by social scientists could be used to test whether the subject believes this, possibly with a polygraph. It would then be possible to ask subjects whether certain design features of a church seem to "reflect" this belief (e.g., the cross often featured on the back wall of the chancel).

Another, related test could be to measure the relationship between the presence of the aroma of incense in a space and those sectors of the brain forming the belief system.

Attributes of Architecture Related to Spirituality

If one accepts the idea that the purpose of the house of worship is to encourage spirituality, then a number of tests might be done to measure how certain architectural features invoke this sense of sacred.

For example, there may be a neuroscientific reason for how we experience color as spiritual. Because we have been genetically endowed with a brain that it is prepared to recognize color, we may be able to link certain colors with spiritual things (purple comes to mind). There is some disagreement in the neuroscience community about where this perception happens and exactly what is going on when we recognize colors. The deeper question is one of consciousness—how does each of us perceive the "redness" of red (what neuroscientists call qualia). Edelman suggests, "Qualia constitute the collection of personal or subjective experiences, feelings and sensations that accompany awareness. Often, the phenomenal scene is accompanied by feelings or emotions, however faint. Yet the actual sequence of qualia is highly individual, resting on a series of occasions in one's own personal history of immediate experience."

Given that qualia are experienced directly only by individuals, a methodological difficulty becomes obvious. We cannot construct a phenomenal psychology that can be shared in the same way that physics can be shared. What one individual directly experiences as qualia cannot be fully shared by another as an observer. A person can report his or her experience to an observer, but that report must always be partial, imprecise, and relative to his or her own personal context.

If this question is eventually answered by neuroscience (and it is not clear that it will be), then the following hypothesis could be posed: The conscious mind is able to make a distinction between various colors and what is considered sacred.

The Last Word

Jim Olds, director of the Krasnow Institute at George Mason University, has the last word on sacred architecture and the brain: "Neuroscience is never going to find a 'God center' and never going to find a center of the brain that is specific to a favorite church. What we're going to find is a distributed set of brain activations across the whole brain—including the cerebral cortex, part of the cerebellum, the basil ganglia, and our midbrain—that together work just like a symphony orchestra, to play a score that yields the music of our experience."

CHAPTER FIVE

Memory of Places and Spaces and the Design of Facilities for the Aging

We tend to think of memories as monuments we once forged and may find intact beneath the weedy growth of years. But, in a real sense, memories are tied to and describe the present. Formed in an idiosyncratic way when they happened, they're also true to the moment of recall, including how you feel, all you've experienced, and new values, passions, and vulnerability. One never steps into the same stream of consciousness twice. All the mischief and mayhem of a life influences how one restyles a memory.

—ACKERMAN (2004)

Figure 5–1. Usse Castle.

Imagine you are an elderly person living in a complex building like the one in Figure 5–2. If you leave your room and go to visit a friend on the other side of the building, will you be able to remember how to get back to your room?

This chapter discusses the various kinds of architectural settings that are dependent on memory processes. This includes residential units for the elderly, stages for theatrical events, control towers in airports, elementary schools and hospitals, and places of worship. There are many more memory-dependent places in buildings, but this short list will provide illustrations of key variables that could lend themselves to neuroscience exploration. The second part of this chapter provides a sampling of the neuroscience literature dealing with memory. The chapter includes suggestions for possible links between neuroscience knowledge and architectural design decisions.

Architects could approach design problems as an opportunity to learn as much as possible about the evidence being generated in neuroscience laboratories. Gradually over the next decade (or two), the intuitive knowledge architects have used to establish such empirical evidence will likely improve design principles. As new facilities that have been designed with this new knowledge are built and occupied, the profession should make an effort to conduct "postoccupancy" studies to evaluate the effectiveness of their designs.

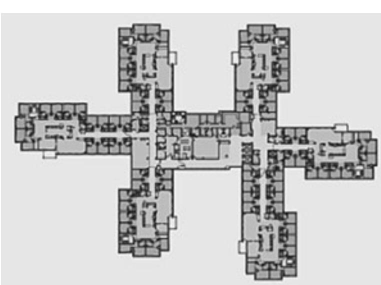


Figure 5–2. Plan of facility for the aging (used with permission from Perkins Eastman).

TWO FORMS OF MEMORY STORAGE

There is a general consensus about the major memory systems of the mind and about the brain areas that are most important for each memory system (Squire & Kandel, 1999).[1] Memory for facts and memory for skills are known by different terms, such as memory with a record and without a record, explicit and implicit memory, or the terms declarative and nondeclarative memory. Declarative memory is memory for facts, ideas, and events—information that can be brought to conscious recollection as a verbal proposition or a visual image. Most people mean this kind of memory when they use the word *memory*: It is the conscious memory of a name like Frank Lloyd Wright, or a trip to Paris to visit Notre Dame Cathedral, or a lecture on the history of the Renaissance. Nondeclarative memory also results from experience but is expressed as a change in behavior, not a recollection. Thus, if you learn to play the piano or play tennis, this skill will be stored in nondeclarative memory. Even though you use it each time you play the piano or hit a tennis ball, you are not aware of these memories. It is an unconscious action. Different forms of nondeclarative memory are thought to depend on different brain regions like the amygdala, the cerebellum, and the striatum.

British philosopher Gilbert Ryle provided a way of thinking about these two forms of memory that seems especially appropriate to architecture. He suggested two kinds of knowledge: one is concerned with knowing *what* (knowledge of facts and events), and the other is concerned with knowing *how* (knowledge of skills, like designing).

Conscious perception is associated with recognition and identification and with the function of the ventral stream of visual processing. Aspects associated with unconscious processing of visual information are not part of our visual awareness. These principles also apply to the faculty of memory. Memory is not a single entity but consists of different systems. Declarative

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[1] This section is based on and adapted from the work of Squire and Kandel (1999), who have graciously given permission for its use. However, the reader should be clear that this is my own version of the material. Any errors in the adaptation are entirely my own.

memory is the only system of which we are consciously aware. However, a number of nonconscious memory functions are present in humans, including priming, perceptual learning, and emotional learning.

Priming

Priming is based on our ability to improve detection of objects or identification of words after a recent experience with them. Priming is a distinct memory phenomenon. Its key feature is that it is an unconscious process. Even though priming improves the perception of recently encountered stimuli, usually we are not aware of the improvement in speed or efficiency of perception. This improvement can persist for a long time, even after a single priming experience.

A simple way to think about priming is that for a period of time after a word or other perceptual object has been presented, less neural activity is required to process that same word or object again. To be more technical, we know that sensory input apparently makes contact with information in the posterior cortex within 100 milliseconds after a stimulus is presented. Apparently, although priming occurs within the same pathways ordinarily involved in perceiving and processing visual information, neural changes occur within these pathways well before information reaches the memory system of the medial temporal lobe, which is essential for declarative memory. Thus, priming may reduce the number of responsive neurons and create a background of relatively silent neurons. Once primed, a small ensemble of well-tuned neurons might handle the perceptual task with the net result being a reduction in neural activity.

Individuals do not have the ability to consult the system that supports priming, even though they have a record in their brain of a recent experience with a building, for example, that enables them to recognize it more quickly. Priming has evolved as a useful function because words or objects we encounter once are likely to be encountered again. This perceptual efficiency is available not only for familiar material but also for a wide range of stimuli: strings of nonsense letters, unfamiliar visual objects (such as views of buildings), novel line patterns, and material presented by voice.

In addition, priming can be observed on tests that require an analysis of meaning. For example, if someone is shown a word list that includes the word *door*, and is then asked to free associate to the word *house*, 45% of the time they will say, “front door.”

Perceptual Learning

While it is clear that perceptually we need to see a tree as being a tree (Fig. 5–3) or know that the face of a friend is their face, *perceptual learning* refers to an improvement in the ability to discriminate simple attributes during sensory processing. This is different than priming. In the priming process, the ability to identify and detect a stimulus improves as the result of having experienced it before. In the case of perceptual learning, we become more expert at discriminating some feature of a stimulus. For example, with practice people can improve their ability to discriminate texture, direction of motion, line orientation, and many other simple visual attributes. Remarkably, this learning is often highly specific to the task and the specific way in which the training is carried out. Training appears to change the structure of the sensory apparatus in the cortex, which is the first place to receive information from the outside world. This process, in which the ultimate long-term effect of experience is to change the structure of the brain, seems to underlie the famous quote of Winston Churchill, “We shape our buildings; thereafter they shape us.”

Figure 5–3. Trees of Carderock.

Experiments have shown that experts are able to perceive differently than the novice. Landscape painters see trees differently than lawyers do, and caricature artists probably see faces somewhat differently than the rest of us would. Some of the difference may be the result of genetics, but another important part is the result of practice. Everyone may make the same perceptual identification of the abbey at Bath, whereas a trained architect will perceive faster that this building is not the cathedral at Chartres or Amiens. The architect owes this ability in part to perceptual learning—changes that have accrued gradually over time in the visual cortex and altered the machinery of perception. Most of these changes are nondeclarative, in the sense that they occur outside awareness and do not evoke conscious remembrances of the past.

Emotional Learning

Priming and perceptual learning provide ways for early stages of perceptual processing to become faster, more efficient, and generally more discriminating as the result of prior experience. However, prior experience can also change the way we feel about what was processed, for example, how we evaluate information—positive or negative reactions to a stimulus. These basic likes and dislikes are largely unconscious products of learning. We feel a certain way about our experience with visiting Notre Dame because of the experiences we have had in visiting other large buildings—or more specifically, other cathedrals. We develop judgments about this visit even if we have never been to Paris before. It appears that learning involving emotions can proceed independently of conscious cognition.

There is a particular emotional learning experience associated with fear. Fear signals appear to move directly from the sensory areas in the thalamus (the first stop in processing) to the adjacent perirhinal and insular cortices, which in turn communicate with the amygdala (Fig. 5–4). The amygdala (for more details, see Appendix 2) is a structure in the medial lobe immediately in front of the hippocampus. It is composed of more then 10 subregions (or nuclei), and of these, the central nucleus is

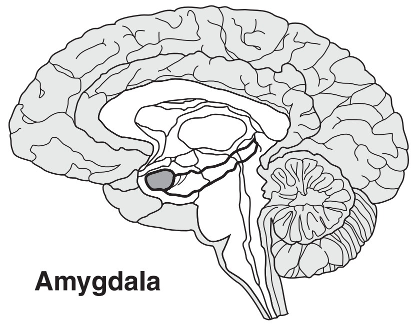

Figure 5–4. Amygdala location.

critical for communicating the fear state widely to other systems that act together to express a response to fear. One of the systems increases heart rate, another causes the movement of the body to freeze, another one slows digestion, and so on. Signals from the thalamus reach the amygdala quickly and alert the fear system while the cortex is still fully evaluating them.

According to Squire and Kandel (1999), "The amygdala and the hippocampal system independently support nondeclarative emotional memories and declarative memories. Under certain circumstances the two systems can work together." For example, people remember emotionally arousing events especially well. If you have entered a large European cathedral for the first time and heard its mighty organ fill the space with the sounds of Bach, you are not likely to forget it. Many visitors to the Lincoln Memorial at night describe an overwhelming emotional experience that they never forget—even if they were only a teenager at the time of their visit.

Memory for Skills, Habits, and Conditioning

Nondeclarative memories have a pervasive influence in everyday life. Squire and Kandel (1999) provide the following examples involving skill learning and habit learning.

When one learns a new tennis forehand stroke, the memory of having had a lesson is different than the demonstration of an improved stroke.

Such learned motor skills are embedded in procedures, which are expressed through performance. Experience shows that trying to express conscious knowledge about a motor skill while performing it is a good way to disturb its execution. We learn a motor skill without having any awareness of what has been learned. Practice seems to recruit additional neurons in the motor cortex and is reflected in increased dexterity and speed of execution. It is not known where the memory trace of a motor skill is ultimately stored. However, motor skill learning probably occurs as changes within the circuits dedicated to performing the particular skill. There is a possibility that memory storage occurs within the areas of the motor cortex that are engaged during practice. Or it may be that essential synaptic changes occur in the connections from the cortex to the neostriatum.

Finally, during the early stages of motor skill learning, the cerebellum (Fig. 5–5) is important. The cerebellum is a large structure lying at the back of the brain, and it is probably necessary for coordinating the specific repertoire of movements required for a well-executed, skilled motion and for organizing the timing of these movements. Thus it appears that the prefrontal cortex, the parietal cortex, and the cerebellum (see appendix 2 for details) are all engaged early in motor skill learning. Their combined activity ensures that the correct movements are assembled and both attention and working memory are dedicated to the task. Once the skill has been practiced enough, the prefrontal cortex, the parietal cortex, and the cerebellum show less activity, and other structures, including the motor cortex and the nearby supplementary motor cortex, become more engaged.

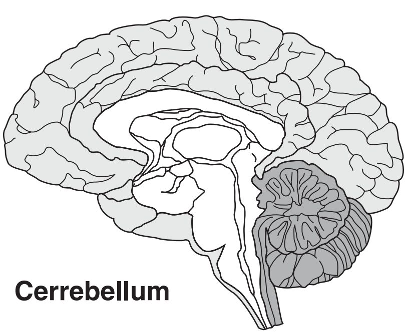

Figure 5–5. Cerebellum location.

These structures probably store the skill in long-term memory to allow future smooth execution of the learned motor skill.

Habit Learning

As we grow up, we learn to say "please" and "thank you," brush our teeth before going to bed, and other behaviors or habits that are the result of training. Most of this learning happens without us being conscious of learning something—it is nondeclarative. Just as learning motor skills is nondeclarative and depends on the neostriatum, so does habit learning. When we learn to discriminate fine wines from mediocre wines, or recognize original artwork from forgeries, we are forming a skill in the sense that we slowly learn the important dimensions of such discriminatory problems. This is not the same as memorizing facts that can be used to discriminate, but it is a skill acquired by gradual mastery.

Conclusion

The reason that we acquire and retain new information so readily is that the systems of the brain that are important for memory are readily modifiable. The synaptic connections with these systems can be strengthened or weakened and are even capable of permanent structural change. This remarkable plasticity of the brain is fundamental to our individuality and all aspects of our mental life. Consequently, the weakening of the capabilities with age or with disease has a profound impact not only on our cognitive functioning but also on our very sense of self.

Squire and Kandel (1999) conclude:

> The emerging synthesis of the molecular biology and cognitive neuroscience of memory that we have described in this book represents both a scientific inquiry of great promise and an aspiration of humanistic and practical scholarship. It is part of the continuous attempt of each generation of scholars and scientists to understand human thought and human action in new and more complex terms. From this perspective, the molecular and

> cognitive study of memory represents only the most recent attempt, historically, to bridge the sciences, which are traditionally concerned with nature and the physical world, and the humanities, which are traditionally concerned with the nature of human experience, and to use this bridge for the improvement of mentally and neurologically ill patients and for the greater betterment of humankind.

Thus, one may suggest that neuroscience really might build a bridge with architecture for the well-being of all of those who experience designed places and spaces.

THE AGING BRAIN

As we age, some of us maintain cognitive functions, such as memory or language, quite well, and others do not. The question that Albert and McKhann (2005) ask is: Does cognitive ability change, as individuals get older in the absence of disease? Researchers have focused on studying optimally healthy subjects across the age range, rather than subjects of just average health. Albert and McKhann (2005) elected to focus on changes in memory because memory can also be studied in experimental animals.

One common way to test episodic memory is to ask someone to learn and recall new information by asking them to listen to a story and recount its details, immediately and after a delay. When healthy individuals take a difficult memory test of this sort, there are significant differences in memory among those in their 50s and 60s, compared with those in their 30s. This difference is even greater in people over 70 compared to 30-year-olds. However, not everyone experiences these changes with age. Some elderly persons maintain memory function similar to that of individuals many decades younger than themselves, whereas others show significant decline.

Possible Causes

This raises the question of why some people experience a decline in memory and some do not. The loss of nerve cells in highly selective regions of the brain has been suggested as a cause for memory decline. This loss does occur, particularly in collections of nerve cells deep within the brain—the subcortical nuclei. These nuclei (which undergo as much as a 50% drop in nerve cells over time), such as the nucleus basalis, send projections to many other regions of the brain and influence the production of chemicals essential for learning and memory. Another possibility is that the mechanisms nerve cells use in learning and memory change with age. Some older subjects activate adaptive mechanisms that may allow them to compensate for age-related changes in function.

Older subjects with preserved memory function exhibit both of these traits: First, they are not experiencing age-related declines in brain structure and function; second, they are activating adaptive brain mechanisms for memory.

Brain Mechanisms

Epidemiological studies can identify the behavior of humans that helps preserve memory function. First, people who maintain memory and other cognitive functions have higher levels of physical activity associated with daily living. These activities include walking long distances, climbing stairs, and lifting objects. The neurochemical mechanisms by which nerve cells in the hippocampus communicate appear to be enhanced by exercise. Physical activity not only improves the cardiovascular system, it also affects specific positive changes in parts of the brain involved in memory. Second, studies have also indicated that those who preserve cognitive function have higher levels of mental activity—they are more likely to be involved in daily activities that are mentally stimulating, such as doing crossword puzzles, playing board games, reading books, and attending lectures.

Third, social stimulation also appears to be important in maintaining cognition. Variously called social engagement, feelings of self-worth, or feelings of self-efficacy, these measures appear related to how connected people feel to others in their family and community and how much they think they can influence what happens to them.

Finally, what's good for the heart also is good for the brain. This understanding has emerged from research showing that controlling high blood pressure, recognizing and treating diabetes, lowering cholesterol, controlling weight, and avoiding smoking are all associated with less disease of the blood vessels of both the heart and the brain. In people with uncontrolled vascular risk factors, cognitive function suffers. Proper preventive measures can lessen these negative effects in the brain.

Neural Plasticity in the Aging Brain

Massive cell loss across the brain and deterioration of the primary receiving surfaces of brain cells does not occur during normal aging and therefore cannot be the cause for the observed decline in cognitive abilities as we age (Burke & Barnes, 2006). Rather, changes in the aging brain are more subtle and selective than once believed, and many important (electrophysiological) properties of neurons in the medial temporal lobe (such as the hippocampus, a structure critical for episodic memory) remain the same during normal aging. There are, however, certain regional differences in the patterns of age-related memory loss, for example, some regions of the prefrontal cortex (a structure critical for working memory and executive function) do show cell loss.

The factors contributing to age-related behavioral impairments include changes in the form and structure of dendrites in specific regions, problems related to connectivity and plasticity mechanisms between certain cells, and the regulation of calcium inside neurons of the hippocampus is impaired. Aging makes an impact on the expression of certain genes (affecting the protein synthesis important to cell function). This could impede the growth of new synapses or modify the synaptic structure necessary to maintain long-term memory.

As more becomes known about the neurobiology of the aging brain, there will be more opportunities to develop therapeutic approaches that can modify biological functions of the hippocampus and other affected brain structures, slow age-related cognitive decline, or even restore partially normal function. Burke and Barnes (2006) suggest that understanding the brain mechanisms responsible for age-related cognitive impairment and finding therapeutic agents that might curb this decline is becoming increasingly important as the numbers of those over 65 years of age is growing worldwide.

Mechanisms Underlying the Formation and Maintenance of Distributed Memories

Experience is represented and stored in the brain in the form of information coded in the coordinated activity of assemblies of neurons (Wilson, 2005). Wilson's laboratory research focuses on these phenomena in the mammalian nervous system. His study of the mechanisms that underlie the formation and maintenance of distributed memories in freely behaving animals is the subject of this section.

Much of Wilson's research has been done with mice as animal models. He used techniques that allow the examination of the simultaneous activity of ensembles of hundreds of single neurons in freely behaving mice. These techniques allow researchers to examine how memories of places and events are encoded across networks of cells within the hippocampus. This research has demonstrated that ongoing patterns of neuronal ensemble activity can predict a mouse's moment-by-moment position as it moves about in space.

When researchers in Wilson's laboratory combined these measurements of ongoing neuronal activity with manipulation of molecular genetic targets, they could study how specific cellular mechanisms regulate neural functions to produce learning and memory. They conducted experiments to record the hippocampal neurons of mice in which a certain receptor that plays a critical role in long-term potentiation had been restricted to a specific subregion of the hippocampus. With this disruption of normal patterns of spatially related neuronal activity, the mice showed deficits in spatial memory.

Wilson (2005) indicates that he was interested in observing how memory deals with the time sequence of related events. He studied the activity of the hippocampal neurons during periods of sleep, because activity in memory is no longer influenced by sensory and behavioral inputs during sleep. He argues that activity in the hippocampus during sleep is a direct reflection of the residual influence of previous experiences on neural substrates and therefore must be derived from underlying mechanisms of memory. During rapid eye movement (REM) sleep in rats, hippocampal neurons were found to replay the sequence of activity that had been previously experienced. The extended patterns of ensemble response could be directly matched with corresponding patterns that had been recorded during training on a simple spatial behavioral task. More than 40% of REM episodes, each lasting 1–2 minutes, were found to match significantly with the sequential patterns established during awake behavior. The correspondence was sufficiently robust to allow reconstruction of the spatial trajectories replayed on a second-by-second basis over the course of an entire REM episode. Overall, these results indicate a primary role of neurons in the hippocampus in establishing recognition of context.

Recent experiments have found a relationship between the activity within the prefrontal cortex and activity of the hippocampus during awake behavior, REM, and slow-wave sleep. Other researchers have suggested that sleep states may be involved in the process of memory consolidation, in which memories are transferred from short-term to long-term storage in the brain and possibly reorganized into more efficient forms. Wilson's research provides evidence for this theory. Recently, he identified explicit events that occur during dreaming periods of REM sleep. He is able to reconstruct the content of these states, allowing him to track specific memories during the course of the consolidation process.

Hypotheses Related to Aging Facilities

Our bodies and minds decline in effectiveness as we pass the age of 65, including:

- *Slower cognitive skills*: Because of the loss of brain cells, it takes longer to process information and draw inferences.

- *Changes in the visual system*: There is a decrease in the size of the eye's pupil and change in coloration of the lens. To see well, a person of age 60 requires three times the illumination that a 20-year-old needs and has greater difficulty in distinguishing certain colors and color combinations.
- *Hearing loss*: Changes in the bones of the ear make hearing more difficult. About 30% of seniors may have some hearing loss.
- *Declining neuromuscular systems*: This produces impairments to gait and balance, resulting in people becoming more susceptible to falls as they get older.
- *Changes in personality*: This results in increased introspection and greater cautiousness. A greater unwillingness to venture out and take risks makes seniors more sensitive to the complexities of travel.

Facilities Design Hypotheses and Comments

The following hypotheses and comments relate the design of facilities for the aging to neuroscience research.

Hypothesis 5–1

Aging facilities that allow residents to furnish rooms with their own furniture (Fig. 5–6) provides a link to their autobiographical pasts. This support for episodic memory enables other forms of memory—semantic and procedural—by associative stimulation.

Figure 5–6. Bedroom in facility for the aging (photo by Robert Ruschak, courtesy of Perkins Eastman).

Figure 5–7. Light in facility for the aging (photo by Chuck Choi, courtesy of Perkins Eastman).

Comment: The brain changes its ability to embed new experiences as we age. Moving short-term experiences into long-term memories and recalling these memories later becomes more difficult. For this purpose, the distinction between three forms of memory—episodic, semantic, and procedural—will prove useful.

Hypothesis 5–2

Providing high levels of illumination—and the resulting availability of high contrast (see Fig. 5–7)—increases acceptance of greater social interactions, including more frequent dining because of increased appetite.

Figure 5–8. Reception area in facility for the aging (photo by Curtis Martin, courtesy of Perkins Eastman).

Figure 5–9. Hallway in facility for the aging (photo by Nacassa and Partners, courtesy of Perkins Eastman).

Comment: As the body ages, it undergoes many changes with regard to physical ability. Understanding how the brain interacts with the nervous system and the muscle systems of the body to support and enhance the physical functions of the elderly would help in the planning of such facilities.

Hypothesis 5–3

The size, shape, and furnishing of rooms in facilities for the aging (Fig. 5–8) influence the sensory responses to these attributes.

Comment: With age, changes in the ability to sense the world around us affect our enjoyment and quality of life. There is a lessening of the sensory abilities of sight, hearing, taste, and smell, as well as perceptions of movement and spatial orientation. There may be ways to help compensate for these losses by providing designers with knowledge of the neurological reasons for such changes.

Hypothesis 5–4

Redundant cuing from the architectural setting for wayfinding (Fig. 5–9) will enable the formation of procedural memories.

Figure 5–10. Dining area in facility for the aging (photo by Jim Schafer, courtesy of Perkins Eastman).

Comment: The ability to find one's way, remembering where one wants to go and having a clear ability to get there, is important to the comfort and well-being of elderly residents. This ability is particularly compromised among those living with Alzheimer's disease.

Hypothesis 5–5

Family style dining (small groups that serve themselves from prepared dishes; Fig. 5–10) promotes socialization and better eating habits, and leads to better health.

Comment: The environment needs to be balanced between challenges to residents and their abilities to cope. Because people who are elderly—and especially those with Alzheimer's disease—have reduced coping abilities, the architectural setting should be designed to reduce its press on them.

CHAPTER SIX

Systems Neuroscience and Building Systems Applied to Workplace Design

The traditional wet laboratory is used for biological or chemical research. This kind of lab is filled with rows of benches overhung with cabinets for glassware and other small equipment, which are important tools of the researchers who work there. In the traditional wet lab, the main workplace is the lab bench, where a scientist prepares and conducts experiments, observes results, and records data in a written notebook. This is also where problems are discussed, apprentices are taught how to undertake experiments, and so on.

Figure 6–1. National Institutes of Health lab.

THE DESIGN OF WORKPLACES

Architects have long been involved in the design of places intended for work—from offices to surgical suites. Though such work is often done in places that are simply available (as opposed to being designed for that use), in this chapter we are concerned with the design issues of what my British friends call "purpose design."

At the end of the 19th century and the beginning of the 20th century, the seven architectural inventions discussed in Appendix 3 changed buildings from four or five floors in height to much taller office buildings—today known as skyscrapers. The Empire State Building (Fig. 6–2; voted America's favorite building in a Harris Poll commissioned by the American Institute of Architects in 2007) is a 102-story contemporary Art Deco–style building in New York City designed by Shreve, Lamb, and Harmon. The tower, which was built in 1931, takes its name from the nickname of New York State. Since the fall of the World Trade Center towers in the September 11, 2001, terrorist attacks, it is again the tallest building in New York City and the second tallest building in the United States. These sometimes gigantic buildings make a commercial statement for their owners (often related to bragging rights about being the tallest building) while enclosing thousands of working spaces for employees.

Figure 6–2. Empire State Building.

In this chapter, we look at some of the research being done by neuroscientists that could provide new knowledge for office designs. We then consider how the design community thinks about the design of spaces for white-collar workers, especially those who work in science labs.

A SCIENTIFIC LOOK AT WHITE-COLLAR PRODUCTIVITY

Frederick Winslow Taylor is sometimes called the father of scientific management—a system based on reducing factory work into small components that could be essentially learned easily and repeated continuously. For example, a worker on an automobile assembly line might be assigned the job of installing the door handles on each automobile body that passes through his or her station. With this form of specialization, the worker's intelligence became defined as little more than the capacity to follow orders developed by the production manager. There was no need to understand the larger process of which the component was a part. The concept of productivity established by Taylor is still used to study working patterns of white-collar workers.

Workers in an office or laboratory are known as white-collar workers—symbolized by the fact that the males usually wear white shirts as contrasted to the blue shirts and overalls of a factory worker. Attempts by efficiency experts to use Taylor's methods to improve productivity in offices or laboratories have been largely unsuccessful. The basic problem stems from the inability to clearly define productivity in the office environment because most work there is not repetitive. Because each worker uses his or her brain to decide what to do next, solve an abstract problem, or plan a new strategy, there is no continuous series of events to be segmented. Most office and lab work requires a different form of intelligence more advanced than that required of workers on an assembly line.

The neuroscience community is beginning to examine how specific changes in the physical and organizational environment can change the structure of the nervous system and improve mental performance. Studies of how the working environment impacts the brain and the mind will want to include exploring the many ways that advanced electronic tools now used in offices and labs impact those processes associated with intelligence. One could speculate that such research could help us understand how long-term memory produced by thinking and learning in more technologically sophisticated work environments increases the efficiency of mental functions. That would seem to be a more important notion of productivity increases than the mechanistic methods of Taylor.

ANOTHER EXAMPLE OF OFFICE WORK STUDIES

Measuring levels of stress in white-collar workers can be done with known biomarkers, such as heart rate monitors or sweat patch collections of small amounts of perspiration. The sweat patch process is greatly facilitated by recent work on cytokines at the National Institutes of Health (NIH) by scientist Terry Phillips and his associates (Phillips et al., 2006).

Cytokines are a group of proteins and peptides that are used in the body as signaling compounds. These chemical signals are similar to hormones and neurotransmitters and are used to allow one cell to communicate with another. Brain cells release neurotransmitters, and some specialized nerve cells also release cytokines. Cytokines are usually released from a variety of specific cells. The presence of neuropeptides and neurotransmitter receptors on immune cells, plus the ability of certain nerve cells to produce and respond to cytokines, establishes a link between the immune system and the nervous system. Furthermore, the interaction of hormones with both the nervous and immune systems establishes a triangle of regulation, which is essential to healthy living. Cytokines are particularly important in both innate and adaptive immune responses. When the immune system is fighting pathogens, cytokines and their smaller relatives (called chemokines) signal immune cells to travel to the site of the infection. The effect of a particular cytokine on a given cell depends on its extracellular abundance, the presence and abundance of complementary receptors on the cell surface, and downstream signals activated by receptor binding.

Phillips, who is chief of the Nanoscale Immunodiagnostics Group of the Laboratory of Bioengineering and Physical Science, National Institute of Biomedical Imaging and Bioengineering at NIH, has developed a method of detecting a variety of cytokines in small amounts of body fluids. This includes using a sweat patch, which, when combined with recycling immunoaffinity chromatography (RIC), represents a viable noninvasive method for measuring cytokines in ambulatory settings over time. The method is unobtrusive and requires minimal active compliance on the part of the subject being studied, without pain or stress. Phillips and his colleagues believe this will open a new generation of studies to address the effects of environmental factors on immune responses in a wide range of different settings.

In an experiment protocol designed to study stress levels in office workers, a sweat patch was proposed to gather a small amount of perspiration from subjects working in a novel office environment. The protocol called for the subjects to maintain a log of their activities during a 24-hour period and have sweat patches applied several times during that period. The assumption was that environmental parameters having to do with the architectural character of the space could potentially be isolated as causing stress for the workers. The protocol also proposed to use heart rate monitors in parallel with the sweat patches. An electronic record would be created by the heart rate monitor and could be correlated with the electronic record from a subject's log of activities.

For various reasons, the experiment has only just been conducted, and the data are still being analyzed. It remains an open question whether the protocol will be sensitive enough to isolate architectural variables from personnel interactions—which would also induce stress.

WORKPLACE DESIGN

In 1995, a team of researchers at MIT formed the Space Planning and Organization Research Group (SPORG) to study the premise that there is an undeniable link between the workplace and work processes. The SPORG team included Turid H. Horgen, Michael L. Joroff, William

L. Porter, and Donald A. Schön from the School of Architecture and Planning, as well as graduate students and visitors. They proposed that all organizations need to rethink their missions, assumptions, and strategies—including the spaces within which the organization operates and the manner in which those spaces are created. This notion of developing more effective workplaces, they suggested, applies to a variety of business and service organizations—from factories and offices to laboratories and financial institutions.

SPORG argued that conceiving of the workplace as a strategic element in the enterprise requires a shift in how to view the workplace itself. Traditionally, the workplace is viewed as a physical container for work. Its design is influenced by considerations of cost, work processes, and organizational culture. But the workplace as a strategic element is more than this: It depends on the internal compatibility of spatial, organizational, financial, and technological arrangements. A change in one demands changes in others. Approaching the workplace in this way can suggest solutions that might not otherwise be considered.

The Wet Laboratory

One workplace studied by SPORG was the traditional wet lab used for biological or chemical research. In a traditional wet lab, the main workplace is the lab bench (see Fig. 6–3).

Today, computers have significantly altered the nature of work in wet labs. Computers are used to automate some of the traditional laboratory

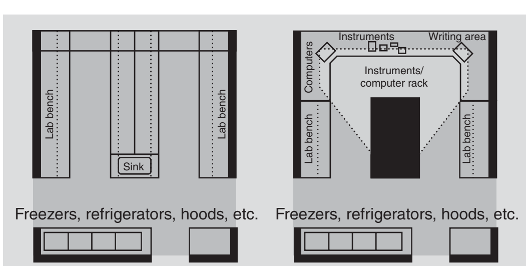

Figure 6–3. Laboratory comparison.

work, such as monitoring and processing experimental data, or they may provide simulations that replace wet experiments. The computer also gives workers access to databases and provides electronic communications with other labs around the world. Older workplaces often have adjacent offices for the use of computers bringing about planning problems. SPORG's solution was to reorganize the basic use of the wet laboratory space as shown in the floor plan in Figure 6–3.

Regardless of whether the team's solution is the one that a neuroscientist and their colleagues would use in today's laboratory, the issue here is that changes in the physical design of labs have been precipitated by the introduction of electronic equipment. There can be little doubt that these changes have also impacted the cognitive processes of those who work in such laboratories. How the brain is engaged in experimental analysis and recording of results is changed by the introduction of electronic equipment. Changes in spatial layouts, background noises, and lighting will also impact these same cognitive processes. Research on such basic relationships of laboratory designs has yet to be undertaken by the neuroscience community—an example of the shoemaker's children who go without shoes.

Historic Research Institutions and Their Facilities

Though the modern laboratory used for scientific research is now a common element of universities, government agencies, and private industry, it is a relatively new concept. It was not until the end of the 19th century that such laboratories began to be seen, and not until after World War II were scientific laboratories ubiquitous.

The Pasteur Institute

The inauguration of Louis Pasteur's laboratory in Paris in 1888 was an important milestone in the history of scientific laboratories, but it was modest. It is still in existence as a research institution, but in new facilities. The institute was a product of Pasteur's victory over rabies, because this vaccine represented a victory for the entire world.

The Bell Telephone Laboratories

Another early laboratory was the Western Electric Research Laboratories (part of the engineering department of AT&T), which were established in 1925 and later consolidated to form Bell Telephone Laboratories. Ownership of Bell Labs was evenly split between AT&T and Western Electric. Its principal work was to design and support the equipment Western Electric built for Bell System operating companies. At its peak, Bell Labs was the premier facility of its type, developing a wide range of revolutionary technologies, including radio astronomy, lasers, information theory, the UNIX operating system, and the C programming language. There have been six Nobel Prizes awarded for work done at Bell Labs.

Modern Laboratories

The Salk Institute

The Salk Institute (Fig. 6–4) is an independent, nonprofit, scientific research laboratory located in La Jolla, California. It was founded in 1960 by Jonas Salk, the developer of the polio vaccine. The institute has 56 labs and focuses its research in three areas: molecular biology and genetics, neuroscience, and plant biology. Research topics include cancer, diabetes, birth defects, Alzheimer's disease, Parkinson's disease, and AIDS. In 2006, the institute employed more than 1,200 researchers and staff.

The March of Dimes provided the initial funding and continues to support the institute. The campus was designed by the architect Louis Kahn.

Figure 6–4. The Salk Institute.

Salk wanted to make a beautiful facility to draw the best researchers in the world. The original buildings of the Salk Institute were designated a historical landmark in 1991.

Salk and Kahn approached the city of San Diego in March 1960 about a gift of land on the Torrey Pines Mesa and were granted their request after a referendum in June 1960. Construction began in 1962; a handful of researchers moved into the first lab in 1963. Additional buildings housing more laboratories, as well as the administrative offices, were constructed in the 1990s, designed by Anshen & Allen. The California Historical Resources Commission deemed the entire 27-acre site eligible in 2006 for listing on the National Register of Historic Places.

Jonas Salk died in 1995. A memorial lies at the entrance to the institute: "Hope lies in dreams, in imagination and in the courage of those who dare to make dreams into reality."

Janelia Farm Research Campus

When Howard Hughes died, he left his vast fortune to the institute he had created originally to fund the four physicians who attended him around the clock the last few years of his life. Founded in 1953, the Howard Hughes Medical Institute (HHMI) is headquartered in Chevy Chase, Maryland, and employs more than 2,600 individuals across the country. It now has an endowment of $16.3 billion.

The Janelia Farm Research Campus (Fig. 6–5) in Ashburn, Virginia, further extends HHMI's commitment to research and discovery. Janelia Farm was created to probe fundamental biomedical questions best addressed through a collaborative, interdisciplinary culture. The initial research focus was the identification of general principles that govern how information is processed by neuronal circuits and development of imaging technologies and computational methods for image analysis. Researchers at Janelia Farm—including the most senior group leaders—engage in active bench science and work in small teams that cross disciplinary boundaries to bring chemists, physicists, computational scientists, and engineers into close collaboration with biologists.

Figure 6–5. Janelia Farm Research Campus.

Robert McGhee, the HHMI staff architect, was an essential part of the design and development of the Janelia Farm campus. The architectural concept for the buildings and labs was to create collaboration and creativity among scientists, with work and relaxation areas to promote interaction and collegiality and discourage isolation. In addition to the interdisciplinary research efforts, supported by advanced technology resources, Janelia Farm is integrally linked to technology dissemination efforts that include hosting meetings, conferences, and workshops and providing courses on how to use its advanced technologies.

The laboratory buildings, designed by architect Rafael Vinoly, are provided with an infrastructure of core support facilities, including rooms for a vivarium, DNA sequencing, instrument design and fabrication, information sciences, mass spectrometry, tissue culture, glassware washing, media preparation, and equipment maintenance. The buildings that house the laboratories were designed to blend in with the natural surroundings of the site and feature flexible laboratory space that can be adapted easily to changing research needs.

The design is guided by four principles that McGhee has developed based on his considerable experience in creating successful working environments for scientists:

1. Understand the researchers' needs versus preferences;
2. Focus the planning effort on what will or could happen versus what is happening today;
3. Keep workspaces standardized and rational;
4. Make the workspaces adaptable over time to accommodate changes in research.

Additionally, it was intended that the design should have an aesthetic that would be consistent with a high quality development.

The original program called for 370,000 net square feet plus underground parking (Fig. 6–6). The research components would constitute more than half of the construction. The program also included 96 rooms for conference housing, 24 studio and 36 two-bedroom apartments (for visiting scientists), meeting facilities, a library (primarily based on Internet access), recreational activities (including a well-equipped gym), and administrative facilities (described as having a view of an enclosed garden area but seen by the administrators as being "underground" compared to the labs). The architectural program indicated that the main goal was to create a campus-like culture—as opposed to merely developing a suburban free-standing research facility resulted in a very long building. Having the labs and flex zones located on one side of the building, with adjacent support space, a public corridor located next to that support space, and offices located on the other side of the corridor made for a "deep" laboratory space. The planners believed that this deeper lab provided more efficient and flexible space than a shallow lab.

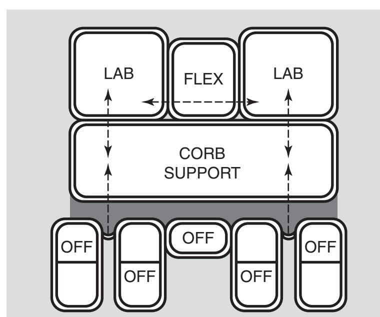

Figure 6–6. Janelia Farm floor plan.

Laboratories for the Centers for Disease Control and Prevention

In designing new laboratories for the Centers for Disease Control and Prevention (CDC) in Atlanta (Fig. 6–7), the architectural design firm Perkins+Will were asked to provide an open, interactive research facility incorporating green design (ecologically and environmentally

Figure 6–7. CDC laboratories.

friendly design). The client and design team wanted light and views in the open labs because people are in those labs for many hours. They believed it was important that people have a connection to the outdoors.

Providing an open, interactive floor plan created a design feature that affords 90% of the spaces an outside view. This plan also includes multi-story spaces open to the exterior.

Hypothesis 6–1

Having a view to provide a connection to the outdoors increases the cognitive activity of laboratory scientists.

Comments: There is an intuitive understanding, perhaps based on verbal reports from users, that being able to see out—even if it is across the lab—is much appreciated—i.e., the view of outside activities, light, and weather. It would be valuable to back up such intuitive notions with neuroscience research that explained how and why the human brain responds to views.

Natural Sciences Building, University of California, San Diego

This building (Fig. 6–8), designed by Bohlin Cywinski Jackson, provides teaching and research space for the study of biochemistry, molecular

Figure 6–8. Natural Sciences Buildling.

biology, and biophysics. The building is intended to integrate scientific collaboration among three departments based in these disciplines.

On a typical research floor, a break room located at the crux of the L-shaped circulation pattern—visible from the corridor and elevators—enhances communication among research groups. Whiteboards, seating, and modular tables help these rooms do double duty as conference spaces.

I was fortunate to have an office on the sixth floor of this building during the two years I was a visiting scholar in the Biology Division (2004–2005).

Hypothesis 6–2

Break rooms for rest, conversations, and snacks located in the midst of laboratory spaces impact the brain in a way that provides intellectual refreshment.

Architects' intuitive notion that providing integration spaces would bring about interdisciplinary research efforts can be determined by the publications produced by the occupants. However, neuroscience studies of how and why the brains of the faculty members respond to the design of a break room are needed and would be useful.

The Biodesign Institute, Arizona State University

Located on the Tempe campus of ASU, the Biodesign Institute (Fig. 6–9) is dedicated to interdisciplinary research between biotechnology,

Figure 6–9. Biodesign Institute at ASU (photo by Timothy Hursley).

nanotechnology, and information technology. Given that the scientific work within this facility delves into the mysteries of nature, the architects felt it was important that the space maintain a connection to natural light and the outside world.

The architectural team of Gould Evans/Lord, Aeck&Sargent designed an open, light-filled atrium and laboratories based on their intuitive notion that this would reflect the values of communication, collaboration, and connection.

Hypothesis 6–3

The proximity of laboratories occupied by different disciplines contributes to collaboration because the brain, by seeking novelty, is more attentive to puzzles generated by another discipline.

Comments: Perhaps this is the case. It would be even more convincing if neuroscience studies would measure how and why such collaborations are reflected in brain processes, and how they are influenced by attributes of the architectural space.

Brain and Cognitive Sciences Complex, MIT

The Brain and Cognitive Sciences complex at MIT (Fig. 6–10) was designed by the team of Charles Correa Associates with the firm Goody Clancy.

The architectural program was complicated by a bureaucratically and philanthropically intricate agenda. Home to the Brain and Cognitive

Figure 6–10. MIT laboratories (photo by Anton Grassl/Esto).

Sciences Department, the complex also was to house two newly endowed centers, the McGovern Institute for Brain Research and the Picower Institute for Learning and Memory, each requiring a distinct presence.

In the center of the building, a five-story glass-roofed atrium brings daylight deep into the building and connects the three distinct departmental presences. Scientists use the atrium for large gatherings. For social interactions, they can choose from a variety of spaces: a bamboo-filled conservatory, a double-height library, and many seminar rooms and tearooms. It could be interesting to have these three groups study their own workspace using neuroscience methods.

Molecular Foundry, Berkeley, California

Designed for Lawrence Berkeley National Laboratory (Fig. 6–11), the Foundry, by the SmithGroup, is composed of laboratories and offices for interdisciplinary research in the nanosciences (the study of molecular formations on a scale of nanometers, the size realm of individual molecules). The laboratory draws from the clear functional nature of the surrounding research facilities, the natural features of the steep hillside, and the breathtaking views of the canyon as it descends into the San Francisco Bay.

The facility is organized architecturally to exploit the views; it also links offices and labs to create opportunities for interaction. The architects intuitively believed that these arrangements are important. It would

Figure 6–11. Molecular Foundry (photo by Timothy Hursley).

be helpful to have their intuition become the basis for neuroscience studies of how and why such architectural features would stimulate the brains of nanosciences researchers to interactions.

> *Hypothesis 6–4*
>
> Nanoscience researchers' neuronal networks are more or less identical to those of neuroscientists.

POTENTIAL NEUROSCIENCE STUDIES OF WORKERS IN OFFICES

Examples of neuroscience studies include the following.

- Natural daylight increases cognitive capacity (essentially the same hypothesis as the one proposed for school rooms).
- The location of a research facility in a rural setting—providing isolation and quiet—contributes positively to higher levels of cognitive activity.
- Offices with views of nature for all who work there increases the quality of the working experience.
- Interactions between researchers from different disciplines enrich the data stored in the cortex in a manner that is measurable.

One method of developing usable hypotheses for neuroscience laboratories would be to conduct postoccupancy studies of existing facilities like those discussed in this chapter. The term *postoccupancy* is generally meant to denote that 1 to 2 years after construction has been completed and people have begun to use the facility. Behavioral scientists have been using postoccupancy studies for decades as a way to explore behavior patterns in specific settings (see Appendix 1). A few architectural firms have also done postoccupancy studies of buildings they designed as a way of learning about the efficacy of their design decisions.

The impact on scientists of architectural features such as spatial configurations, lighting, thermal control, and safety (perceived as well as actual) have been studied by behavioral scientists. Deeper probes designed to reveal why the brain responds to such architectural features would now seem to be in order.

For example, there is some evidence that depriving researchers of daylight and the ability to stay visually oriented (because there are no windows) has negative consequences for their performance (Sternberg & Wilson, 2006). This leads to a hypothesis: Interior glass walls that allow daylight to penetrate deep into a laboratory stimulate circadian rhythms. Or perhaps, providing windows that allow a sense of connection to the outdoors stimulates cognitive processes by providing a continuous panorama of novel events for the visual cortex. The opposite position might suggest a hypothesis: Providing windows that allow a sense of connection to the outdoors produces a distraction (at a subconscious level), resulting in a lack of attention to experimental apparatus.

There are also recorded observations about the equipment provided to laboratory workers and their mental (as well as physical) stimulation. For example, it might be hypothesized that providing a ping pong table for use of the staff in the laboratory will increase mental acuity and reduce cognitive fatigue. Or sharing the use of small conference spaces in hallways not only provides opportunities for interdisciplinary exchanges but stimulates cognitive activity in general.

Levels of Stress in the Work Environment

Stress has been defined as any external (to the body) stimulus that threatens homeostasis, the normal equilibrium of body functions. High levels of stress lead to disease and even death because they compromise homeostatic mechanisms. Although high levels of stress can be debilitating, there can also be a benefit from appropriate levels of stress. As Esther Sternberg is fond of saying, a fighter pilot landing his plane on the deck of an aircraft carrier better be "stressed" if he wants to mobilize all of his mental and physical abilities and avoid an accident.

Stress levels in laboratory workers are more easily understood as those induced by organizational issues. One's relationship to a boss or a colleague is a common issue in all work situations. We are concerned in this book with the impact of design variables in the physical setting. There are different levels of stress for each individual and for the range of variables in their working environment to which they react. For example, there is some evidence that providing lab workers with knowledge of the potential risks and hazards in the lab and providing instruments that constantly monitor such hazards will reduce stress—and improve productivity as a result.

Learning, Working, and Memory

Memory has three components of interest: the ability to acquire information (recognition), the ability to retain information (forming memories), and the ability to recall information. In the course of the working day, lab workers will have some experiences that are so exceptional they will never forget them. Other events are so insignificant that they do not register as learning experiences. Because attributes of the physical environment can potentially enhance memory-forming processes, it is useful to pose hypotheses that might test such conditions.

> *Hypothesis 6–5*
>
> Sensory-rich environments stimulate memory and learning.

Comments: The reverse logic might also be considered, that is, sensory-reduced environments facilitate recall and learning. Because it is possible that some individuals might be more effective at recall and learning, a range of subject response would be expected. Additionally, there may be age-related factors—in the sense that older workers have a generational response to traditional office or laboratory layouts.

Hypothesis 6–6

Open-space office or laboratory layouts have an influence on memory and learning.

Comments: Variables in the architectural attributes could include the volume of the space created by open plans, the acoustic qualities (no doors to close to keep out ambient noises), or special lighting arrangements. How such variables affect working memory (and thus learning) could be studied first in an experimental setting and then in actual offices or laboratories.

Hypothesis 6–7

Providing displays of past activities of the organization can cue memories.

Comments: Though a working lab would not normally include artifacts that would add to the clutter, it is not unusual to see a periodic chart of the elements in a chemical lab. Testing the effectiveness of these charts on stimulating memory could be tested.

CONCLUSION

There are numerous other labs and workplaces than the ones discussed herein, and I hope that the examples included provide readers with an adequate exposure to the variations in design and use.

CHAPTER SEVEN

Methods and Models for Future Research

> *I propose to both my colleagues in neuroscience and my colleagues who are architects that we create a merger of disciplines, to form a new discipline that future students will populate. We need to begin to accumulate the body of knowledge that can be used in design. Factual knowledge about how design changes our brain can be, as one of my architectural colleagues and friends said, "an arrow in the quiver of the architect."*
>
> —GAGE (2003)

This chapter is a presumptive effort on my part. Even though I am a student of neuroscience, I am not a practicing neuroscientist. For that reason, I begin by quoting scientists with established credentials. In the neuroscience world, I would probably be called a "popularizer"—someone who champions a science by providing explanations that are nontechnical. David Huron has suggested, "Popular dissemination of the fruits of research inspires smart people to enter a field, and connecting with colleagues on the other side of disciplinary fences often leads to important interdisciplinary interaction" (Huron, 2007)

In the book *Einstein* (Isaacson, 2007), there is this description of scientific approaches:

> Some scientific theories depend primarily on induction: analyzing a lot of experimental findings and then finding theories that explain the empirical

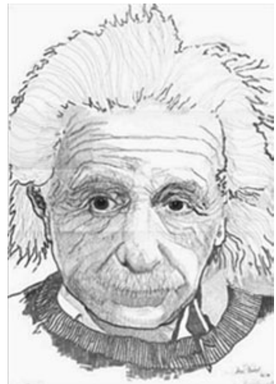

Figure 7–1.

patterns. Others depend more on deductions: starting with elegant principles and postulates that are embraced as holy and then deducing the consequences from them. All scientists blend both approaches to differing degrees. Einstein had a good feel for experimental findings, and he used this knowledge to find certain fixed point upon which he could construct a theory. But his emphasis was primarily on the deductive approach.

In a 1919 essay called "Induction and Deduction in Physics," Albert Einstein described his own preference for the latter approach:

> The simplest picture one can form about the creation of an empirical science is along the lines of an inductive method. Individual facts are selected and grouped together so that the laws that connect them become apparent. . . . However, the big advances in scientific knowledge originated in this way only to a small degree. . . . The truly great advances in our understanding of nature originated in a way almost diametrically opposed to induction. The intuitive grasp of the essentials of a large complex of facts leads the scientist to the postulation of a hypothetical basic law or laws. From these laws, he derives his conclusions.

Next to Einstein's great discovery, there would seem to be an equivalent brilliant application of the human imagination in the discovery of the double-helix structure of DNA by James Watson and Francis Crick. These collaborators were still very young—Watson was 25 and Crick

37—when they unlocked the secret structure of our genes that had for so long eluded their fellow scientists. They combined their well-honed scientific knowledge with a leap of imagination. This seminal achievement in 1953 determined that the structure of DNA is a double-helix polymer, a spiral consisting of two DNA strands wound around each other.

METHODS, MODELS, AND RELATED HYPOTHESES

Here I present some recent research results and relate them to hypotheses described in earlier chapters of this book.

Research Result 1

Michael Fox and Marcus Raichle (2007) say:

> The majority of functional neuroscience studies have focused on the brain's response to a task or stimulus. However, the brain is very active even in the absence of explicit input or output. . . . Much of what is currently known about brain functions comes from studies in which a task or stimulus is administered and resulting changes in neuronal activity and behavior are measured. From the electrophysiological work of Hubel and Weisel to cognitive activation in human neuroimaging, this approach is a paradigm that requires subjects to open and close their eyes at fixed intervals. . . . If we hope to understand how the brain operates, we must take into account the component that consumes most of the brain's energy: spontaneous neuronal activity.

In their conclusion, they say:

> When interneuron classification eventually matures, will it be possible to predict with certainty which particular form of plasticity is exhibited by each synapse? Perhaps the most challenging question that remains to be answered is how the immense potential computational power that is represented by these forms of plasticity contributes to organizing the temporal structure or cortical rhythms and in storing information. Experimental and

theoretical efforts to address these questions will no doubt be rewarded by exciting discoveries.

Is it possible that this area of exploration could be useful in looking at the following hypothesis related to the design of science laboratories (from Chapter 6)? Recall Hypothesis 6–3: The proximity of laboratories occupied by different disciplines contributes to collaboration because the brain, by seeking novelty, is more attentive to puzzles generated by another discipline.

Research Result 2

Scientific American (Unknown, 2007) has suggested: "For all of the delights and horrors human vision provides, it has only one way of collecting information about life: cells in the retina register photons of light for the brain to interpret into images. When it comes to seeing structures too small for the eye to resolve, ones that reflect too few photons for the eye to detect, microscopy must lead the way."

In Chapter 3 (on vision and light) Hypothesis 3–2 raised the following supposition: Recognition of architectural features is impaired when ambient lighting conditions are below a certain threshold. The same issues of too few photons for the eye to detect may determine what this threshold is.

Research Result 3

Sejnowski and Churchland (1999) say:

> How the brain represents its world, both inner and outer, is now seen within the framework of a new paradigm—one that is "naturalistic." Sensory systems are a fruitful starting point for exploring how neurons represent anything. The intensive study of single cells in various sensory systems, especially in the visual system of cats and monkeys and the auditory systems in barn owls and bats, has yielded neurobiological data of major value to neuro-computation.

I think this suggests a key difference between a *current* representation, such as the act of perceiving a teacher talking to her class, and a *stored* representation, which is part of one's background of knowledge, such as the knowledge of how to draw a floor plan for a school or what school you went to when you were a child. Most of our knowledge is *stored* knowledge in memory, but when we are experiencing a perception, the current representation can be influenced by stored representations. Thus, you would probably recognize a women standing in front of a group of children as a teacher because your stored representation of teachers provides that data.

In Chapter 2 (discussion of school design), I explored an issue of considerable concern to architects—the impact of natural daylight on learning. As in Hypothesis 2–4, a child's brain responds to natural daylight (compared to artificial light) in a manner that enhances learning. Does the statement by Sejnowski and Churchland (Churchland & Sejnowski, 1988) that "sensory systems are a fruitful starting point for exploring how neurons represent anything" provide a starting point for exploring the impact of lighting?

Research Result 4

Fred Gage (2003) proposed a possible research project that would link the worlds of neuroscience and architecture in a common interest during his address to the 2003 AIA convention. First, he suggests, a hypothesis is generated. For example, large windows in a school are effective for enhancing academic performance of children. Then an experiment with quantifiable outcome measures is designed. This requires identifying comparable schools, with same age groups, same economic status, and yet different in terms of their design and availability of space and of light coming in through the window openings. Then the experiment would be conducted, and the outcome would be evaluated with statistical methods. A long enough time period would be required, with enough standard tests of outcome performance to be able to accurately assess whether any measured differences were reliable.

If the answer is that large windows in a school are effective in enhancing the academic performance of 9-year-olds of a certain socioeconomic status, these findings would need to be generalized to different age groups, and different school districts, to see whether this principle holds up. The experiment might conclude that for some reason, having large windows, allowing open space with lots of stimulation coming in, is beneficial.

But *why* is having a large window beneficial? This is the next, important step in following up the first experiment (where the conclusion indicated that for "some reason" windows were beneficial)—moving to deductive experimentation. What about the external stimulation is enhancing the students' ability to acquire new information? At this point, neuroscientists and architects can begin to work together to obtain new knowledge about the underlying brain mechanisms. For example, it is possible to imagine that external stimulation, even in a classroom where students are concentrating and learning, acts as a general activator in certain brain areas, making the brain more receptive to the information from the teacher. This new hypothesis might form the basis for a new round of deductive experiments.

Research Result 5

William Rostene, Patrick Kitabgi, and Stephane Melik Parsadaniantz (2007) indicate that:

> Chemokines are not only found in the immune system or expressed in inflammatory conditions: they are constitutively present in the brain in both glial cells and neurons . . . We have shown that recent data suggest that chemokines could be a new class of neurotransmitter, neuromodulator or neurohormone in the human brain; this is in addition to their action on neuronal migration, neurite outgrowth and neurogenesis—phenomena that are mainly observed during embryogenesis. Moreover, we are beginning to discover that chemokines play a part not only in pathological situations in the brain, but also in normal brain functioning . . . Research into the effects of chemokines in normal CNS function is at an exciting stage.

Could these findings help in exploring Hypothesis 6–2 (break rooms for rest, conversations, and snacks located in the midst of laboratory spaces impact the brain in a way that provides intellectual refreshment)?

Research Result 6: Mind–Body Problem

When we look inside the brain, we do not see the functional activities of cognitive psychology—such as memories, thoughts, and perceptions. What we can see with modern imaging equipment are the blood vessels, gray matter, and white matter of the brain—the stuff of neuroscience. Ward (2006) suggests that developing a framework for linking these two sets of phenomena will face the tough problem of mind–body interface.

Bruce McEwen (2007) suggests:

> Often overlooked in the discussion of vulnerability to anxiety and mood disorders, as well as difficulties in coping with daily life and its consequences for physical health, is the matter of individual temperament. Research has shown that happiness, as a trait is part of a larger spectrum of positive emotions, including optimism and exuberance. There are indications that a positive outlook on life is associated with lower vulnerability to stress, a discovery that reinforces our growing appreciation and better understanding of the mind-body interconnection.

Hypothesis 5–1 proposed that facilities for the aging that allow residents to furnish rooms with their own furniture provide a link to their autobiographical pasts. Consequently, they might have a more positive outlook on life reducing their susceptibility to stress and associated immunity problems.

Research Results 7

Patel (2008) has proposed that music and speech are "particulate" systems, that is, systems in which a set of discrete elements that have little meaning in themselves (such as tones in music or phonemes in speech), are combined to form structures with a great diversity of meanings. This

Figure 7–2.

property of speech and music distinguishes them from the holistic sound systems used by many animals, in which each sound has a particular meaning (e.g., distinct calls for mating or signaling the presence of predators).

Patel prefers to think of the commonalities rather than the differences between language and music. He argues that these two domains, although having specialized representations (such as pitch and intervals in music, and nouns and verbs in language), share a number of basic processing mechanisms, and the comparative study of music and language provides a powerful way to explore these mechanisms. Among the mechanisms is the ability to form categories for learned sounds, extract statistical regularities from rhythmic and melodic sequences, integrate incoming elements (such as words and musical tones) into syntactic structures, and extract nuanced emotional meanings from acoustic signals.

There is an analogous approach to architecture and the brain. Architectural structures consist of elements (such as patterns of voids, boundary lines, colors), and assemblies of these elements are then considered syntactical in a way that forms the language of architecture—an orderly arrangement of harmonious elements. These mechanisms can be studied if one develops a common framework for diverse approaches to research within the cognitive science and neuroscience fields.

When we use the visual system to perceive such architectural elements, we form categories for each of them (such as windows, doorways, ornamental elements, etc.). With these categories stored in memory, we then can assemble those regularities that form harmonious structures, and extract emotional meanings. A complete assembly (much like a complete poem or concerto) will often bring about recognition of the full meaning—in the language of architecture—that the assembly is a high school, a colonial house, a Greek Orthodox church, your home or office. Each person has stored in memory the meaning of an architectural assembly based on experience. Each person has a unique inventory of these visual memories usually overlaid with emotional and sensory content, for example, this is the church in which I was married and I can still hear the bridal march; or this was my kindergarten room and I can still smell and taste the peanut butter and jelly sandwiches; or this is the house where I lived when I was a child.

As with music and language, the connections of architectural elements in memory depends on one's ability to form categories for learned elements, extract statistical regularities from rhythmic and harmonic architectural sequences, integrate incoming elements (such as windows and doors) into syntactic structures, and extract nuanced emotional meanings from visual signals.

Petr Janata (2007) has suggested: "Understanding how the brain accomplishes music is likely to enhance our understanding of the brain's inner workings for the simple reason that musical behaviors include the same elements of perception action emotion, and other mental operations as so many other kinds of behavior."

Later in his article, Janata proposes: "The angular gyrus appears to be part of a network that is more active when a person's thoughts are directed inwards, as when evaluating how one feels about some thing, or when forming larger-scale action plans. It might, therefore, be critical in giving music its emotional meaning."

Toward the end of his article, Janata suggests a specific method to explore:

> One way to try to dissociate the emotional components from the more mechanistic aspects of binding information might be research using transcranial magnetic stimulation. This techniques employs pulsing strong magnetic fields above specific brain areas in order to create temporary lesions. I would predict that stimulating the angular gyrus would result in a transient loss of the sense of emotional meaning without affecting musical score reading, whereas stimulation of the adjoining supramarginal gyrus might have the opposite effect.

Finally, David Huron (2007) summarizes work in this field: "Music cognition research is in its golden era. Tremendous progress has been made in understanding musically evoked emotions, expectation, memory, the acquisition of musical skills, style, sociocultural factors, and other aspects of this great art."

Research analogies between the perception of music in the brain and the perception of architectural elements seems potentially well suited to Hypothesis 3–1: The brain is hard-wired to respond to proportions based on the golden mean. Hypothesis 4–6 also states: Harmony in architectural designs elicits more positive brain responses than those that are clearly nonharmonious. Hypothesis 4–8: A dark surface above our visual plain (the area generated from our eye level by peripheral vision), when intersected by a dark vertical plain that approaches but does not touch the overheard plain, induces a sense that the overhead plain is floating above us.

Research Result 8

James V. Haxby, from the Psychology Department of Princeton University (2006) has this to say:

> When Galileo looked at the planets with his telescope and discovered the moons of Jupiter, he transformed our understanding of the cosmos. When van Leeuwenhoek looked at pond water through his microscope, he discovered a world that transformed our understanding of life. High-resolution imaging of brain functions now promises to transform our understanding of how neural activity represents information—the physical basis of knowledge.
>
> Most neuroimaging work on the cerebral cortex has focused on the functional architecture of the macroscopic areas such as the object vision pathway in the ventral occipitotemporal cortex, where researchers have emphasized specialization for object categories—faces, places, buildings, body parts, small man-made objects—or for a visual process (expert recognition).

The results of the experiments Haxby describes show that models (based on lower-resolution imaging) positing that large areas of the cortex have a single function are incorrect. Instead, the code for the representation of faces and objects is found on a much finer scale. However, the results themselves are completely consistent with low-resolution imaging measures of face selectivity in the fusiform face area.

The voxels that responded maximally to cars and sculpture must also respond to other categories. Further experiments will be necessary, however, with careful, theory-driven sampling of categories to fully characterize the real tuning functions of these cortical spots.

Hypothesis 3–3 proposed that the transformations of the ventral stream focus on size, shape, color, and so on, of an architectural setting provides long-term perceptual knowledge that enables humans to recognize specific buildings. Haxby's research method could explore whether this hypothesis enables us to recognize the Capitol Building in Washington.

Research Result 9

Cognitive neuropsychology is a term used to describe an approach for brain studies using patients with acquired brain damage to advance theories of normal cognition. It is common to call this method *cognitive neuroscience*—a broader-based concept that is less restrictive in terms of methodology (Ward, 2006). This provides a view of brain models in which the brain *might* implement a given cognitive function. Whether the brain actually does implement cognition in a particular way—using this approach—will eventually be a question for empirical research in cognitive neuroscience.

Technological advances in imaging methods have led to the development of functional imaging and have helped explain brain lesions more precisely in ways that were not possible before (except at postmortem exams). For example, scientists once used a method of direct stimulation of regions of the brain by electrical pulses during open brain surgery for epilepsy, though such direct stimulation is rarely used today. The modern equivalent of such studies of brain lesions uses magnetic (not electric) fields and is called transcranial magnetic stimulation. These methods can be applied across the skull rather than stimulating the brain directly.

Hypothesis 3–5 raised a question about the function of windows in visual field perception. This hypothesis said the visual system's attention span—especially the visual field in the peripheral area—is restricted by the size of a window's opening. It might be that transcranial magnetic stimulation could be used to test this hypothesis.

Research Result 10

A virtual reality presentation was originally prepared for the Research Program of the General Services Administration's Public Building Service (Fig. 7–3). The image is only a glimpse of the actual three-dimensional view available to a participant who enters the six-sided "cave" of virtual reality. Wearing a special pair of glasses, linked to the virtual reality software program on nearby computers, one can see walls, ceilings, floors, and furniture that give the appearance of reality. As this tool becomes even more realistic, it offers the possibility, when combined with portable scanners, to test the neural experiences of architectural settings in which the parameters can be quickly changed (e.g., color of walls).

ARCHITECT'S METHODS AND MODELS

Although there have been a number of highly imaginative architects who have produced design concepts powerful enough to become a basis

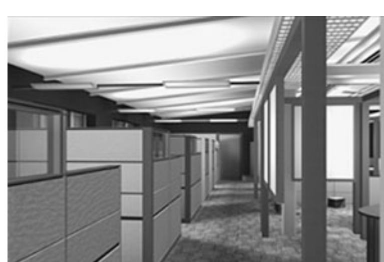

Figure 7–3. Virtual image by ChiuShui Chan (Dept. of Architecture, Iowa State University).

for emulation by future generations, their ideas were primarily intuitive leaps of their imaginations—without a grounding in a knowledge base beyond the technology of building materials. Frank Lloyd Wright, whom I consider the most original architect of past century, produced an astounding architectural vocabulary that no one has been able to use in a satisfactory way. When Wright died, his genius could not be emulated. By contrast the work of Watson and Crick, because it was well grounded in science, became the seed for hundreds of future discoveries by all who shared their paradigm.

Toward a More Rigorous Method

Architectural readers who are interested in exploring more rigorous methods than intuition might wish to read the following recommendations from the neuroscience literature.

The process of research involves examining the existing literature, identifying an important question, and formulating a research plan. *Fundamentals of Neuroscience* (Squire et al., 2003) discusses a generally accepted procedure for organizing research. Sometimes the plan is purely descriptive, for example, determining the structure of a protein or the distribution of a neurotransmitter in the brain. Descriptive initial research is essential to the subsequent inductive phase of experimentation, the movement from observations to theory, seasoned with wisdom and curiosity. Descriptive experiments are valuable both because of the questions they attempt to answer and because of the questions that their results allow us to ask. Information obtained from descriptive experiments provides a base of knowledge on which a scientist can draw to develop hypotheses about cause and effect in the phenomenon under investigation.

Once a hypothesis has been developed, the researcher has the task of designing and performing experiments that are likely to prove or disprove the hypothesis. This is the deductive phase of experimentation, the movement from theory to observation. Through this paradigm, the neuroscientist seeks to narrow down the vast range of alternative explanations for a given phenomenon. Only after attempting to disprove the hypothesis as thoroughly as possible may scientists be adequately assured that their hypothesis is a plausible explanation for the phenomenon under investigation.

At the conclusion of their experiments, researchers' first task is to report their findings to the scientific community. The dissemination of findings often begins with an informal presentation at a laboratory or departmental meeting, eventually followed by presentation at a scientific meeting that permits the rapid exchange of information more broadly. One or more research articles published in peer-reviewed journals ultimately follow the verbal communications. Science depends on sharing information, replicating and thereby validating experiments, and then moving forward to solve the next problem.

CONCLUSIONS

Aristotle wrote that "happiness is the consequence of a deed"—that is, it is the result not of chance but of using for the best all the opportunities that we encounter in our lives.

Now that you have arrived at the end of this book and have had an opportunity to read the chapters but have not yet examined the appendixes, I highly recommend that you take the additional time to do so. Appendix 1 is of particular interest if you are a neuroscientist thinking of organizing a research project based on one or more of the hypotheses discussed here. If you are not a neuroscientist, Appendix 2 will be useful in providing you with an introduction to the field. Finally, Appendix 3 should be of interest to everybody.

APPENDIX ONE

Environment–Behavior Studies: A Precursor for Neuroscience in Design

JOHN ZEISEL

Between 1972 and 1981 in a Pennsylvania hospital, 23 pairs of patients, all undergoing cholecystectomy [gallbladder removal] operations, were selected by matching sex, age (within five years), being a smoker or a non-smoker, obese or within normal weight limits, general nature of previous hospitalization, year of surgery (within six years), and floor level. One of each pair was assigned to a room with a view of a brick wall (like the view on the right), whilst the other had a view of a "natural scene" with deciduous trees (like the view on the left). Patients with a natural view spent a shorter time in the hospital than those with the brick wall view (7.96 days compared with 8.70 days per patient) and had fewer negative notes made about them (1.13 per patient compared with 3.96 per patient). The "natural view" group requested significantly fewer doses of analgesics in the period between two and five days after surgery, when patients are most in control of their own pain relief. These results indicate that patients with a "natural view" make a recovery, with less pain relief needed.

—ULRICH (1984)

Figure A1–1. Double windows.

How the physical environment created by designers, especially architects, affects the people who use them has been of concern to architects as far back as Vitruvius, who defined the purposes of architecture as *firmitas*, *utilitas*, and *venustas* (structural stability, appropriate spatial accommodation, and attractive appearance), translated popularly as "commodity, firmness, and delight." Utility, or "appropriate spatial accommodation," clearly means a building's use and usability; purpose and delight also relate to human responses to environmental design. Le Corbusier, the great French architect of the early 20th century, referred to housing design as the work of creating a "machine for living." Although the word *machine* might be too mechanical a response for many social scientists, these words clearly indicate that Corbusier thought that how inhabitants used housing was, in his design approach, an important outcome. Finally, the modern movement in architecture beginning with the work of architects such as Walter Gropius at the Bauhaus school in Germany in the 1930s coined the slogan "form follows function." Once again, these architects clearly saw one element of function to be a building's use.

These architects and architectural movements all believed in the power of architecture to support social ideals, human needs, physical health, spiritual aspirations, and many other very human dimensions. What they did not do was include in their design process explicit description of the social and human dimensions they aimed to meet. They also did not build into their design process and theory a way to systematically assess the degree to which a specific physical design and environment actually achieved its social and human goals. They did not include research into human and user needs before designing, nor did they measure the effects of buildings in use.

One reason for this omission was that architecture was seen by most practitioners, clients, and the public in general as a vehicle for the architect's self-expression, as a way for clients—often organizations—to meet corporate needs, and as artistic expression.

An equally important reason was that when architecture was developing as a field and profession, there were no well-established social sciences to be incorporated into the design process. Psychology, sociology, and to some degree modern anthropology—with theories, methodologies, methods, and social and psychological facts—all emerged in the mid-20th century. During this flowering of the social and psychological sciences—drawing to a large degree on European theoreticians and researchers, such as Émile Durkheim, Vilfredo Pareto, and Georg Simmel—some social scientists in fact studied social phenomena related to the built environment. They didn't call themselves environmental psychologists (Ittelson, Proshansky, and Winkler, 1970) or environment-behavior experts (Zeisel, 1980), but these forefathers of this field definitely developed the building blocks that eventually supported this field and helped architects see value in using them.

STUDIES BY INNOVATORS

Who were these innovators, and what did they study? Robert Sommer, a social psychologist, studied how people changed their environments to meet their needs and how, in turn, these environments affected behavior. In *Personal Space*, Sommer (1969) studied and identified the way lower lights in bars enabled greater intimacy among patrons, and how in mental hospitals the arrangement of chairs influenced whether patients felt isolated or socially connected. Edward T. Hall, an anthropologist, identified in *The Hidden Dimension* (1966), how different cultures interpreted space in social relations—with some feeling insulted if their conversation partner didn't stand close enough to smell them, and others feeling insulted if they did. Sociologist Herbert Gans studied social life in the predominantly Italian American West End neighborhood of Boston in his book *Urban Villagers* (1962). He identified (among other things) how families used the separation of kitchens from living rooms in their apartments to maintain culturally based gender identification and separation.

With all this intellectual fervor boiling up and linking environment and behavioral phenomena, it was not long before the field of environment–behavior (E–B) studies formally emerged. First to appropriate this field were psychologists. A group of psychologists at the City University of New York published a textbook of readings they called *Environmental Psychology* (Proshansky, Ittleson, & Rivlin, 1970). The chapters, not surprisingly, were written by and about psychologists, architects, sociologists, anthropologists, and others. The theories and methods included were drawn from all these sciences of the human condition.

CONCEPTS TAUGHT IN SCHOOLS OF ARCHITECTURE

Eventually more textbooks appeared, and courses covering these subjects appeared in universities worldwide—some housed in schools of architecture or interior design departments, others in departments of psychology linked to departments of design.

What was taught in these courses? The field included theory, methods, concepts, and environments drawn from the various disciplines that made it up. Quickly, as can be seen in the following discussion, these elements took on an identity of their own and were seen as constituting this new field.

Among the concepts included and studied in E–B studies are privacy, crowding, wayfinding, environmental perception, territoriality, and personalization. Among the methods employed are focus interviews, questionnaires, observation of behavior, observation of physical traces and cues, analysis of group data, and analysis of plans.

Among the environments systematically studied employing these concepts and methods are streets, housing, offices, museums, schools, hospitals, Alzheimer's residences, and children's play environments.

RESEARCH METHODS

Two major research methodologies and one design process have been developed in this field particularly to relate to architecture and other design professions and processes: User needs programming studies, postoccupancy evaluation (POE) studies, and evidence-based design.

The knowledge developed in this field has greatly enriched architecture. Many buildings have been better designed because their architects have taken a course or read an E–B textbook. Many buildings designed with an E–B perspective and methods work better for their users. The research carried out on buildings in use—in user needs and POE studies—has enriched the design of other building types.

The question that seems to have been answered by these developments is how to design better buildings—how to better accommodate and meet user needs. The answer to the question of why these environments work better is still missing, and the linkages presently being made between neuroscience and architecture are likely to shed a bright light on this question in the decades to come.

What makes up this field of E–B studies, also known as environmental psychology?

ENVIRONMENT–BEHAVIOR CONCEPTS

- *Privacy:* "Controlling the degree and type of access others have to you and your territory," is the way Irwin Altman (1975) defines privacy. A closed door is necessary in some cultures to prevent others from engaging in conversation, whereas in others, just turning one's back is enough.
- *Crowding:* Roger Barker developed a key concept that underlies crowding studies, namely, the concept of behavior settings. He uses this approach to demonstrate that crowding is a relative concept; all rooms and other physical spaces have inherent social properties, among them comfort level users have in groups of different size. A small after-school social club meeting in a large gymnasium is likely to feel uncomfortable because the space feels "undermanned," to use a Barker term, whereas the same group in a small classroom might feel crowded.
- *Wayfinding:* A fundamental human need is to find one's way in the physical environments in which we live, work, and play. In the E–B literature, research on wayfinding plays a central role. Kevin Lynch's classic study of how

Boston taxi drivers find their way around the city identified five physical elements critical to wayfinding: pathways, districts, landmarks, nodes, and boundaries.

- *Environmental perception:* E–B researchers have also studied people's reactions to buildings and spaces. Architects like to ask how the users of their buildings "read" their environment; therefore, E–B researchers have spent a great deal of energy studying this aspect of the person–environment interaction.
- *Territoriality:* Everyone who uses space—whether in a bedroom, an office, a parking lot, or a restaurant—expropriates part of that space as his or hers. Each person stakes out her or his turf, setting up indicators of ownership, much like wolves and dogs leave a marker scent at the edges of the territory that they are prepared to defend. Graffiti on walls in urban areas has traditionally been considered one way gang members establish the boundaries of the territory they control.
- *Personalization:* In those places we spend a lot of time, such as homes and workplaces, we have a tendency to want to make it homey and personal. We might put pictures of family members on the wall or put trophies and awards on shelves. Personalization is linked to territoriality, but it is different. Personalization reminds the person and others who encounter the space exactly who lives and works there, not merely that the territory is staked out. Decorated front yards in housing areas, pictures of employees' children on desks in workspaces, and students who wear their school colors on their jackets are all examples of personalization.

ENVIRONMENT–BEHAVIOR METHODS

Because the field of E–B studies in architecture developed primarily among social scientists, data-gathering methods employed in this field tend to be drawn from sociology, anthropology, and psychology. Used in natural and experimental situations, as well as before and after buildings are occupied, the methods generally fall into three areas: asking questions, observing people and the physical environment, and analyzing data archives, including plans and other forms of architectural information.

- *Focus interviews:* Used to understand the way building users think about an E–B situation or concept, focus interviews with individuals as well as groups enable researchers to understand the "definition of the situation" in which they find themselves.
- *Questionnaires:* These structured instruments are employed to collect large amounts of data from a large number of people that can be quantified and analyzed statistically.
- *Observation of behavior:* Much of what E–B researchers want to learn about is the interaction people have with their physical environment—how they use it, navigate it, and change it to meet their needs.
- *Observation of physical traces and cues:* People have left physical traces of their behavior for millennia, and anthropologists mine these traces to develop theories about past civilizations. Similar methods are used in E–B studies to determine what people have done to their environments to interpret what this might mean for analysis of social relations in environments, antisocial behaviors that have left traces, and meeting user needs.
- *Analysis of group data:* In the course of managing businesses, schools, and other complex environments, an administration often collects data on those who use the buildings. For example, hospitals collect data on such things as illnesses, length of stay, and blood pressure. Schools collect data on attendance, grades, and incidences of vandalism or other property damage. Businesses collect data on absenteeism, productivity, and copy machine usage. All of these, when correlated with characteristics of the built environment of those enterprises, give insights into E–B interactions that might inform future design. For example, at the *Minneapolis Star Tribune* newsroom (Zeisel, 2006), the rate of carpal tunnel syndrome, found in medical records, indicated the need for more ergonomic furniture.
- *Analysis of plans:* Unique to buildings and other design settings are schematic and construction plans. Just as data collected on users sheds light on the behavior side of the E–B equation, plans contain data that can be useful in understanding the environment side. For example, if users of an office building complain about heat or cold, plans of the ventilation design can yield explanations.

One way to organize the E–B studies carried out over the past three decades is in terms of the types of settings studied. For architects who design buildings and often compare buildings of a certain type to each other, this can be helpful. Among the popular environments studied systematically in use are settings for living, work, education, transportation, and health care.

- *Housing:* Housing—mass housing rather than individual houses—has intrigued E–B researchers since the field was founded. Different cultures live in different types of housing. Poor housing is crowded and often full of social life. Higher cost housing presents researchers with the opportunity to study environmental perception, among other topics. What in the environment, for example, do buyers perceive as reflecting higher value to a property?
- *Offices:* Because many people spend half their lives working in offices and workplaces of some sort, these settings have also been the focus of E–B researchers. In particular, researchers have been interested in how the physical environment can improve of reduce productivity, how employees develop their own personal work space, and how teams who work together establish territories that belong to them. For example, the work of Jacqueline Vischer (Vischer, 2005) has shown that the space employees occupy is a key element in the employer–employee "socio-spatial contract" and thus plays a critical role in organizational productivity.
- *Streets:* Public streets have been a focus of E–B studies since the beginning of the field because they are a social setting for many neighborhoods and because street social life and the way people feel about cars represent the glue for most housing schemes. Issues of developing pedestrian zones, creating social magnets, and dealing with teenagers on streets are favorite subjects.
- *Schools:* The role of environment in education in schools has always been of interest to E–B researchers and architects with whom they work. From studies of the open plan schools of the 1970s to issues of vandalism and property damage, school design issues have been on the forefront of the E–B radar screen. Among school designers, questions arise about the importance of daylight to children's ability to learn, as well as the benefits and challenges posed to children by open plan schools versus schools with primarily bounded space around classrooms.
- *Hospitals:* Hospitals and health care settings generally have been a central to the work of designers who employ E–B approaches and data, as well as to

E–B researchers and consultants. For example, Janet Carpman's important work on wayfinding in hospitals demonstrated that legible signs with limited information located at crossroads and other decision points along a pathway are most effective. Such clear signage and logical planning saves staff time and eases the life of hospital users and visitors.

- *Alzheimer's residences:* People living with Alzheimer's disease are among those who most need well-designed environments. The areas of the brain that create and hold cognitive maps of their surroundings are damaged, but they can easily read and negotiate "naturally mapped" settings. Zeisel's work has shown that eight characteristics—including safe and camouflaged exits, walking paths with destinations, and therapeutic gardens—all contribute to reduced symptomatic behaviors.
- *Children's play environments:* Children use public playgrounds, school playgrounds, and paths in housing estates to exercise and play. Their behavior and how play behavior is affected by environmental design has been a corner of E–B studies since the 1960s.

E–B studies have also influenced the design process that many architects employ. Three research and design linking processes are either employed by many architects or known by them.

- *User needs studies:* During the design programming phase, in which the performance characteristics of a building are determined and data are gather data on the building-related needs of various users of a building without a specific building in mind, E–B practitioners carry out user needs studies. Architects draw on such E–B data and information in books, articles, and research reports to inform themselves of basic and sometimes special needs associated with particular user groups, such as children in playgrounds; employees in office buildings; patients, visitors, and staff in hospitals; and people living with Alzheimer's disease in assisted living residences.
- *POEs:* Buildings and other settings have goals and objectives to meet, including such things as meeting user needs for functionality and comfort, user satisfaction, image development for an organization, economic viability, support for efficient operation, and so on. Systematically studying how a building in use performs along predetermined parameters like this is called a POE. In the design, construction, and use sequence, POEs enable the

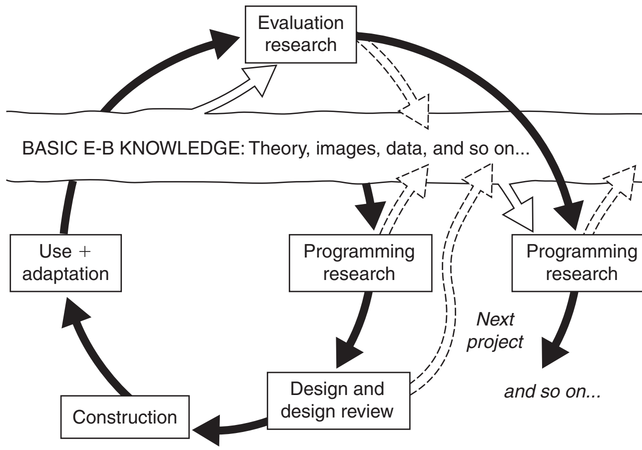

Figure A1–2. E-B Knowledge.

profession of architecture to continually upgrade the E–B information available from actual buildings by which to make high-quality design decisions.

- *Evidence-based design:* This approach to research and design interaction differs from the other two processes, in that the designers and their decisions drive what data are used and what studies are carried out (Vischer & Zeisel, 2008). Drawn as a parallel to evidenced-based medicine, in which health care professionals are more and more basing their diagnoses and prescriptions on available data, evidence-based design decision making is taking hold of many designers' imaginations because it puts the use of research data—among these E–B data—in the hands of the design professionals making decisions, unlike POE studies.

THE NEXT STEPS: NEUROSCIENCE IN THE MIX

E–B studies—user needs studies and POEs—can help us understand *what* the relationship might be between designed environments and behavioral outcomes. They will never be able to tell us, from a physiological and neuroscience point of view, *why* these relationships occur. This requires that neuroscience knowledge be inserted into the mix.

The following figures (Fig. A1–3 and A1–4), drawn from *Inquiry by Design* (Zeisel, 2006), illustrates how design hypotheses might link E–B data and neuroscience data into a single model to finally be able to ask both the *what* and *why* questions in the same design research project.

Model for E/B/Neuroscience Design Research Hypotheses				
Domains of Study				
Design	Neurosciences		Environment-Behavior	
Variables in each domain				
Physical environmental elements	Neuroscience dimensions	Physiological factors	Behavioral outcomes	Performance outcomes
Measurement techniques targeted to specific disciplines				
Measures describing the characteristics of environment such as plans and dimensions	Neuroscientific methods to measure this dimension such as PET scans, MRI, and ERP evoked potentials	Indicators of physiological reactions such as cortisol saliva tests and blood pressure readings	Behavioral observation and other measurements such as systematic observation, photography, & self-report	Paper and pencil test, performances, portfolios, expert judgment

Figure A1–3. Model for E/B chart.

E/B/N Design Research Hypotheses				
That the light and noise characteristics of neonatal intensive care units, if not controlled to respond to the developmental needs of premature infants, will have both inunediate and long term negative health impacts on the person's auditory and visual systems and associated behavioral and performance outcomes.				
Domains of Study				
Design	Neurosciences		Environment-Behavior	
Variables in each domain				
*Lighting intensity, duration, and frequency *Sound levels	*Neuronal development in auditory and visual systems	*Characteristics of the eye and ear	*Ability to discriminate frequencies *Myopic vision	*Hearing problems, lack of musical skills, and learning and work problems
Measurement techniques targeted to specific disciplines				
Lux and decibel measures	PET scans, MRI, ERP evoked potentials	Physiological interventions–CAT scans	Auditory testing, vision tests	Test scores, school performance, job performance

Figure A1–4. E/B/N Design chart.

Were we to turn this model into an environment/behavior/neuroscience design research hypothesis for lighting in neonatal intensive care units, it might look like Figure A1–4 and would generate a much richer set of data.

In sum, great strides forward are made on the shoulders of giants, as Robert Merton points out in his studies in the history of science. Architects have been interested in the users of their buildings since the start of the profession. As the social sciences have increasingly been able to provide useful research approaches and information about these users, architects and architecture have embraced these allied fields. One of the earliest steps in this direction was to embrace what could be learned from psychology, sociology, and anthropology—the field known as environment–behavior studies and environmental psychology. The next step in the quest to establish a firm link between built environment and people is to engage the neurosciences in the same way—carrying out basic research, embedding hypotheses from the neurosciences in design, and testing these to determine their effects. Neuroarchitecture, however, will be more successful the more it incorporates and builds on the information and approaches the social sciences and E–B studies have to offer.

APPENDIX TWO

A Basic Library of Neuroscience

Imagine the brain, that shiny mound of being, that mouse-gray parliament of cells, that dream factory, that petit tyrant inside a ball of bone, that huddle of neurons calling all the plays, that little everywhere, that fickle pleasuredrome, that wrinkled wardrobe of selves stuffed into the skull like too many clothes into a gym bag. Sometimes it's hard to imagine the art and beauty of the brain, because it seems too abstract and hidden an empire, a dense jungle of neurons. . . . The art of the brain is to liken and learn, never resist a mystery, and question everything, even itself.

—ACKERMAN (2004)

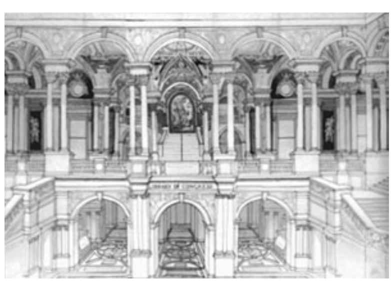

Figure A2–1.

THE BASICS OF NEUROSCIENCE

This appendix is an introduction to what is known about the brain and mind for readers who are not neuroscientists. There are encyclopedic renditions of how the brain is organized and how it works at the molecular and cellular level. These volumes, which contain thousands of pages, cannot be easily summarized in a few pages. What follows is a relatively simple presentation on the brain and its principal components. Chapters of this book explore subjects such as memory, sensory systems, and consciousness. The background material in this appendix will help those readers not yet familiar with neuroscience in understanding that most complex object in the universe—the human brain.

The difference between the brain and the mind needs to be clear. You use the word *mind* every day. You might say, "I think I am losing my mind." Or "never mind," or "I can't keep my mind on what I am doing." However the mind is not a synonym for *brain*. The mind is a process that uses the organ of the brain as its instrument. Only humans can use their minds to think about the past, contemplate the future, and be aware of being aware.

No other species creates habitats or communities that are as elegant, as structurally daring, or as functionally diverse as ours. Spiders, bees, beavers, ants, and corals (as in coral reefs) build intricate and fascinating habitats, but they are the result of instincts, not creativity. No other species has produced a building designer like Michelangelo. Birds, whales, wolves, and cats all make sounds to communicate with their mates and with us, but these sounds are born of instinct and the structure of their larynx, as contrasted to human language. In spite of some conjecture, there is no evidence that any other species could produce a creative writer like Shakespeare. The unique and marvelous development of the human mind has made this possible. The human brain is also unique in being flexible enough to use information in creative ways and to adapt to relatively rapid changes in the architectural settings used for sheltering our lives.

DNA

Deoxyribonucleic acid (DNA; see Fig. A2–2) is an organic chemical of complex molecular structure. DNA codes genetic information for the transmission of inherited traits. In 1953, James Watson (Watson & Berry, 2003) and Francis Crick determined that the structure of DNA is a double-helix polymer, a spiral consisting of two DNA strands wound around each other.

Each strand of DNA consists of 3.2 billion base pairs—A, C, G, or T (representing the molecules adenine, cytosine, guanine, and thymine). Each triplet of pairs (representing three molecules) instructs special machinery inside the cell to grab onto a particular amino acid. When enough amino acids are assembled in a chain, we have a protein, and proteins are the building blocks of the body and brain. Amino acids are assembled into proteins in ribosomes, small cellular particles containing a second form of nucleic acid called RNA.

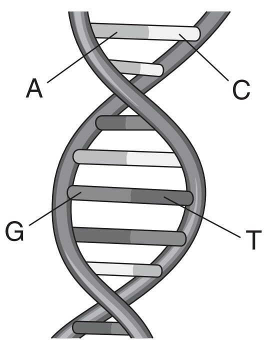

Figure A2–2.

A *gene* is an instruction, like the directions in a bead-weaving kit, but written in terms of molecules. In humans, 99.9% of our genes are identical. Only 80 of the 80,000 genes of our total makeup distinguish us from each other. Genes provide an evolutionary memory that enables our brains to be assembled with only minor changes (mutations) from those of our ancient ancestors. Because these ancestors of some 50,000 years ago lived in the savannahs of Africa, many of the hard-wired networks of our brains are based on what these hunter-gatherers needed for survival.

THE BRAIN AND ITS COMPONENTS

What Is the Brain?

As Rita Carter (1998) tells us, the brain is "as big as a coconut, the shape of a walnut, the color of uncooked liver and the consistency of chilled butter." It has two halves called *hemispheres*, covered with a wrinkled gray tissue called the *cerebral cortex* (Fig. A2–3). If this gray matter were unfolded, it would be about 30 inches square and about the thickness of a table napkin. Lodged within its six thin layers are 100 billion cells—10 billion of them are neurons and the rest are glial cells (which serve as the glue to hold neurons in place).

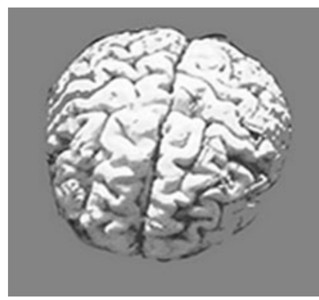

Figure A2–3.

Neurons

Neurons (Fig. A2–4) are the primary working components of the brain—something like transistors in a computer. However, unlike transistors, neurons are living components that are constantly changing, forming networks, receiving signals from other neurons, sometimes damaged by disease or accidents, sometimes make mistakes, and sometimes die. Neurons are assembled in the brain in "families" or areas, each with a special responsibility, such as making it possible to hear, feel, taste, or smell.

Neurons are the basic components of the brain. More than 100 billion of them are embedded (glued in place by glial cells) in the cortex, where

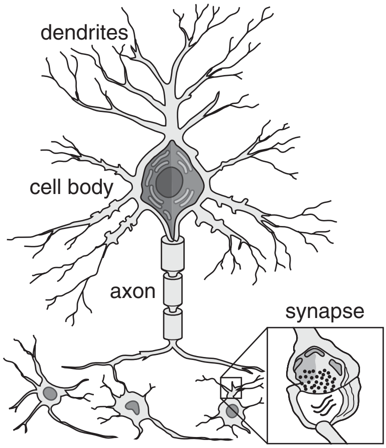

Figure A2–4.

they provide continuous activity for the mind. The major parts of a neuron are as follows.

- The *cell body* is where important housekeeping functions occur, such as storing genetic material and making proteins and other molecules needed for the cell's survival and the activity of neurons.
- *Axons* serve primarily as output channels and carry messages to other cells.
- *Dendrites* are the primary input channels. They make multiple connections with other neurons via thousands of synapses.
- *Synapses* are components at the end of an axon that connect to other neurons either via direct electrical signals across dendrites or by the release of chemicals from the storage sites of the axon's terminals. These released chemicals are called *neurotransmitters*. There are more than 50 varieties of neurotransmitters. The number of connections in the brain is so large that it probably is a quadrillion (10^{15}). Such an enormous number of connections provides nearly incomprehensible flexibility.

Action Potentials

There is a concept in neuroscience called action potential that needs to be understood. An *action potential* is a brief (about 1,000th of a second) reversal of the electric polarization of the membrane of a neuron (Fig. A2–5). Every sensory experience has a goal of activating one or more action potentials somewhere in the brain. It is useful to think about this activity as the creation of a single bit of information (e.g., like the sound of one instrument in the total sound of an orchestra).

The illustration in Figure A2–5 is a cross-section through two terminals (sometimes called pods). The left terminal (A) is at the tip of an axon and the right terminal (B) in located on a dendrite. These pods are separated by a very narrow space (called the synaptic cleft), across which chemicals (called neurotransmitters) flow.

An action potential is produced when an electrical signal is received by the axon of the neuron (A) to begin a chemical reaction that will eventually release neurotransmitters from its pod. Neuron (A) is said to be the "presynaptic axon terminal." After there is a chemical exchange, the dendrite (B) is said to be the "postsynaptic dendrite spine" (or terminal).

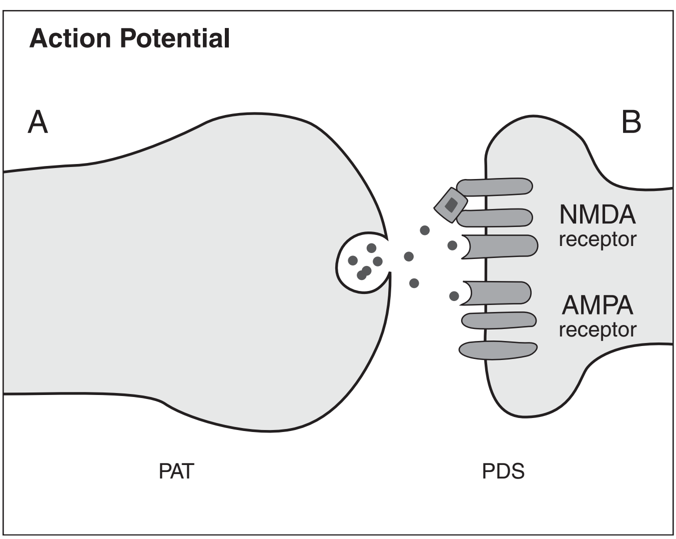

Figure A2–5.

There is a very clever locking mechanism (labeled NMDA) on the terminal of the postsynaptic dendrite (B) that allows the chemicals contained in a neurotransmitter to flow only one way. However, once the neurotransmitters have made it across the synaptic cleft, a reaction releases this locking mechanism (actually a molecule of magnesium) to allow a chemical (sodium) to flow between the presynaptic and postsynaptic terminals and establish a feedback loop. Once established, the presynaptic neuron (A) can more efficiently send additional neurotransmitters across to the postsynaptic dendrite (B) establishing what is called a long-term potential (LTP). This LTP binds the neurons together for any future activities that come along the same path. Subsequently, sodium ions are pumped out of the cell and potassium ions are pumped in by protein transport molecules. This restores the original ion concentrations and readies the neuron for a new action potential.

If a child is studying the ABCs or a musician is practicing on the piano or you are learning to play tennis, the brain can guide visual,

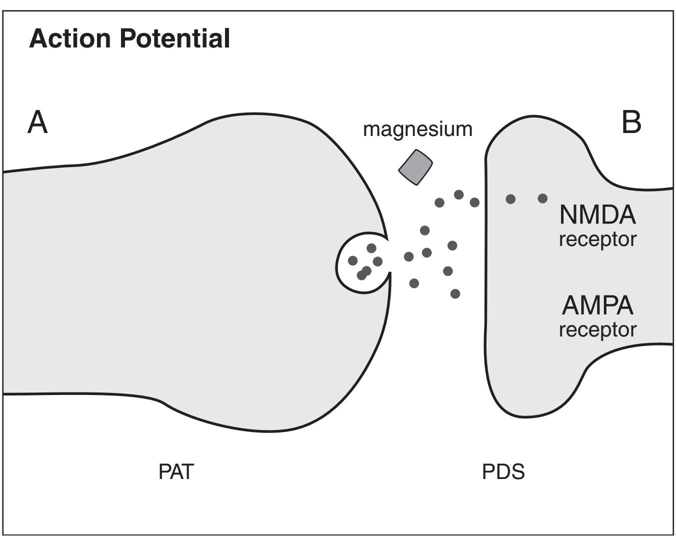

Figure A2–6.

aural, and muscular experiences in a manner that produces a series of LTPs.

Your brain probably will provide you with the ability to recognize Figure A2–7 as Frank Lloyd Wright's famous house Fallingwater. That's because the first time you visited Fallingwater or saw photographs of the house, an image was stored in your memory. Each time you have seen the same or similar photos of the house, you have reinforced the previously created image. This process creates an LTP between your visual system and the image.

Figure A2–7.

Cajal and Golgi

The small size of neurons made it difficult for scientists to study them before the invention of compound microscopes in the late 17th century. Most neuronal cells are in the range of 0.01 to 0.05 millimeters in diameter. A pencil lead is about 2 mm across; neurons are 40 to 200 times smaller. The detailed study of neurons became possible after Camillo Golgi discovered that by soaking brain tissue in a silver chromate solution, now called the Golgi stain, a small percentage of neurons became darkly colored, making them visible by using a microscope. This allowed Golgi to resolve in detail the structure of individual neurons and led him to conclude that nervous tissue was a continuous reticulum (or web) of interconnected cells much like those in the circulatory system.

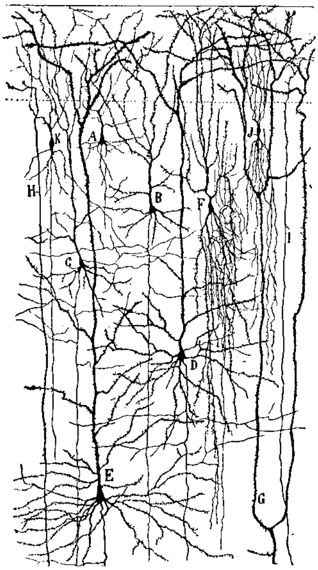

Figure A2–8.

The staining method also made it possible for Santiago Ramon y Cajal in 1888 to begin his 25-year series of publications on how neurons provided the key elements of brain circuitry. He developed what is known as the neuron doctrine, which states that the individual unit of the nervous system is a single neuron. This theory was in contrast to the reticular theory advanced by Golgi. However, with the discovery of electrical synapses, some have argued that Golgi was at least partially correct. For their work, Cajal and Golgi shared the Nobel Prize in Physiology or Medicine in 1906.

THE PRINCIPAL COMPONENTS OF THE BRAIN

If you opened up the brain and looked between the two hemispheres, you would find a number of components of the brain. Each of these components is known to provide specialized functions—all of which are amazing.

The Brainstem

We begin exploring these components by looking at the brainstem (Fig. A2–9), the most ancient part of the brain. Scientists believe that it evolved more 500 million years ago in the species from which we eventually descended.

The brainstem is formed from the nerves that run up from the body via the spinal column to carry information from the body to the brain. A variety of cells in the brainstem determine the brain's general level of alertness and regulate the homeostatic processes of the body, such as breathing, heartbeat, and blood pressure.

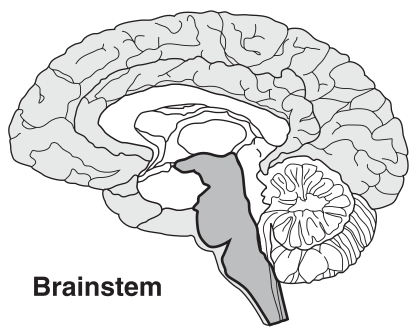

Figure A2–9.

The Cerebellum

The cerebellum (Fig. A2–10)—the little brain—is the section of the brain that coordinates sensory input with muscular responses. It plays a major role in motor learning, such as learning how the fingers should move when playing a violin. Once the brain has stored this learned motor skill, it can repeat the motions automatically without involving the cerebellum.

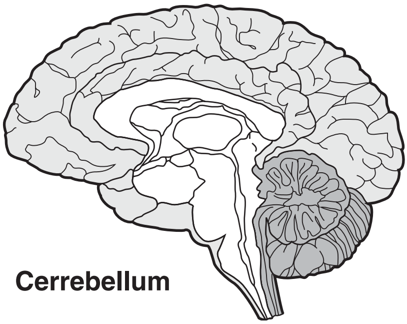

Figure A2–10.

The Hippocampus

The name for this important component of the brain comes from the Greek word for seahorse, because the hippocampus (Fig. A2–11) is shaped like a seahorse. Most of the activities of forming and recalling memories depend on the hippocampus for processing. Humans in complex buildings or cities may encode hippocampal memory sequences to find their way. A well-known study of the hippocampus of London taxi drivers indicated that it is necessary for facilitating navigation in places learned in the past, particularly where complex large-scale spaces (like London) are concerned. The study showed that the hippocampus of taxi drivers grew in size to accommodate the large amount of place memories required.

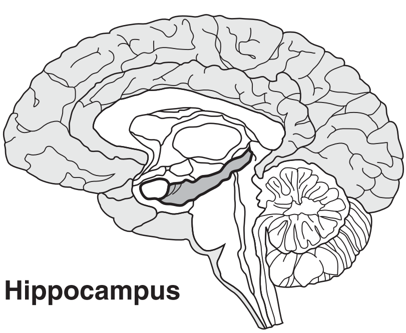

Figure A2–11.

The Thalamus

The thalamus (Fig. A2–12) is the waystation of the brain's networks. It functions something like a control tower in an airport, because it is where all sensory signals (except the olfactory ones) are processed to an appropriate area of the cortex.

The hippocampus, cerebellum, and thalamus, in collaboration with the cortex of the brain, are involved in the processes of recording and recalling time and space events because they have to do with ordering (smoothing) the inputs and outputs of the brain.

If memory is considered "the ability to repeat a performance," it is obvious that the quality of performance depends on the system that supports memory. Unlike memory in a computer, which is rigidly determined by its electronic program, brain-based memory is inexact but capable of broad degrees of generalization. The brain's properties of inexactness and association derive from the fact that one's memory records are selective—not everything one experiences ends up as a record. Different individuals have different memories, and they use them in different ways as a result of the way the appendages have processed the output of the brain.

Consequently, it seems likely that each person's experience of an architectural setting will be colored by their unique memories and the selective working of the way their appendages have recorded and recovered memories.

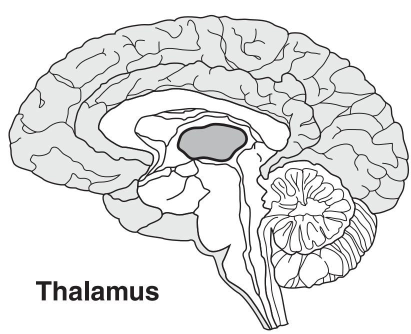

Figure A2–12.

The Amygdala

The region of the brain most specifically concerned with emotions, such as fear, is the amygdala (Fig. A2–13). It coordinates those responses to emotional states that generate secretions distributed throughout the body by the circulation of blood (endocrine) and those involuntary secretions created by the nervous system (autonomic). The amygdala also underlies emotional memory.

The experience of an emotion can be activated by causes and processes within an individual or by some combination of both internal and external causes. A stimulus from one of the sensory systems (e.g., visual, auditory, tactual) is often processed by the amygdala via the thalamus for any emotional content. This processing occurs in what is known as the limbic system. This system provides both a carrot and a stick to guide behavior. Positive emotions, such as feelings of affection, bonding, love, pleasure, and happiness, arise in response to external events that are positive, including artistic and musical expression. Negative emotions such as fear, anger, envy, disgust, and depression, arise in response to events that threaten survival, well-being, or sense of fair play.

An interesting observation from neuroscience studies is that we often experience emotions before we consciously are aware of them. There are two separate paths for processing emotional events—the subcortical pathway specializing in events that require rapid responses and the

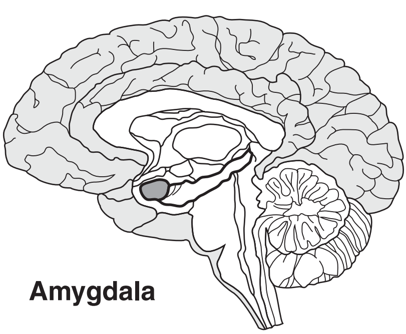

Figure A2–13.

corticoamygdala pathway that provides evaluative information needed for cognitive judgment of what is going on to decide how to cope.

The Hypothalamus

The hypothalmus (Fig. A2–14) provides the control center for many functions of the autonomic nervous system that coordinates the muscles and for involuntary responses. It has important links with the endocrine system used to produce substances (hormones) the body distributes through the bloodstream. It also regulates body heat in response to variations in external temperature. It contains a center for determining wakefulness and sleep. And it regulates fluid intake, feelings of thirst, and sexual behavior and reproduction.

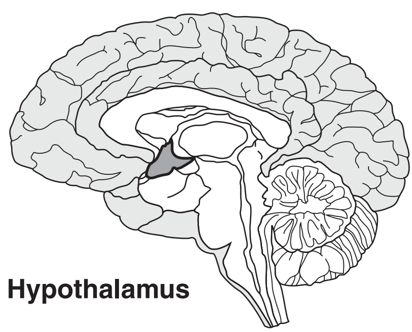

Figure A2–14.

The Lobes of the Cerebral Cortex

Each hemisphere of the cortex is divided into four lobes—areas of the brain that service specialized functions (Fig. A2–15). The occipital lobes in the back of the head are used for vision, the temporal lobes near the ears are used for auditory perception and language comprehension (Wernicke's area), the parietal lobes near the top of the head are used for spatial perception, and the frontal lobes are used for executive functions, such as abstract thinking, planning, working memory, motor control of muscles, and language production (Broca's area).

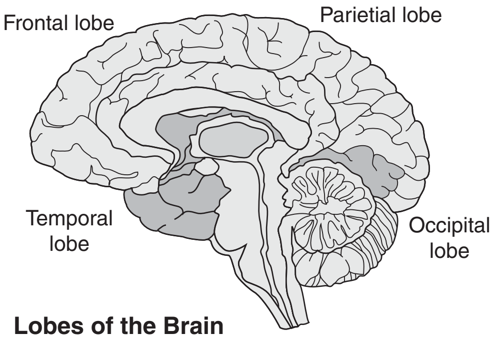

Figure A2–15.

The brain is assembled by a self-organizing system—its components arrange themselves during fetal development with no master controller from outside. Once the brain is fully functional, it constantly generates new thoughts spontaneously. An important thing to understand is that signals entering the brain from various sensory systems are all the same—speaking physiologically. The lobe of the brain to which the signal travels determines whether it generates vision, hearing, or other sensations. The neurons in the occipital lobe, for example, turn signals sent from photons of light striking the back of the retinas in our eyes into visual images.

Modern brain scanning equipment and computer modeling have made it possible to understand the structure of the living brain as it works inside the human head. The neuroscience community has made remarkable progress during the past two decades, but there is still a long way to go before we fully understand how the brain performs all of its amazing activities.

SENSORY SYSTEMS AS EXPERIENCED IN ARCHITECTURAL SETTINGS

Although it would seem obvious that all of our sensory systems are used in forming our experiences of the world, most people think primarily of the visual system as the basis for experiencing architectural settings. Although there is clearly an important relationship between light and vision in forming experiences of places and spaces, the other sensory systems also play a role. For example, there is clearly an acoustical aspect of buildings sensed by the brain's auditory (hearing) system—from listening to the sound of music in a cathedral to hearing what the teacher has to say in a classroom. Our sense of touch responds to textures and surfaces like the roughness (or smoothness) of stone and the hardness of a metal doorknob. Our sense of smell (the olfactory system) can detect the pleasant odor of a cedar closet or the terrible smell of a house that was ravaged by fire or floods. Though we may not literally taste the materials in a building, the design of a restaurant can have an impact on our conditioned response to the taste of the food. Proprioception is the sense that relates our awareness of the location of our body (and its parts) in space and is important in moving about in a building, especially in walking up and down stairs.

In Chapter 3, there a detailed discussion of vision and the role it plays in forming our experiences in architectural settings. In what follows, we learn more about the other sensory systems.

Hearing and Sound

The configuration of the human ear is a remarkable part of our sensory systems. We are able to hear accurately a crumb drop on the floor in a quiet room and, at the other extreme, the roar of a jet engine or the noise of a rock band. We can discriminate sounds from the deep bass of an organ—so deep that we can feel it—to the high pitch sound of a police whistle.

Sound waves flow along the inner canal from our outer ears to the eardrum, where they vibrate the three delicate bones of the middle ear (see Fig. A2–16). These vibrations are then transmitted to the fluid-filled cochlea, which is partially protected from damaging loud sounds by brain signals to the bones of the inner ear. The sounds coming into the left ear are primarily transmitted to the right side of the brain, and vice versa. The difference in sound arriving in the auditory cortex from one side and then the other makes it possible for us to know from which direction the sounds originate.

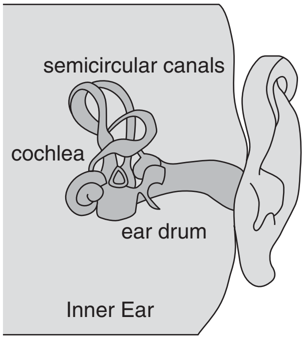

Figure A2–16.

The auditory system simultaneously deals with many aspects of sound, including loudness, pitch, harmonics, and the timing and orientation of multiple sounds. It does this work using a system of parallel processing. Once both ears have processed a sound, it is sent via the cochlea to the thalamus and, from there, it is relayed to either the A1 or A2 areas of the auditory cortex. These cortical areas, located in the temporal lobes of the brain, again form feedback loops to the thalamus so that slight delays in the signals from each ear can provide bits of information by inducing a postsynaptic LTP to be used in discriminating the direction of the sounds.

There is a special area of the brain known as Broca's area (after the French neurologist Paul Broca who discovered this functional area in 1861) where speech is formed, and a second area called Wernicke's area (after Carl Wernicke) where understanding of language occurs. The auditory system is important in the functioning of both of these areas.

Sound waves coming into the middle ear move the tympanic membrane, and the ossicles provide the amplification needed to move the fluid in the cochlea (Fig. A2–17) in the inner ear. The cochlea's spiral shape resembles a drinking straw wrapped around a pencil. A primary structural portion of the cochlea is the basilar membrane, which bends in response to sounds.

In most environments, the auditory system is subjected to many sounds—from people talking in the background to a radio playing and

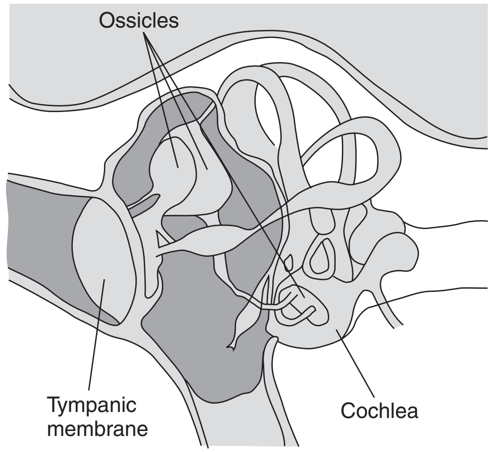

Figure A2–17.

cars honking. Our brains are required to analyze which sounds are important and ignore the others as noise to which we not need pay attention. The common features of most sounds include intensity, frequency, and a point of origin. Each feature is treated differently by the auditory system.

Taste and Smell

The sensory systems of taste (gustation; Fig. A2–18) and smell (olfaction) are the detection systems of chemicals in our environment. We can perceive flavor only when both sensory systems are used. The neural circuits involved in gathering and transmitting information from each system are processed in parallel and are merged to produce flavor only at rather high levels in the cerebral cortex.

Taste is determined by receptors, called tastebuds, the number and shape of which vary greatly from person to person. A large number of tastebuds appear to provide a greater sensitivity to the four gustatory qualities—sweet, salty, sour, and bitter. The tastebuds are located on the surface and side of the tongue, the roof of the mouth, and the entrance to the pharynx (the space between cavity of the mouth and the throat).

Some of our taste preferences are hard-wired. We all have a special liking for sweet things, probably related to the taste of breastmilk. We instinctively

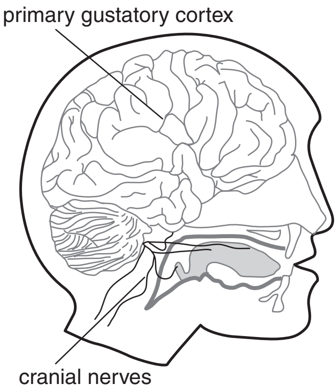

Figure A2–18.

reject things that are bitter, probably related to avoiding poisons in plants we might eat. We may sometimes crave salty foods when the body recognizes a deficiency in this key nutrient.

The Basics of the Gustatory System

Inside the mouth, we have a large, extremely flexible tongue used for eating, swallowing, and talking. It is attached to the floor, or bottom, of the mouth. Tastebuds are located on the surface of the tongue, with those at the tip used to transmit sweetness, those on the sides used for saltiness and sourness, and those at the back used for bitterness. Each food produces a unique combination of the basic tastes. More important, the taste of the food is combined with its smell, so that it is the simultaneous response of the brain to the chemical systems of taste and smell that makes flavor known.

The Olfactory System

The nose, equipped with olfactory nerves, is the special organ of smell (see Fig. A2–19). The nerves of smell terminate in the nasal cavity in several small branches; these are embedded in the soft mucous membrane

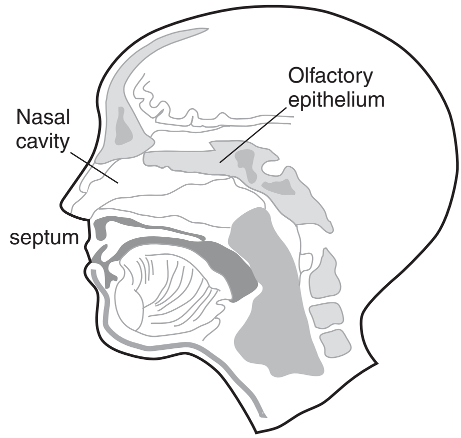

Figure A2–19. Olfactory System

and are elongated as epithelial cells projecting into the free surface of the nose in an area called the olfactory epithelium, a thin layer of cells that covers the nasal cavity.

The olfactory nerves within the nose also determine differing tastes of substances taken into the mouth, that is, many of our sensations of taste are really the brain's response to smell. For example, the taste of burned toast.

Research on smell has identified seven primary odors—camphor-like, musky, floral, peppermints, ethereal (dry cleaning fluid, for example), pungent (e.g., vinegar), and putrid (foul smelling or stinking)—that correspond to the seven types of smell receptors in the olfactory-cell hairs.

We lack a clear understanding of how information produced by odors is understood by the brain. Little progress has been made in determining how the brain perceives complex fragrances, such as hot chocolate or freshly baked bread.

The olfactory system can distinguish thousands of odors. For most animals, the olfactory system is the primary mode of communication and influences many important functions. Scientists are just beginning to learn how the system works. Olfactory information travels to the cortex of the brain directly from the receptors in the nose—bypassing the thalamus, through which all other sensory signals pass. The result of this bypass is that when we are sleeping, we have no ability to smell fire or smoke—a good reason to have a smoke detector in your bedroom.

Olfactory receptors (like many other cells in the body) continually grow, die, and regenerate in a cycle that lasts about 4 to 8 weeks. In fact, olfactory receptor cells are one of the very few types of neurons in the nervous system that are regularly replaced throughout life. The surface area of the human epithelium membrane is only about 10 square centimeters, whereas this area in some dogs can be over 170 square centimeters, and dogs have more than 100 times more receptors in each square centimeter.

Neurons in a specific place in the olfactory bulbs respond to a specific odor. Thus, the smell of a particular chemical (e.g., amyl acetate, or the smell of bananas) is converted in a specific map whose form depends on the nature and concentration of the odorant.

Touch

The sense of touch (or tactile sensation) is more accurately known as peripheral mechanisms of somatic sensation, that is, receptors located in or on the surfaces of the body. Receptors associated with touch are of various kinds and are denser in some areas—for example, the tips of our fingers are densely packed with receptors, enabling blind people to read Braille type. Surfaces of different textures can be divided subjectively into groups responsive to touch that include slippery, rough, leathery, and wet, but neuroscience knows little about texture perception. Tactile sensations enable us to tell the shape of objects we touch (blind people are especially sensitive to this ability). We can tell the difference between something that weighs 20 pounds versus 2 pounds, because the force of gravity is sensed in the muscles. We have special thermo-receptors to record temperature.

The differences in our senses of touch are the result of responses to touch receptors that produce signals all over the body, transmit these signals via the spinal cord to the thalamus, and then to the somatic sensory areas in the brain's cortex. For example, one region (called the top medial edge of the somatic sensory area of the cortex) that responds to signals from the hips. Some parts of the body have much larger areas of the somatic sensory cortex devoted to them, for example, the fingers, the toes, and the lips.

We all experience the sense of something being hot or cold when we touch it. But we also know that the air in the space surrounding us registers on our skin as hot and cold—that is, the room air is touching our skin. We are able to perceive changes in our average skin temperature of a little as 0.01°C. Temperature-sensitive neurons in the spinal cord and the hypothalamus maintain stable body temperature, but the thermo-receptors in the skin make it possible to perceive temperature.

Proprioception

Proprioception is the process by which the body unconsciously varies muscle contraction in immediate response to incoming information from external events or conscious thoughts. The combined feedback mechanisms of proprioception and kinesthesia (the sense of joint motion) control muscle responses and posture. These mechanisms are ones we use unconsciously (once we have trained our bodies to remember what to do) because we need to be conscious and selective in paying attention to the other senses. It would obviously be awkward to try to walk by *thinking* about each step we take and how we need to move our legs and feet.

GLOSSARY OF NEUROSCIENCE TERMS

Amygdala: A part of the brain that relates to emotional experiences, especially those of a fearful or threatening nature.

Axon: The primary branch (or trunk) of a neuron whose terminal releases small containers (synaptic vesicles) for neurotransmitters. Charges in the axon when they have reached an appropriate level create an action potential.

Brodmann areas: The 52 regions of the cortex defined by the cell types active in an area, for example, area 17 is the primary visual cortex.

Cerebellum: A structure at the back of the brain important for dexterity and smooth execution of movement. The literal meaning of the word is "little brain."

Cerebral cortex: The folded layer of gray matter that looks a lot like cauliflower.

Cognition: A variety of higher mental processes, such as thinking, perceiving, imagining, speaking, acting, and planning.

Cognitive neuroscience: A field of study that aims to explain cognitive processes in terms of brain-based mechanisms.

Corpus callosum: Billions of fibers forming a bridge between the two hemispheres of the brain.

Dendrites: Branching structures that carry information between neurons.

Glia: Support cells of the nervous system involved in tissue repair and in the formation of myelin. They provide the "glue" for holding neurons in place.

Gray matter: Matter that consists primarily of neuronal cells incorporated in convoluted folds of the cerebral cortex.

Gyrus: A raised fold of the cortex.

Hemispheres: The left and right halves of the brain, each of which provides specialized functions.

Hippocampus: An organ that relates experiences to memory and learning.

Hypothalamus: A variety of nuclei concerned with the regulation of body functions, such as hunger.

Limbic system: A region of the subcortex involved in relating the organism to its present and past environments. It includes the amygdala and the hippocampus.

Modularity: The notion that certain cognitive processes (or regions of the brain) are restricted in the type of information they process because they are specialized for certain processes.

Myelin: A fatty substance deposited around the axon of some cells to speed conduction.

Neural network models: Computational models in which information processing occurs using many interconnected nodes.

Neuron: A type of cell that is present in the brain and serves as the key element of cognitive functions. There are three general types of neurons: sensory neurons, which relay information from the senses; motor neurons, which carry impulses to effectors; and interneurons, which transmit impulses between sensory and motor neurons,

Neurotransmitters: Chemical signals released by a neuron that affect the properties of another neuron.

Spatial resolution: The accuracy with which one can measure where an event is occurring.

Sulcus: A buried groove in the folds of the cortex.

Synapse: The small gap between neurons through which neurotransmitters move looking for appropriate receptors.

Temporal resolution: The accuracy with which one can measure when an event occurs.

Thalamus: The brain's major relay center between sensory organs (except smell) and the cortex.

Top-down processing: The influence of later stages on the processing of earlier ones (e.g., memory influences on perception).

Voxels: Thousands of small volumes of neurons that are important in brain imaging studies—for example, the voxels in the right lingual sulcus respond to images of buildings.

White matter: Tissue of the nervous system consisting primarily of axons and support cells lying in sheets just below the gray matter.

APPENDIX THREE

Architecture: History and Practice

A designer makes things. Sometimes he makes the final product; more often, he makes a representation—a plan, program, or image—of an artifact to be constructed by others. He works in particular situations, uses particular materials, and employs a distinctive medium and language. Typically, his making process is complex. There are more variables—kinds of possible moves, norms, and interrelationships of these—than can be represented in a finite model. Because of this complexity, designer's moves tend, happily or unhappily, to produce consequences other than those intended. When this happens, the designer may take account of the unintended changes he has made in the situation by forming new appreciations and understandings and making new moves. He shapes the situation, in accordance with his initial appreciation of it, the situation "talks back," and he responds to the situation's back talk.

—SCHON (1983)

Figure A3–1. Margaret Morrison building at CMU.

This appendix provides a short history of architecture, a discussion of what architects do in practice, and how architectural schools are organized. This is followed by a few examples of specific neurological discoveries related to how our brains respond to images of buildings and harmony and symmetry. The intention of this appendix is to give readers who are not architects a basic understanding of what architecture means in the context of this book. A glossary of architectural terms is also included.

Architectural design reflects the value systems of the society that produces the buildings. This is not a written record but one contained in the fabric of the building, in its size and proximity to other buildings, and the very fact that it exists at all. For example, in the past, banks were housed within other commercial structures. Then, they became small classical buildings located in the town center. Today, they are housed in the large office towers as financial centers of most metropolitan areas. In contrast, schools have been separate structures in communities as far back as ancient Greek and Roman times. In 19th-century America, there were thousands of one-room school buildings. Once the school bus was developed and children no longer had to walk to school, larger school buildings were created by consolidated school districts. In no community today is there any comparable investment between school buildings and financial centers. Therefore it seems clear what our society's message—architecturally speaking—will be to future generations about the value we placed on education as compared with banking.

It certainly is not necessary to know the history of architecture to be interested in how the brain and mind perceive and experience architectural settings. But because the collection of architectural buildings now existent around the world were a more or less evolutionary development over centuries, it seems useful to trace their origins and prototypes.

ARCHITECTURAL CONCEPTS USED IN THIS BOOK

Most people think of architecture as buildings designed by well-known architects—such as the buildings shown in the architectural history section that follow. Though there are buildings whose external design is likely to impact human experiences, for example, the great cathedrals of Europe, most building exteriors are of less importance to human experiences than are the spaces inside. These interior spaces are where the average person spends more than 90% of his or her time.

This book makes a distinction between *places* (buildings, malls, parks, etc.) and *spaces* where human experiences are largely formed. For example, we might remember a place where we once lived (a house) and think of it as a structure that provided shelter for our home—the spaces where we were protected from the weather and provided a personal sense of security. But the home was also where we experienced spaces for sleeping, bathing, and general hygiene—laundry, eating, and drinking (often with family and friends)—cooking and serving, entertainment (television, radio, Internet, etc.), hobbies and crafts, and work undertaken in a home office.

The experiences we have in such spaces have the potential to be studied by neuroscience. These spaces range from white-collar work in offices—reading, writing, typing, computer interactions, and so on—to manual labor in factories—physical exertion, skilled manipulation of tools, and so on. Spaces to be studied would include learning spaces at every level: elementary classes (kindergarten to seventh or eighth grade), secondary education (eighth to ninth grade through high school in the United States), college (from community colleges, to universities; and higher education), and graduate studies from master's to postdoctoral. Another important area would be spaces used for health maintenance, health care, treatment—sometimes under emergency conditions—operating rooms and treatment for medical conditions, and recovery rooms, long term and short term. The chapters in this book explore many of these possibilities.

A SHORT HISTORY OF ARCHITECTURE

The history of buildings can be approached as a chronological record, or as a technological progression, or as evolving design concepts. In the following, an attempt has been made to combine these three approaches. Not all of the chronological periods usually covered in an architectural history book are included here.

There are few buildings still standing that date back more than 5,000 years (roughly 3,000 B.C.). There are several reasons for this, including the fact that there were no human settlements with sufficient resources to build anything more than shelter for their inhabitants to live in. Architecture, throughout history has provided for symbolism, ritual, and magic. Trachtenberg and Hyman suggest, “Neolithic man had achieved a degree of security in the face of nature, but the world remained fearsome and perplexing, especially to a humanity with our same basic needs, feelings, and powers of imagination, but dauntingly little knowledge” (Trachtenberg & Hyman, 1986).

One of the most mysterious monuments still standing is the collection of stones at Stonehenge (Fig. A3–2). There can be only speculation about what motivated the design of this monument. At the exact time of the summer solstice, the rising sun comes up over the apex of the Heel Stone. The construction was highly accurate, with all the uprights plumbed and with mortice-and-tenon joints securing the horizontal beams against slippage.

On the other hand, the purpose of the great pyramids at Giza (Fig. A3–3) was clearly to provide tombs for the bodies of the pharaohs of the Fourth Dynasty (2,500 B.C.) an eternal resting place. Solving the mystery of their design and construction remains speculative as well. The technological mystery is how these gigantic blocks of stone could be moved into place with no more than human muscle. This is overshadowed, for our purposes,

Figure A3–2. Stonehenge.

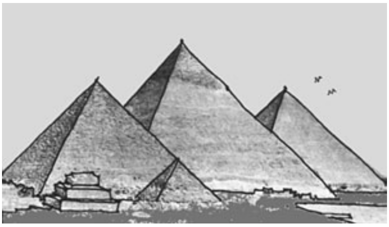

Figure A3–3. Pyramids at Giza.

in how the minds of their designers were able to develop the perfect proportions of these giant structures. They are designed with the elegance of a Swiss timepiece, and each is precisely oriented to the points of the compass—before there were any instruments to provide these data.

Mohenjo Daro (*mound of the dead*) was a city of the Indus Valley civilization built around 2,600 B.C. in what is now Pakistan. This ancient city is the largest of the Indus Valley and is widely recognized as one of the most important early cities of South Asia and the Indus Valley civilization. Mohenjo Daro was one of the world's first cities, contemporaneous with ancient Egyptian and Mesopotamian civilizations. It is sometimes referred to as "an Ancient Indus Valley metropolis."

The architectural achievements of the Greeks during the fifth and fourth centuries B.C. are among the wonders of the early history of human design. "Greek architecture does not amaze and overwhelm with mere scale and complexity; it has vigor, harmony, and refinement that thrill the mind as well as the eye" (Trachtenberg & Hyman, 1986).

Entasis (Fig. A3–4) in architecture is the convex curve given to a column, spire, or similar upright member, to avoid the optical illusion of hollowness or weakness that would arise from normal tapering. Entasis is almost universal in Classic columns. Exaggerated in Greek archaic Doric work, it grew more subtle in the fifth and fourth centuries B.C. (Entasis is also occasionally found in Gothic spires and in the smaller Romanesque columns.) In the many attempts that have been made to find a mathematical basis for the entasis, it has been reduced to all kinds of elliptical hyperbolic, parabolic, and even cycloidal curves. The immense variety of forms indicates, however, that the curve was probably laid out freehand and is purely empirical.

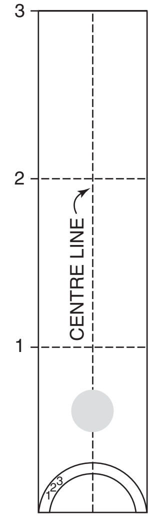

Figure A3–4. Entasis in columns.

The sublime creation of High Classic Doric architecture is the Parthenon (Fig. A3–5) on the Athenian Acropolis. The building was erected between 447 and 438 B.C. Its unity of proportion produced its uncanny harmony. It is what the Greeks called "frozen music"—a metaphor for celestial harmonies.

The remarkable visual developments in the Parthenon are its optical refinements that involve variations from the perpendicular and especially from straight lines. Hardly a single true straight line is to be found in the building. Historians believe these optical refinements contribute to the visible grace of the temple and its vitality—so much so that the basic design concept has been incorporated in classical facades down through the ages, including such well-known buildings as the Supreme Court of

Figure A3–5. Parthenon.

Figure A3–6. Supreme Court.

the United States (Fig. A3–6), constructed between 1932 and 1935 and designed by noted architect Cass Gilbert.

The architecture of the Roman Empire (from about 300 B.C. to 365 A.D.) seems to have absorbed much from the Greeks, but the invention of the round arch (see examples in the walls still standing in Madrid; Fig. A3–7) and its extension into the barrel vault was a substantial technological advance over the simple post and beam construction technique. It made possible the impressive aqueducts and structures like the Coliseum.

Though a logical extension of the round arch, the pointed arch of Gothic architecture made possible many new advances. The floor plan of Gothic cathedrals could be elongated to allow for religious processions.

The development of the flying buttress made it possible for the walls to be filled with glass (as in the Abbey church in Bath, England; Fig. A3–8). The visual experience of the 12th- to 14th-century European cathedrals still engenders a sense of awe in visitors that must have been even more astounding for the citizens of the cities in which they were erected. Many of these citizens devoted their entire life, as dedicated religious volunteers, to working on the construction of a single cathedral. Several

Figure A3–7. Madrid wall in old city.

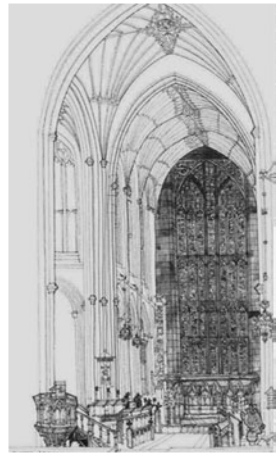

Figure A3–8. Abbey at Bath, England.

generations of workers from the same families were often involved in long-term projects.

It was not just in Europe that architecture flourished, however. In the Islamic world, the Alhambra in Granada (Fig. A3–9) is one of the greatest of all Muslim contributions to the history of architecture.

Mosques dedicated to religious activities characterize Islamic architecture. The Ottomans created their own design of mosques, which included large central domes, multiple minarets, and open facades.

Architectural developments in China, Japan, India, Africa, and Central America were happening at about this same time in history, but they are generally not as well known to those of us who live in the West. (See section on Chinese architecture in Chapter 4).

Figure A3–9. Alhambra, Spain.

Architectural history books dwell at some length on the Renaissance and Baroque periods of architecture (from roughly the 15th century to the 19th century in Europe) because numerous building still exists from those periods, and they represented a turning point in human development.

> The Renaissance vision was based on new concepts of the spiritual and intellectual autonomy of the individual, on the power of human reason, and on freedom from dependence on the supernatural. These concepts had evolved from the early Humanist ideas of antiquity as a time when man had been the measure of all things and the faculty of reason his most prized natural gift, when each individual constituted his own authority by virtue of his rational powers. (Trachtenberg & Hyman, 1986)

Two important developments began during the Renaissance. One is the concept of individual authority, eventually becoming the basis for the manifestoes of early 20th-century architects who broke with the long traditional design of the classics. The other is the rapid development of science, when the faculty of reason became a basis for exploring the world. Neuroscience is the latest development in this history going back to the Renaissance.

An example from the Baroque period that seems to stand directly at the physical and intellectual center of these developments is the great Baldachin over the high altar of St. Peter's in Rome (Fig. A3–10), designed by Bernini in 1624. The power of the Church (and of the popes) is now challenged by the power of the intellect.

THE GREAT WATERSHED IN THE HISTORY OF ARCHITECTURE

Toward the end of the 19th century—roughly from 1856 to 1889—an enormous burst of creative energy was invested in the processes of invention and innovation. So much so that the U.S. Congress in 1899 proposed that the Patent Office be closed, because surely everything that could ever be invented had been invented by then. There were seven key inventions

Figure A3–10. St. Peter's altar.

in this period that dramatically changed the technology of buildings and cities. For thousands of years, as we have seen, a process of slow change in structural methods evolved from post and beam construction to the fan vaulting of the late Gothic cathedrals. But there had been little change from Roman times in the method of heating buildings or dealing with bathing and waste disposal. Lighting changed a little from candles to oil lamps, but lights were still small fires that often caused major ones. Horses and buggies were the main transportation system for those who could afford them. The business of merchants was recorded by hand on pieces of paper sent to others via messengers, Pony Express, or eventually mail on trains.

Physics Emerged in the Mid-19th Century

Conceptually, physics is the science that deals with the structure of matter and the interactions between the fundamental constituents of the observable universe. In the broadest sense, physics (from the Greek *physikos*) is concerned with all aspects of nature. Its scope of study encompasses not only the behavior of objects under the action of given forces but also the nature and origin of gravitational, electromagnetic, and nuclear force fields. The ultimate aim of physics is to find a unified set of laws governing matter, motion, and energy at small (microscopic) subatomic distances, at the human (macroscopic) scale of everyday life, and out to the largest distances (e.g., those on the extragalactic scale). This ambitious goal has been realized to a notable extent. A remarkably small set of fundamental physical laws seems able to account for all known phenomena. The body of physics known as classical physics can largely account for such phenomena as heat, sound, electricity, magnetism, and light.

The revolution in building technology began in 1855 when the Bessemer process for smelting iron ore into steel was invented. The application of steel to beams and columns that could be incorporated in buildings did not happen until 1883 (in the Home Insurance Building in Chicago). With the advanced design methods (Fig. A3–11) that physics made possible, the strength of steel beams and columns and their connections could be carefully calculated. No longer were buildings confined to the five or six floors of stacked masonry units. The skeleton of the building was now free to soar higher.

The invention of the elevator (Fig. A3–12) safety device by Elisha Graves Otis in 1889 made it possible to introduce a convenient method of moving up and down in buildings as they became taller. For thousands of years, stairs were the only method of vertical transport in buildings, and people are not generally disposed (or even physically able) to walk up more than five or six flights. The elevator, therefore, became a necessary adjunct to steel-framed buildings. Elevators required the development of motors, electrical controls, and safety mechanisms—all of which depended on physics for their design.

Figure A3–11. Steel structural system.

Figure A3–12. Otis elevator safety catch.

The invention of the light bulb (in 1880) that used electricity as its energy source greatly reduced the number of fires from oil and gaslights. More important, the electric light bulb made it necessary and economically possible to invest in electricity generating plants, relay stations, wire distribution systems, and other electrical apparatus (Fig. A3–13). Both electrical generators and motors underwent substantial development in the final decades of the 19th century. In particular, French, German, Belgian, and Swiss engineers evolved the most satisfactory forms of armature (the coil of wire) and produced the dynamo, which made the large-scale generation of electricity commercially feasible. By the beginning of the 20th century, electrical systems were installed in cities. The first practical incandescent lamps became possible after the invention of good vacuum pumps.

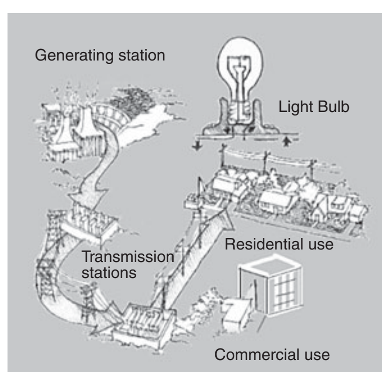

Figure A3–13. Electrical systems in cities.

Thomas Edison has received the major credit because of his development of the power lines and other equipment needed to establish the incandescent lamp in a practical lighting system in buildings and along streets.

Though fireplaces are still found in many homes, neither fireplaces nor stoves that require fuel to be distributed to each location and for the ashes to be removed would be practical in a modern office building, hotel, or hospital. Specific heat of solid materials is the principle from physics that led to the development of central heating systems (Fig. A3–14) in buildings. The control devices for furnaces by 1868 made central heating possible. At first, coal was the primary fuel; gradually, oil and natural gas were introduced, and today electricity provides an alternative to these fuels.

Fluid mechanics, which in large part provides the theoretical foundation for hydraulics, deals with such matters as the flow of liquids in pipes, rivers, and channels, and their confinement by dams and tanks. This knowledge eventually led to the development of indoor plumbing systems (Fig. A3–15) for the disposal of human wastes. Perhaps the invention with the greatest impact on the growth of cities was the flushing valve for water closets introduced in England in about 1878. This simple device made practical water distribution systems and the associated sewer systems. Cities in Western society gradually made the necessary investments in the infrastructure for plumbing, greatly reducing the incidence of disease.

Communication systems in building and cities were greatly advanced by the 1876 invention of the telephone (Fig. A3–16) by Alexander Graham Bell. The telephone is an instrument that is designed for the simultaneous

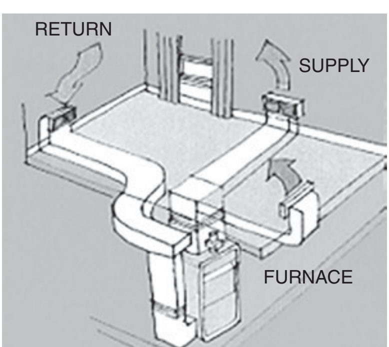

Figure A3–14. Heating system for house.

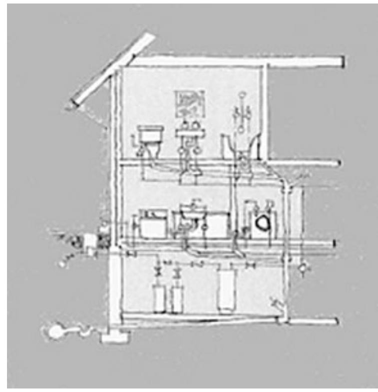

Figure A3–15. Plumbing system for house.

transmission and reception of the human voice. Inexpensive and simple to operate, it provides its user a personal type of communication that cannot be obtained through the written word. The development of telephone systems by the Bell Laboratories (founded in 1925) was largely based on the science of physics. In the early 1900s the telephone was largely responsible for the architectural layout of office buildings. It could be argued that the telephone was the parent of the Internet and certainly the ubiquitous cell phone.

The last major invention on this short list of inventions that revolutionized the design of building and cities is the automobile (Fig. A3–17). The invention of the internal combustion engine by Gottlieb Daimler and his co-worker, Wilhelm Maybach, in 1882 made the automobile possible. They patented one of the first successful high-speed internal combustion

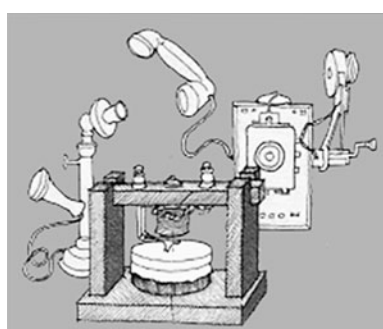

Figure A3–16. Telephone development.

Figure A3–17. Horseless carriage.

engines (1885) and developed a carburetor that made possible the use of gasoline as fuel. The internal combustion engine is a prime mover, and it emerged in the 19th century as a result both of greater scientific understanding of the principles of thermodynamics and of a search by engineers for a substitute for steam power.

Conclusions

The remarkable thing about these inventions is that they still dominate the technology of buildings and cities after more than a century of unprecedented growth in science and technology. Building codes, engineering courses, architectural specifications, and examinations for architectural licenses are all based on the technologies these seven inventions produced. After 7,000 years of slowly developing the commodity, firmness, and delight of buildings, these inventions completely changed the world. For good or bad, there are no urban development projects anywhere in the world that are even considering alternative technologies. The introduction of computers in the second half of the 20th century has dramatically changed many aspects of our lives, but not our buildings. As you will read in the rest of this appendix, architectural history and theory was soon set adrift by these technologies (and the intellectual climate that made them possible). Now, at the beginning of the 21st century, what it means to produce a well-designed building is largely a matter of academic ferment and the opinions of architectural critics.

ARCHITECTURE HISTORY IN THE UNITED STATES

Most of the early "architecture" (meaning buildings considered in architecture history books) of the United States was copied from European examples. Most of the early architects were educated in Europe, so it is not too surprising that their buildings reflected the European models. Gradually, we developed what was to be called Colonial architecture—reflecting our status as a colony of Great Britain.

One of the earliest examples of Colonial architecture is the Octagon House (Fig. A3–18) in Washington, D.C., that is now the headquarters for the American Architectural Foundation (visible behind it is the American Institute of Architects office building). William Thornton—a dentist who had educated himself in things architectural and became the first architect of the U.S. Capitol as well—designed this house in 1801. The owner was Colonel John Tayloe III, a friend of George Washington, who had persuaded Tayloe to help give the new city of Washington a substantial dwelling.

Georgian architecture is the name given in English-speaking countries to the architectural styles current between about 1720 and 1840, named after the four British monarchs named George. In the American colonies, Colonial Georgian blended with the neo-Palladian style to become known more broadly as "Federal" building styles. Georgian buildings were largely built of wood with clapboards; even columns were built of timber, framed up and turned on an oversized lathe. The establishment of Georgian architecture was largely aided by the fact that unlike earlier styles, which were disseminated among craftsmen through the direct experience of the

Figure A3–18. Octagon House.

apprenticeship system, Georgian architecture was also disseminated to builders through the new medium of inexpensive suites of engravings. From the mid-18th century on, Georgian styles were assimilated into an architectural vernacular that became part and parcel of the training of every carpenter, mason, and plasterer.

Federal architecture occurred in the United States between 1780 and 1830, particularly from 1785 to 1815. The period is associated with the early republic and the establishment of the national institutions of the United States. The English style came to America by way of British pattern books and an ever-swelling wave of masons, carpenters, and joiners who emigrated from England. After the American Revolution, in a display of patriotic zeal, the entire period in America, including Georgian architecture and furniture, became known as Federal. The most common symbol used in the Federal style is the American eagle.

The 20th Century

After the technological revolution spurred by the inventions mentioned previously, architecture and architects were freed from the constraints of Classic designs. Two special architects emerged early in the 20th century: Louis Sullivan and Frank Lloyd Wright.

Sullivan (1856–1924) was a believer in the idea that architecture is the truthful mirror of a nation's values. He set himself the goal of creating a genuine American architecture free from the classic orders of the past. Although he probably succeeded in his own work, except for his pupil, Frank Lloyd Wright, no architect of note carried on Sullivan's quest. Perhaps his most successful buildings were the eight banks he designed for savings and loan institutions in small towns in Iowa, Minnesota, Ohio, and Wisconsin. These banks showed his ability to rethink a classic problem many times with results that were always fresh. His design for the National Farmers Bank in Owatonna, Minnesota, constructed in 1907–1908 (Fig. A3–19) is considered by many critics to be his best.

Wright (1867–1959) worked for Sullivan in the beginning of his career, but soon went on to forge a long legacy of unique buildings. Because he

Figure A3–19. Bank designed by Louis Sullivan.

lived to be 92, he really had three career phases. His early career took place in Oak Park, Illinois, from 1889 to 1910, during which he produced the Unity Temple, Taliesin, and the Robie House (and many others). His middle period from 1936 to 1951 (after a bad experience during the Depression) included the Johnson Wax buildings in Racine, Wisconsin, Taliesin West, and Fallingwater (Fig. A3–20). After a new spurt of energy when he was 70, he designed the Solomon R. Guggenheim Museum in New York and many other projects. Fallingwater, his most famous design (shown here), clearly set him apart as a genius.

While Fallingwater is his most well-known masterpiece, he produced more than 400 others that have never been successfully imitated. His genius was unique, as was his personality and his infamous private life.

In Germany between 1910 and 1930, the Bauhaus became the source of major new prototypes of what has become known as modern architecture. Walter Gropius, the founder of the Bauhaus who became the chairman of Architecture at Harvard University in 1937, set the tone with his design for the Fagus Factory in 1913 (Fig. A3–21). His educational reforms at Harvard soon swept across the United States and changed architectural

Figure A3–20. Fallingwater house.

Figure A3–21. Fagus Factory by Gropius.

education from one modeled on the Ecole de Beaux Arts in Paris to a free-floating sort of modernism.

Among the buildings I personally most admire (as do the majority of members of the American Institute of Architects) is the Thorncrown Chapel (Fig. A3–22) in Eureka Spring, Arkansas. Designed by E. Fay Jones in 1980, it is vastly popular with the public as well. There is no resident congregation; many couples have had their marriage ceremony there. It derives its unique structure from a requirement by the owner of the land (and the client for the chapel) that no trucks or heavy equipment come on to the land. Each structural member (pieces of wood) had to be light enough to be carried in by hand.

The central entrance pyramid of the Louvre in Paris designed by I. M. Pei (Fig. A3–23) is considered by many to be his special contribution to an extraordinary legacy of modernism—which began with his education at Harvard under Gropius. The main pyramid rises 71 feet above the

Figure A3–22. Thorncrown Chapel in Arkansas.

Figure A1–23. Louvre pyramid by I. M. Pei.

ground, providing the central feature to a vast new entrance to the main galleries. It is a complex steel structure sheathed in reflective glass. In addition to this pyramid, Pei's major projects include the National Center for Atmospheric Research in Boulder, Colorado (1961); the East Gallery of the National Gallery of Art (1974); the Bank of China Tower, Hong Kong (1989); and the Rock and Roll Hall of Fame, Cleveland, Ohio (1995).

SMART ARCHITECTURE

Although there have been vast changes in the technological base available over the past 100 years, there have been only minor modifications to the original set of urban innovations discussed previously. Two areas where change occurred are electronic control systems for transportation systems and the use of computers and the Internet for communications. There is today a more daring use of steel-reinforced concrete structures, new and improved elevators, air-cooling systems added to heating systems, better looking plumbing fixtures, better light bulbs, and faster automobiles. Essentially the same seven primary inventions from the 19th century dominate the urban infrastructure.

Many young architects with strong technological backgrounds are developing concepts and demonstrations of what they call "smart" architecture. They believe that the process of creating new buildings can move closer to that of advanced technological systems in which every element of a building has an operative nature. This concept is based on designing and making environments for human activities that are "intelligent"—they are able to adapt to the activities in real time. We have all seen plays or operas where the stage setting is changed between acts and sometimes during the action on the stage. Smart architecture carries this concept to the next level. It provides spaces, lighting, temperature controls, acoustics, and other parameters of the architectural setting with the technological means for changing in real time. In the more advanced systems, the architectural setting would anticipate human activities and thus play an interactive role.

The creators of smart architecture envision walls, floors, lighting, and so on, of architectural settings as having the ability to communicate information to the user—a large computer system that includes human actors as elements of the hardware and software. For example, MIT's Media Lab has invented something called the Magic Carpet system, which includes a series of piezoelectric wires in the floor to sense footstep dynamics, such as pressure and movement, and provide this information to control systems for lighting, temperature, and security.

New materials, many still in the development stage, show promise in facilitating these dynamic architectural settings. The following are some examples: magnetostrictive materials change shape when subjected to a magnetic field; memory alloys that are thermally or stress driven undergo a phase change under stress—from a high-temperature phase to a low-temperature phase, and return to the original high-temperature phase when reheated; electrochromic materials change color on application of an electrical voltage (electrochromic windows darken when a voltage is applied and become transparent when voltage is removed); and biometric materials can be used to convert a biological response into an electric signal. It is also potentially possible that some of these materials will be able to learn and adapt over time, much like living systems.

A designer/architect would then become a stage manager for the activities being housed and would serve his or her clients on a continuous basis. This would be made more technologically feasible because the materials themselves can adapt to changes in real time and because the design processes incorporated in computer-based systems will allow the architect real-time access to client information systems and to building elements that can be modified in real time as well.

DRAWINGS OF HOUSES BY 5-YEAR-OLD CHILDREN

This is a special area of architectural perception that has interested me for many years. Studies have shown that children who are age 5 make almost identical drawings of houses. They have no ability to make a drawing of the house in which they live or to copy the drawings of other children. Research results emerging from neuroscience laboratories and clinics around the world are beginning to provide an understanding of why this is the case.

Before the age of 5, most children lack the motor skills required to make geometric drawings—they scribble. After the age of six, most children begin to make more complicated drawings, including making copies of other drawings they have seen. Here are two examples of houses by five-year-olds related to me.

In the past 10 years, I have been collecting drawings of houses made by five-year-old children. The remarkable thing is that children around the world and as far back as 1938 (which is as old a record as I have been able to find) draw essentially the same house. A flat view of the main facade,

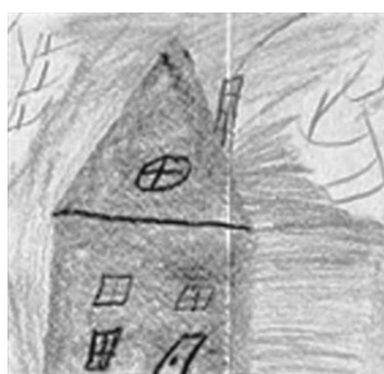

Figure A3–24. House drawing by Richard.

Figure A3–25. House drawing by Sarah.

with a pitched roof, two windows subdivided into four parts, a door with a knob in the center, and sometimes a chimney. In what follows, I will first show some examples and then propose two possible neuroscience reasons for these drawings.

Figure A3–26 is a drawing by a boy living in Israel in an apartment building that looks like the one show in Figure A3–27. Note that the drawing of a house bears little or no resemblance to where the child actually lives. There are many other examples from other places in the world that show this same relationship.

Another example "house" drawings can be found in a collection made by children who lived through the Spanish Civil War. It was believed at the time that having children make drawings was a form of therapy for dealing with the horrors of war. The Spanish Welfare Association of America first

Figure A3–26. House drawing by Israeli boy.

Figure A3–27. Typical apartment in Israel.

published the drawings in 1938. Two drawings from that collection are show in Figures A3–28 and A3–29.

There is another collection of drawings contained in an unpublished booklet titled "Children's Drawings from the Concentration Camp of Terezin." At this camp, teaching was forbidden, but drawing was allowed, and almost all the young prisoners drew pictures. Only 100 of the more than 15,000 children "processed" here survived; the rest perished at Auschwitz. The author of this booklet says, "These drawings depict the lost homes, towns and countryside, which were living on in their memories." But the author had no way of knowing that these drawings show the same house drawn by 5-year-old children all over the world and likely have no resemblance to their actual homes.

Figure A3–28. House drawing by Spanish child (one).

Figure A3–29. House drawing by Spanish child (two).

One drawing was made by Thomas Kauders (Fig. A3–30), who was born in 1934 and died at Auschwitz 1943. Even though he was 9 when he died, he probably made the drawing around 1940, when he was 5.

Another drawing was made by Julia Ogularova (Fig. A3–31), who was born in 1933 and died at Auschwitz in 1944. The drawing was also likely made around 1940, when she was 7. Note that one of her houses is three-dimensional, something 7-year-olds are able to do.

Figure A3–30. House drawing by Thomas Kauders.

Figure A3–31. House drawing by Julia Ogularova.

A Special Case

One of the most remarkable results I have had in collecting these drawings was to find that a child in a small village in Mozambique in 2001 drew an almost identical house to one drawn by a Spanish child in 1938.

In 2001 my daughter Carol, who was then in the U.S. State Department, went to Mozambique. In a small village she visited, she was able to get this drawing by a 5-year-old girl named Erica Lagos (Fig. A3–32). Note the remarkable resemblance to the drawing by a Spanish child

Figure A3–32. House drawing by Erica Lagos.

in 1938. The windows in both drawings are located at the outside edges of the house.

This seems to me to be clear evidence that neither child was drawing a picture of the house in which they lived (the child in Mozambique lived in a round wooden hut with no windows and no chimney). It also suggests that somewhere in the past our brains are hard-wired for this image.

Figure A3–33 is a copy of a summary page from a book by Rhoda Kellogg (1969, 1970), who had collected more than a million drawings by young children from all over the world. She shows here her analysis of some

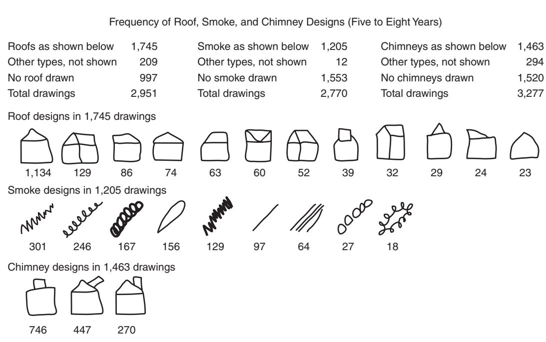

Figure A3–33. Summary analysis of house drawings (Roberta Kellog).

2,951 drawings. Note the dominance in her analysis of the simple facade shown in my collection.

Possible Explanations

The case history of a young woman (DF) who suffered irreversible brain damage when she was exposed to carbon monoxide, as described by Melvyn A. Goodale (2000), provides a possible explanation to this performance by 5-year-old children. As a result of her accident, DF could not recognize the faces of her family and friends or identify common objects by their appearance. Her hearing was not damaged (that's how she recognized members of her family). The damage was exclusively to her visual system.

Ten years after her accident, when she was shown a drawing of an apple or a book (like in Figs. A3–34 and A3–35), she could not identify the objects. She also was not able make a copy of the drawings of an apple or a book; she could only produce scribbles like those shown in Figure A3–36.

DF's inability to make any more than scribbles was because her visual system did not allow her to perceive the shapes and forms in the original drawings. She was clearly able to use her hands to control drawing with a pencil, because when she was asked to draw both and apple and a book

Figure A3–34. Drawing of an apple.

Figure A3–35. Drawing of a book.

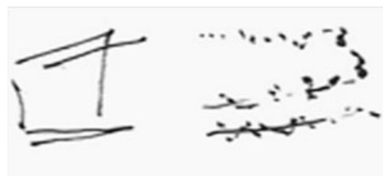

Figure A3–36. Scribbled drawing.

from memory she did a reasonable job (see her new drawing in Fig. A3–37). She had access to "low-level sensory information" (the basic stored images of things like an apple or a book).

It would seem possible that 5-year-old children whose corpus callosum (see Appendix 2) has not yet fully developed would lack the ability to perceive in one hemisphere and transfer that information to the opposite hemisphere to use in making drawings. However, when they are asked to make a drawing of a house, they call on the low-level sensory information stored in their memory and, with their limited drawing skills, produce the two-dimensional house drawings seen earlier in this section. How and why children all around the world have this identical image stored in memory is mystery I would like to solve.

Figure A3–37. Drawing of apple and book.

Another Possibility

A second speculation is related to the discovery that there are voxels in right lingual sulcus (Fig. A3–38; see Appendix 2) that respond strongly (and almost exclusively) to images of buildings. This is similar to the voxels responsive to faces, but clearly a different set. There is a hypothesis by James Haxby (2001) that these voxels emerged in the period when we were hunter-gatherers—some 50,000 years ago. Our ancestors may have stored images of landscape configurations to find their way back to their community after they had been hunting. I wonder if a more powerful reason would be the need for everyone (not just hunters) to recognize his or her home. Over the centuries, this concept of home and house have merged in the brain to produce a stored primary image that is recalled by 5-year-old children. What that image actually looks like in the brain has not been discovered. Because children at age 5 have only limited ability to make drawings—they can draw a square, a triangle, a circle, and a free-form shape (according to Kellogg)—their representation of the house image they have in memory is the simple drawing shown in the examples.

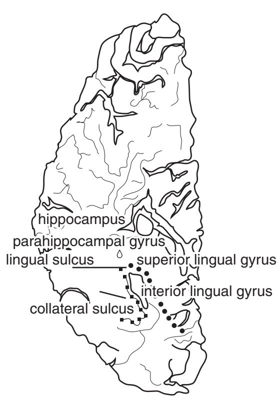

Figure A3–38. Drawing of lingual sulcus.

WHAT DO ARCHITECTS DO IN PRACTICE?

Will Bruder has stressed that architecture is a marriage between poetry and pragmatism. Architects strive for this balance when exploring qualities of spaces. The profession of architecture is typically thought of as a service industry (pragmatism); more important, it has been said that architecture is the mother of all arts—full of passion, touching our souls (poetry). The architect provides very concrete functions, such as designing the dining room next to the kitchen; however, he or she also provides many thoughtful intangibles that typically transcend a client's expectations.

The practice of the profession of architecture is defined as rendering services that require the application of art, science, and aesthetics of design and construction of buildings, groups of buildings (including their components and appurtenances), and the spaces around them where in the safeguarding of life, health, property, and public welfare is concerned.

According to the U.S. Environmental Protection Agency, from 1992 to 1994, the average American spent 87% of his or her time indoors. Just as scientists are inherently optimistic as they search for truths or cures, architects are very optimistic in believing they, too, will impact many lives. There are over 80,000 licensed architects in the American Institute of Architects (AIA; the largest architectural professional organization). Architects are generalists in that they have a broad knowledge base of many disciplines (structural engineering, sociology, business, etc.) while specializing in the practice of architecture. They are trained to be problem solvers. They seek the truth when they design a project. As Louis Kahn stated, "Architecture is the search for what a building wants to be. Form is *what*, design is *how*." The collaboration with neuroscientists will allow us to understand *why*. Architecture is not about a predetermined applied style; it is about spaces for human use.

Design is an inherent collaboration between the architect and the client, consultants, contractor, and users/inhabitants. The consultant team might include only a few members (structural engineer, mechanical/plumbing engineer, electrical engineer, landscape architect for a residence) or many more for a large institutional project, such as an urban courthouse.

The architect leads the design team throughout the entire process of design and construction, maintaining the original vision of the project.

Architectural Services

Though the kind of professional service provided to a client by an architectural firm is quite varied, the standard form of architect's services proposed by the AIA includes the following.

1. Providing the overall administrative services for a project, representing the client. This includes managing and directing all consultants.
2. Providing other types of supporting services, such as arranging for geological studies of the site.
3. The architect's design services—including those of structural, mechanical, and electrical engineering consultants, and other consultants as needed—that are usually in several phases and described in project methodology.

Project Methodology

Every project is new and requires fresh background research and approach. The methodology for each project is, however, essentially similar.

1. Predesign and Programming: The architect meets with the client or client group; together, they determine preliminary needs and scope, including budget and schedule. Square footage needs as well as detailed needs are determined. Relationships and adjacencies of the required spaces are determined. Site analysis, long-range or master planning, and/or feasibility studies may be conducted. During this time, especially on institutional or commercial projects, an exhaustive case study search is conducted. Similar to a literature review, the design team seeks to understand what has previously been done and learned for the project type or related project types. Programming typically results in a document that the team uses and refers to throughout the entire design process.
2. Schematic Design Phase: A project concept or hypothesis is formed during this phase (a potential area for collaboration with neuroscientists). Designs are preliminary and based on information discussed with the client. This phase will often include three-dimensional models as well as drawings of the proposed design.

3. Design Development Phase: This phase includes the refinement of the design developed in schematic designs, and includes plans, sections, elevations, construction details, and equipment layout. Written specifications for all of the materials and systems to be used are prepared.
4. Construction Documents Phase: Documents are further detailed and refined. Completed documents are sealed by the licensed architect (and consultants) and ready to be given to the contractor for bids. Other methods, such as design-build or construction management, allow for the contractor to participate early on in design (from programming or schematic design) and help track costs.
5. Bidding: For most clients, the architect arranges for contractors to bid (or sometimes negotiate a price) and prepares legal documents for the owner to use in contracts for the work.
6. Construction Administration: The architect will observe the work being done by contractors and prepare periodic reports for the client. This is to ensure intent of the project concept is continued during the construction and detail level. Often times, conflicts or unforeseen circumstances require in-the-field design modifications. In some cases, the architectural firm may continue to work with the client as facility managers. They provide continued service to the client during their transition into the new building, including helping with furniture, fixtures, and equipment installation.
7. Postoccupancy Evaluation (POE): More firms are conducting evaluations of the projects after a sufficient length of occupancy—usually a year or more. This may be done informally and anecdotally through meetings with the client or it may be done formally. A formal POE may include observation, questionnaires, focus groups, interviews, and facility data analysis (an area of service that could usefully provide material for hypotheses to be tested by neuroscientists).

Project Tools

Hand drawing and model making are still fundamental skills of an architect, using pencil or ink on vellum, Mylar, sketch paper, or napkins, and constructing scale models out of chip board, balsa wood, or foam core. A team working together in one location is still the preferred method;

however, the computer has become the dominant tool of the profession and allows design teams to work remotely on a project. Software is being created constantly that allows for collision detection between the disciplines (e.g., a pipe that should not be intersecting a beam), 3D modeling, and an increasing amount of data to be contained within the drawings.

HOW DOES ONE BECOME AN ARCHITECT?

According to the National Council of Architectural Registration Boards (NCARB), "All States, the District of Columbia, and four U.S. territories (Guam, the Northern Mariana Islands, Puerto Rico, and the Virgin Islands) require individuals to be licensed (registered) before they may call themselves architects or contract to provide architectural services." Many architecture school graduates are employed in the field even though they are not licensed or while they are in the process of becoming licensed.

A licensed architect is required to take legal responsibility for all of his or her work. Licensure requirements usually include a professional degree in architecture (typically a 5-year program), a period of practical training or internship (commonly 3 years), and passage of all divisions of the Architect Registration Examination (ARE). On successful passing of the ARE, a license is granted to practice in that jurisdiction only. To practice in other jurisdictions, the architect must apply for reciprocity—either to the individual jurisdiction or to NCARB for certification.

Schools of Architecture

There are more than 100 university-level educational programs of architecture in the United States. There are also many educational programs that provide 2 years of preparation for architectural technicians (who tend to be draftsmen or computer operators). Forty-five architectural programs are based on obtaining a BArch or BS in architecture degree at the end of 5 years. Ninety-two architectural programs are based on 2 or 3 years of graduate study—usually after a 4-year degree in environmental design—resulting in an MArch or MS in architecture degree. One school, the University of Hawaii, gives a doctorate of architecture degree at the end of 2 or 3 years of graduate studies. There are 29 architectural programs at the doctorate level. They range over a wide spectrum of subject matter (see Fig. A3–39).

University Programs in Neuroscience and Architecture, listed by state

	Location		University	N:S Prog	Neuro-Psych	Arch. Prog	Arch. PhD	Notes
	State	City						
•	CA	Berkeley	University of California at Berkeley.	X		X	X	Building Science Laboratory
•	CA	Los Angeles	University of California at Los Angeles,	X		X	X	
•	Canada	Montreal	McGill University	X		X	X	
•	Co	Denver	University of Colorado Health Sciences Center, Department of Pharmacology	X		X	X	
•	FL	Gainesville	University of Florida	X		X	X	
•	IL	Champaign	University of Illinois at Urbana-Champaign, Biological Psychology	X		X	X	Human Environment Research Lab
	MA	Cambridge	Harvard			X	X	
	MA	Boston	Harvard Medical School, Program in Neuroscience	X				
	MA	Cambridge	Massachusetts Institute of Technology, Brain and Cognitive Sciences	X		X	X	
•	MI	Ann Arbor	University of Michigan.	X		X	X	RB
•	NJ	Princeton	Princeton University	X		X	X	(no web link)
•	NY	New York	Columbia University	X		X	X	
•	NY	Ithaca	Cornell University	X		X	X	College of Human Ecology (Masters Prog.)
	PA	Pittsburgh	Carnegie Mellon			X	X	Pittsburgh Science Learning Center (NSF); Existing collaboration with Univ. of Pitt.
•	PA	Philadelphia	University of Pennsylvania	X		X	X	
•	TX	College Station	Texas A&M University	X		X	X	Educational Facilities Laboratory; RB
•	TX	Austin	University of Texas at Austin	X		X	X	
•	WI	Milwaukee	University of Wisconsin-Milwaukee	X		X	X	RB: Institute on Aging and Environment

• Denotes school that offers both neuroscience and architectural degrees.

Figure A3–39. Chart of university programs. Developed by Meredith Bazniak.

Graduate programs at the Ph.D. level are the norm in neuroscience programs and the exception in schools of architecture. The 29 schools of architecture that do have doctoral programs have a wide range of intellectual interests. These interests range from programs devoted to "history and theory" (most of them) that tend to be scholarly in terms of history and obtuse in terms of theory. Candidates in these programs are not likely to be interested in learning about neuroscience. However, there are 10 or 12 doctoral programs in architecture schools that include science and engineering research. These schools include such subjects as computer simulation and design, behavioral science studies of children in schools or patients in a hospital, and building systems studies where interdisciplinary research explores new systems development. Candidates in these more technically oriented programs might be interested in exploring interdisciplinary programs with neuroscience students.

Finding Ph.D. candidates in neuroscience programs that are willing and able to orient their studies to include one or more of the hypotheses listed throughout this book will be difficult at first. However, if funding for such studies becomes available (and funding from traditional sources become scarce), there will be greater probability of finding recruits.

My personal bias is to have neuroscience students provided with one semester of courses especially prepared for them to assist them in learning enough about architecture and building science to frame their thesis projects in directions that will be valuable to the architectural profession. I find it unlikely (but not impossible) that graduate architecture students will be able to acquire the necessary knowledge of neuroscience (which would need to be more than is included in this book) in less than several years. It is conceivable that bright and ambitious architectural doctoral candidates could learn enough in a special neuroscience course to collaborate with experienced neuroscientists. How to get universities to invest in the preparation of the one semester's content for architecture students or for neuroscience students will again be a challenge. Wealthy individuals or organizations like the National Science Foundation, who become interested in the potential such programs could offer, might be persuaded to endow these linking programs.

ARCHITECTURAL GLOSSARY

Architecture: The art and science of designing places for human habitation. Or, the sum of all of those buildings forming a category—for example, Colonial architecture. Or, the products resulting from the services of architects with shared value systems—for example, modern architecture.

Baldachin: The topmost element in an elaborate altar (as at St. Peter's in Rome).

Barrel vault: A continuous tunnel formed by extending a round arch over and over.

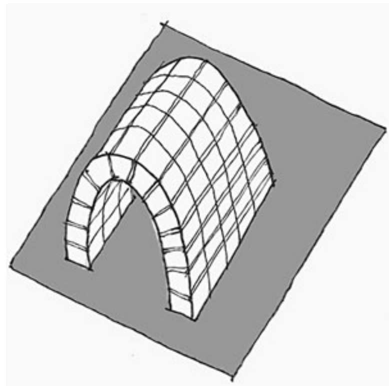

Figure A3–40. Barrel vault.

Beams: The horizontal components of a structural system that carries a load.

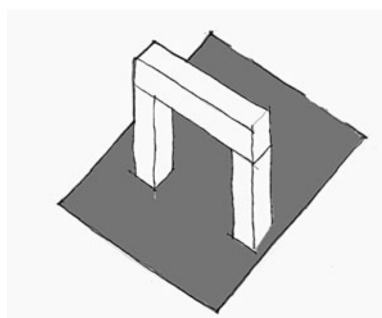

Figure A3–41. Post and beam.

Entasis: The curved surface of an upright member.

Facade: The "face" of a building as seen from one side.

Fan vaulting: An elaborate structural design in the ceiling of late Gothic cathedrals produced by a series of arched sections.

Flying buttress: the structural component of a Gothic cathedral that is located outside the walls of the building and extended across an opening to gather the thrust from the inner arches.

Figure A3–42. Flying buttress.

Harmony: A pleasing or congruent arrangements of parts.

Mortice-and-tenon: A way of fastening two elements together by creating a wedge that fits into a notch in order to be secured.

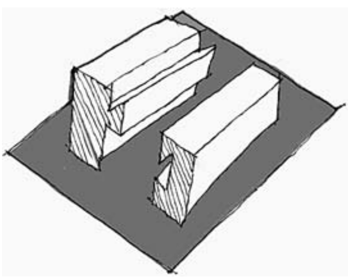

Figure A3–43. Wedge.

Orders: A term used to apply to a category of designs, as in the Doric, Ionic, and Corinthian orders of Greek architecture.

Pitched: A term used to describe a roof that slopes at an angle as contrasted to flat.

Places: A term used in this book for buildings, malls, parks, and so on.

Plumbed: A term used in describing a process for measuring if something is upright.

Pointed arch: Formed by stones or brick arranged to form a pointed round pattern.

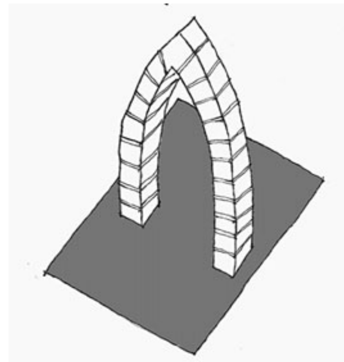

Figure A3–44. Pointed arch.

Post: In simple structures, the vertical member of structural system.
Prototype: A design that serves as a model for future design decisions.
Round arch: Formed by stones or bricks arranged in a circular pattern.

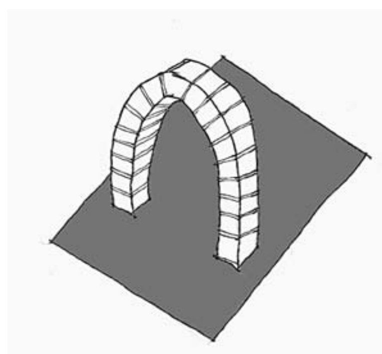

Figure A3–45. Round arch.

Scale: An indication of size as in large scale structures.
Spaces: A term used in this book for where we have personal experiences.
Stacked masonry units: A wall consisting of stones or bricks stacked on top of one another—usually forming a structural wall in older buildings.

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