

**Evidence Based Design:
A Scientific Review for Architectural Applications**

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By
Heather Munoz

Thesis Committee:

Chair: Joyce Noe
Dak Kopec
Scott Sinnett

Abstract

For centuries architectural cues have been subjectively created and designed on intuition, some are well-done and others fail. Occupants interpret the space about them giving the context meaning and defining a program. While those interpretations will vary due to varying cultures, personalities, and experiences the common denominator for perception is the neuroscience behind the hundreds of stimuli receiving information from the confounding space. Designers should think out those stimuli and carefully design for the best impressionable impact. The proposal herein is to encourage designers to strive for the best sensory environment beyond subjective methodologies and into objective studies. A growing field that encourages architects to acquire data and test hypotheses is evidence-based design that seeks to enhance the possibilities of spatial impact on human perception and behavior.

The purpose of this thesis is to explore the possibilities within science, particularly neuroscience, to discover how to create enhanced sensory impressions. The methodology undertaken follows the three research typologies typical of evidence-based development. The first is a literature review of the emergence of architectural design from an historical subjective application to an amalgamation with objective practice. An anatomy of the body, senses, and neurology is unveiled as a basis to understand the realm through which architectural stimuli must pass to elicit any type of response. To test the application of physiological evidence for design an experiment is conducted in which blood pressure, heart rate, and written survey measures are taken to discover impacts of color on a participants review of space. In response to both experimental data and research findings, the final step has been to create a prototypical design that applies evidence to architectural applications followed by analyses of participants' interpretations. Throughout this dissertation research studies are intertwined to help bridge the connection between science and architecture to enlighten the reader of the possibilities instilled in this art for humanity.

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Introduction

Background/ Field of Study

Architecture has the premise of “creating design solutions for buildings.” Predominantly the creation of space has developed through the fields of art, psychology, and structural innovation. An architect designs a building on his/her best interpretation of the program and client’s desires under the restrictions of budget, site, materials, and technology. This interpretation, varying amongst architects, makes it rather intuitive and personal.

Architect Roger Lewis poses in the *Washington Post*: “how can one reliably evaluate architecture to distinguish between excellent design and mediocre or poor design?”¹ Evaluation criteria can obviously be made on building performance, structural integrity, and environmental interface, however the aesthetic is less easily defined.

Since aesthetics is impressionable, architecture should be primarily created based upon its’ servitude to the occupant and community. People have different opinions, believe different beauties, and culturally reside in space differently. Yet people’s common denominator is that they experience their environments through the body and its’ multiple sense organs. It is posed within this thesis that an “excellent” design is one which stimulates the mind and produces results. The principles for such a conclusion is evidence-based design (EBD).

Evidence-based design has been a growing field since the 1980’s. It was first initiated in the medical profession before its’ application into architecture. Evidence-based medicine (EBM) is defined as “the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients. The practice of evidence based medicine means integrating individual clinical expertise with the best

¹ Roger Lewis, “Shaping the City,” *Washington Post*, May 16, 2009, accessed April 12, 2011, <http://www.washingtonpost.com/wp-dyn/content/article/2009/05/15/AR2009051501480.html>.

available external clinical evidence from systematic research.”² At the core of EBM is scientific rigor that advances practitioners’ knowledge of modern assertions made of the profession through clinical trials, reviews, and interventions. Evidence is then systematically reviewed to select only applicable criteria.

The appearance of evidence-based design in architecture happened in part due to findings in hospital design. Recovery records were compared between patients who were assigned to rooms with a view and those whose windows faced an adjacent brick wall. It was discovered that those exposed to a view were released sooner and had fewer negative evaluations on nurses’ notes.³

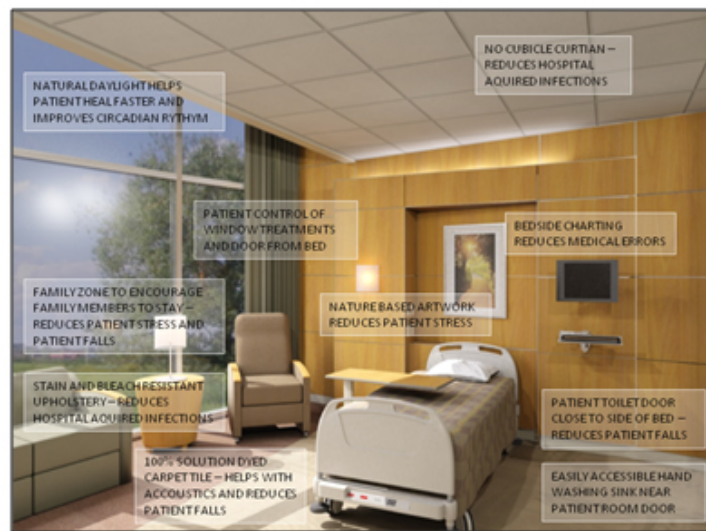


Figure A - Evidence-Based Design Patient Room (Axium)

Evidence-based design emerged as a consequence with the following definition taken from the AIA Journal of Architecture:

“an evidence based designer makes decisions - with an informed client- based on the best available credible research and evaluations of projects. Critical thinking is

² David L. Sackett, et. al, “Evidence based medicine: what it is and what it isn’t,” *BMJ* 312 (1996): 71, accessed April 23, 2011, <http://www.bmj.com/content/312/7023/71.long>.

³ Roger S. Ulrich, “View through a Window may Influence Recovery from Surgery,” *Science* 224 (1984): 420-421, accessed April 15, 2011, <http://www.jstor.org/stable/1692984>.

required to draw rational inferences about design from information that seldom fits a unique situation precisely.”⁴

EBD differs from EBM in that it stresses “information” rather than “evidence” and “credible” instead of “systematic.” This shift in language sets up the framework for EBD to be about a gathering of data to set up “communicable knowledge.”

There is the idea that evidence-based design is an already instilled notion rather than a new process, often leading to the dismissal of new proposals that challenge the traditional firm. However, such an impression is countered with the clarification between research and design made by the Royal Institute of British Architects (RIBA). They use professor and research designer Bruce Archer’s definition of research: “systematic inquiry whose goal is communicable knowledge.” The RIBA uses this definition to counter the argument that the design process is inherently research based:

“ Architects clearly have to be thorough, but they are not necessarily systematic. Choices and decisions are made but not normally through systematic evaluation. More crucially, whilst architects may believe that knowledge is there in the building to be appropriated by critics, users or other architects, they very rarely explicitly communicate the knowledge. It thus lies tacit, thereby failing Archer’s second test of communicability. Designing a building is thus not necessarily research. The building as building reduces architecture to mute objects. These in themselves are not sufficient as the stuff of research inquiry.”⁵

From the RIBA, for architecture to be evidence-based means to communicate knowledge, whether it be a concept or through product results.

⁴ D. Kirk Hamilton, “Four Levels of Evidence-Based Practice,” *The AIA Journal of Architecture* (2006), accessed April 23, 2011, <http://www.arch.ttu.edu/courses/2007/fall/5395/392/students/garay/Research/Research.pdf>.

⁵ J. Till, “What is Architectural Research? Three Myths and One Model,” *Royal Institute of British Architects* (2005), accessed April 23, 2011, <http://www.architecture.com/Files/RIBAProfessionalServices/ResearchAndDevelopment/WhatisArchitecturalResearch.pdf>.

Opponents of evidence-based design reject the overt use of data and research claiming that it erases the passion of creativity, innovation, and raw architectural beauty. However, American Institute of Architects' member Karl Sonnenberg argues that research should be thought of as just another parameter that must be considered for creativity to occur: "if it's really evidence and proof, it just becomes part of the parameters, like gravity or the strength of materials like anything else you have to work with."⁶

The EBD method is slowly being incorporated into firms. Evidence-based design asks the architect to release the romantic notion of raw creativity and to acknowledge unknown factors. It requires firms to restructure a "studio culture" that encourages architects to take on "unfamiliar roles as informal researchers."⁷ The EBD method is slowly being brought into firms, and as original design solutions are awarded and published using this methodology it is plausible that the field of evidence-based design will continue to grow.

An emerging sub-category of evidence-based design is neuroscience with architecture. Humans spend about 90% of their time inside a built construct. Therefore, an architectural setting is undoubtedly influencing our brain, which is the center for our perceptual formations. Neuroscience is the study of the brain and nervous system, and it's leading researchers believe the organ system controls behavior and is modified by environmental conditions.⁸ This thesis will examine some aspects of brain and neuron system function to gain some principal understandings for evidence-based design applications.

⁶ Zach Mortice, "Evidence-Based Design: The Deeper Meaning to Sustainability, Building Performance, and Everything Else," *AIArchitect* 16 (2009), accessed April 12, 2011, http://info.aia.org/aiarchitect/thisweek09/0626/0626b_evidence.cfm.

⁷ *Ibid.*

⁸ Fred H. Gage, foreword to *Brain Landscape: The Coexistence of Neuroscience and Architecture*, by John P. Eberhard, (New York: Oxford University Press, 2009), xiv, accessed April 23, 2011, <http://lib.myilibrary.com.eres.library.manoa.hawaii.edu?ID=193090>.

A leading proponent for this development is the Academy of Neuroscience for Architecture founded in 2003 by the San Diego Chapter of the AIA. The institution acts as an instrumental leader in research and education to advance knowledge, linking neuroscience and human response to the built environment. President, John P. Eberhard argues for the study of neuroscience as the new applied science for architecture in the 21st century.⁹ Architecture influenced by neuroscience is a novel paradigm, yet inescapable if neuroscience reveals discoveries that will encourage a new generation of practice models.

Architects might argue why neuroscience? As designers we seek to create human responses through stimuli interventions. Neuroscience makes difficult measures better defined with technological advances that more precisely show human responses to stimuli. Neuroscientist Fred H. Gage supports the fusion of architecture and science in his foreword to John P. Eberhard's book *Brain Landscape*:

“ 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 affect 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.”¹⁰

The bridge between neuroscience and architecture has been approached by leading professionals such as Eberhard but the facilitation has not yet been fully incorporated into practice and education. Though each discipline, neuroscience and architecture, may be “intellectually curious” of what the other has to offer, a submersion into a new field would alter a tradition of practice, and therefore poses some discomfort.

⁹ John P. Eberhard, *Brain Landscape the Coexistence of Neuroscience and Architecture*, (New York: Oxford University, 2009): 3, accessed April 23, 2011, <http://lib.mylibrary.com.eres.library.manoa.hawaii.edu?ID=193090>

¹⁰ Gage, foreword, xv.

However, if the field of architecture is truly generated to serve the community and become evidence-based a disregard for the emerging field of neuroscience would be ignorant and negligent.

This dissertation argues that scientific evidence can be used beyond healthcare and education and utilized in every-day architecture. Architecture is the built construct of connectivity. People may differ in personalities, culture, ethics, and ethnicities but a common factor is that all people are neurologically similar. Architects can use the study of brain science and sensory transmittance to design spaces that elicit not only a psychological response but a physiological response from the occupant to facilitate a heightened awareness of self with building.

Project Statement

The goal of design should be one that seeks to enhance an awareness of self with building. Architecture should speak of knowledge, health, and well-being of its' occupant. To best fulfill this obligatory role both objective and subjective methodologies should be employed. Architecture is an art that is magnified through its' capacity for personal interactions with humans. Yet many spaces are void of essence and meaning. Such a debasement in architecture deprives the art from reaching its' fullest potential as an influential psychological medium. For architects to be able to enhance the users' perception of building they must acknowledge those stimuli that contribute to a heightened awareness of the encompassing space. An awareness of those stimuli has been sought throughout history in the form of observational methods. The concern in this dissertation is the understanding of stimuli based on scientific evidence.

The intention in this thesis is to highlight how to create a heightened awareness of the encompassing space for the occupant. Often details are overlooked, stimuli isn't significant, and spaces are forgotten. This goal leads to the study of perception to unravel how people perceive spaces. If designers can better understand perception then sensory design expands. The human consciousness of the environment would not be feasible

without understanding how the brain works. The properties of neurons and their firing apparatus are the principles for perceptual formation. This basic study emerges as huge possibilities are unraveled when neuroscience and architecture overlap to influence human identity, behavior, emotions, and memories.

The second purpose of this document is to bridge architectural applications with neuroscience data. This fusion comes as an emergence of evidence-based design that incorporates research studies into architecture. The value of EBD not only lies in its' architectural applicability but its' demonstration of conceptual results that put a leading edge in the competitive market of design. Research behind design choices manifests a product that not only engages an occupant but increases the assurance that conceptual goals are met and investments are worthwhile.

A series of applicable research studies are incorporated and a prototypical design helps fathom science in architecture. The proposal is that the design of spaces and environments would change based on knowledge of physiological data and result in better overall outcomes for designer, client, and occupant.

Chapter One: Perception

“There would be no space at all for me if I had no body” Merleau-Ponty (phenomenological philosopher), 1962.

Perception is the awareness or understanding of one’s environment through the interpretation of sensory information. That information enters through the receptors on the body and is interpreted by the nervous system. Perception is not merely passive but is often determinant on past experiences, expectations, and learning that give stimuli another dimension of complexity. To have a heightened awareness of a space there must be a strong perceptual connection. According to psychologist Richard Gregory, much of the information received by the senses are lost by the time they reach the brain. Therefore, perceptual processes are significant for designers to understand as they create stimuli, especially if they are trying to achieve a goal through the medium. Perception also plays a central role in behaviors. These behaviors are the result of an experience derived from a sensation that causes one to organize sensory information for the purpose of interpreting the world about them.¹¹ Environments have been debated about their possibilities of influencing behaviors, and through knowledge of perception and the nervous system one can discover the grounds and argument for environmental behavioral effects.

1.1 Mind-Body Conundrum

Perception is also key into unraveling the mind-body problem. This conundrum questions how the experience is formed. A sensation enters the body and is interpreted by the mind, yet that interpretation is a series of physical processes by the body that are transformed into an experience. This brings up the question of how much of ourselves is a summation of electrical impulses versus autonomy. The body reacts relatively the same among individuals: the stimuli cause for a bodily reaction via the receptors, followed by a

¹¹ Bruce E. Goldstein, *Sensation and Perception*, 3rd ed., (Belmont: Wadsworth Publishing Company, 1941), 3.

series of synaptic jumps between neurons that make traveling to the brain occur. In this instance life is merely electrical impulses, but then the mind aspect comes into play. The brain is the center at which sensations get interpreted. Science has called this interpretation the job of the mind.

The mind brings meaning from experiences, beliefs, culture, and personalities. However, there is another reaction that is less dependent on the mind for interpretation. The instant pull away from a hot surface, or the trigger of arousal at the site of an accident are interpretations that are instead rather electrical impulses. There is the constant switch between body, the electrical signals, and the mind, the perceptual experience. Though there is a strong direction towards the mind being most influential, the concern with this thesis is just how much of one's self is influenced by the response of the body. This knowledge could empower designers with the potential ability to create for sensations that trigger a subsequent response. For an understanding of how an occupant interprets the environment a psychological and physiological basis for perception must first be understood.

While the mind may influence interpretation, it is through our body that we experience the world as different stimuli act upon our senses to inform us of our surroundings. Without the human figure there would be no distinction between our existence and those objects that surround us.¹² One uses the self and body as a control. Those stimuli that act upon the self, and the perceptions that result, dictate what the space is and can do. The body records the change of sensory input and thereby can identify time, place, function, etc. making self-awareness often conditional upon the body's relationship to the surroundings.

¹² Antonio R. Damasio, *The Feeling of What Happens: body and emotion in the making of consciousness* (New York: Harcourt Brace, 1999).

1.2 Psychological Space

As individuals we are constantly scanning our environment, primarily to keep safety around our body. Therefore, any event or stimuli that occur adjacent to or upon our being are given dominance. It can be assumed then that stimuli which is perceived as being within the personal space is more emotionally intense than those outside the realm of the occupant's space. Furthermore, any object or event that is approaching our personal space is predicted to have a greater emotional impact because it threatens our equilibrium.¹³ Such an understanding allows a manipulation of space that determines stimuli localization and spatial proximity development in relationship to the occupant so as to create for a desired emotional response.

The concept of the “personal bubble” was introduced by Edward T. Hall who correlated psychological and physical data of space. Personal space is the surrounding area that an individual deems psychologically theirs, and an invasion of this space often results in discomfort.¹⁴ The following is a diagram in which Hall gave physical dimensions to the realms of spaces. These dimensions are typical of a westerner, their applicability worldwide is highly variable because different cultures, densities, and experiences shape the realm of the personal space.

¹³ Muhlberger A. et al., “The Impact of Changes in Spatial distance on Emotional Responses,” U.S. National Library of Medicine (2008): accessed February 24, 2011, <http://www.ncbi.nlm.nih.gov/pubmed/18410193>.

¹⁴ Edward T. Hall, *The Hidden Dimension* (New York: Doubleday & Company, Inc., 1966), 110.

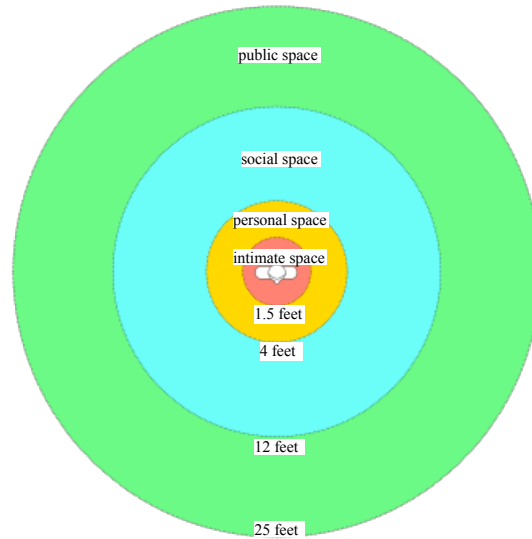


Figure 1.1 Edward T. Hall's Personal Reaction Bubble (MyLiteraryQuest)

“Intimate distance,” $x < 1.5$ ft., is predicted as the best emotional, reactive, and memorable experience zone. Often times an intimate encounter can cause physical discomfort because at this zone the sensory inputs are so intense that they could be overwhelming. For example, vision in the intimate zone is enlarged and nearly all of the retina is stimulated; vision can often become distorted and blurred.¹⁵ At the “personal zone,” $1.5 \text{ ft.} < x < 4 \text{ ft.}$, there is a separation between self and object. In this instance the physical discomfort is lost and a psychological protective sphere is formed. As previously discussed the body is seeking safety and its’ place in the environment. A non-contact zone allows this security while at the same time personally encountering stimuli and objects. Visual distortion is no longer an issue yet the muscles in the eyes are still contracting. This physiological response is showing an arousal and an awareness of stimuli.¹⁶ However, this personal zone can still result in discomfort. A phenomenon of this personal space, according to neuropsychologist Elias, is that perceptive fields tend to overlap, an example is a feather hovering just above the skin without touching and yet the sensation of a tickle

¹⁵ *Ibid.*

¹⁶ *Ibid*, 113.

is perceived.¹⁷ The level of proximity and sensitivity can sometimes be seen as offensive because of the anticipation of a burst of the bubble, which has shown true in many aggressive outpours in overcrowded social gatherings.

At the “social distance”, 4 ft. x 12 ft., intimate detail is lost yet detail about type and quality can still be perceived. The social distance is often used in gatherings and at the far phase, seven to twelve feet, attention begins to be lost.¹⁸ Finally, the “public distance”, 12 ft. x, is considered outside the “circle of involvement” and a level of formality arises.¹⁹ At this distance the sense of smell and touch are nearly lost, and the sense of vision realizes a whole scene rather than detail. According to Hall, the “public distance” is of a “frozen style,” a formal unchanging public communication.²⁰

Since man exhibits behavior based upon territoriality these four spaces have been depicted so as to classify the perception of man in his environment. Those perceptions are once again deemed by the senses which distinguish spatial relationship and object adjacency. Spaces, or rather distances relative to occupant, can be skillfully designed and exhibit different stimuli in different zones to cause for varying impressions.

1.3 Memory

Memory is the accumulation of experiential interpretation of our “bodies as they exist in and are of this world.”²¹ It is through perception that we determine our body’s role or position in our environment. Therefore, it seems inclusive to say that memory is a level of perception that has been retained by the brain.

¹⁷ Lorin Elias and Deborah Saucier, *Neuropsychology: clinical and experimental foundations* (Boston: Allyn and Bacon, 2006).

¹⁸ Hall, *Hidden Dimension*, 116.

¹⁹ *Ibid.*

²⁰ *Ibid.*, 119.

²¹ Frances Downing, *Remembrance and the Design of Place* (College Station: Texas A&M University Press, 2000), 13.

Memories are not simply “stored” somewhere in the brain. Rather they are active ingredients that shape the way one performs, behaves, plans, and thinks. In essence, memories use experiences to change the nervous system. This change is literal, the structure of the neural circuits are altered. Neurons are linked based on their firing apparatus. The firing causes for a chemical change to take place within the neurons that leaves the neuron sensitized to stimulation of the same source. Memories are formed when “mega-patterns” are formed. Those mega-patterns involve a series of connected neurons that have developed a pattern of frequent firing, in which a repeated synchronized firing pattern binds the neurons together, causing for any slight reaction of one to trigger all those that have then become associated with it.²²

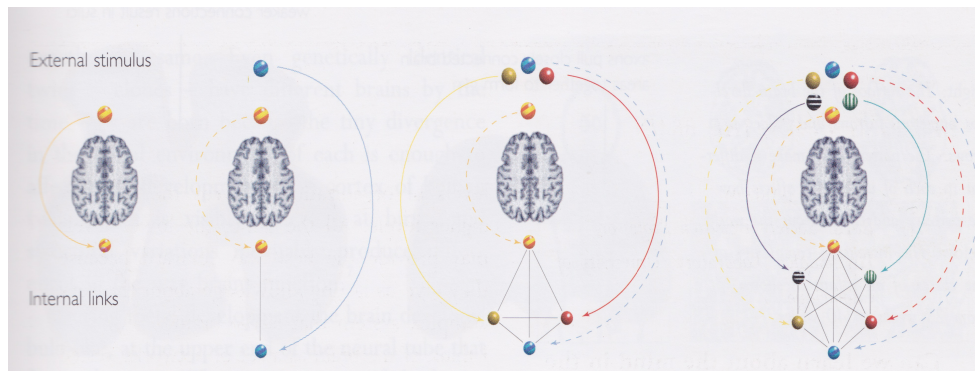


Figure 1.2 Sensory Impact (Carter, 1998)
 Something of the outside world alters our subsequent perception, which in turn alters an impact, which further alters our perception of it

The memory of a place is often the result of a stimulus causing one of these neurons in this pattern to fire. When triggered all other neurons get triggered, creating a recollection, based on the past experience of that pattern.

In London researches have acknowledged the growing field of neuroscience and architecture. In a recent publication they triangulated neuroscience, cognition, and space syntax as it relates to way-finding in complex buildings. The brain primarily supports

²² Rita Carter, *Mapping the Mind* (Berkeley: University of California Press, 1998), 159.

navigation through the neurophysiology of the hippocampal formation.²³ It was found that firing patterns in rat subjects were different when exploring a three dimensional environment versus a horizontal environment. A recent work completed by Dr. Christoph Holscher, cognitive scientist, observed participants navigation of complex buildings and found that floors stacked vertically, which were varied in plan, caused confusion and disorientation among participants. Similarly, the recording of rat subjects brain imaging showed a columnar-packing of cells being fired in the vertical dimension, which lends interpretation for an ease of navigation based on a rather 2.5 dimensional space syntax.²⁴

When way-finding, information from the environment is being sent to the brain for interpretation for self-motion. The firing patterns of cells are triggered upon the first entrance and respond with new patterns to changes in boundaries, landmarks, textures, etc. Thus the brain learns the environment. Therefore, visual similarity, architectural landmarks seen from multiple vantage points, and view-enhancing mediums, like multi-story atriums, trigger a recollection of an already created firing-pattern allowing for orientation and predictability.

Memory is also strongly formed with a relatable identity. Memories of spaces and events would be much less meaningful without emotion. Such an expectation comes from both an understanding of science and theory. In considering neuroscience for memory recollection, the amygdala is the center for emotional encoding and is also the source that helps the hippocampus store memories. Therefore, it is no wonder that those memories which have some emotional content are best stored and recollected. Filmmaker Fritz Lang, who was trained as an architect states it best in his film *Metropolis*, “there can be no understanding between the hands and the brain unless the heart acts as mediator.”²⁵ This clause pinpoints the idea that emotion is the interference for cognitive processes.

²³ Ruth Dalton, Hugo Spiers, and Christoph Holscher, “Navigating Complex Buildings: Cognition, Neuroscience and Architectural Design” (paper presented at the NSF International Workshop on Studying Visual and Spatial Reasoning for Design Creativity, Aix-en-Provence, France, June 14-15, 2010), accessed March 4, 2012, http://reine.arq.unam.mx/VersionEspanol/Recursos/01Principal/Archivos_PDF_to_HTTP_2011/NavigatingComplexBuildings.pdf.

²⁴ *Ibid.*

²⁵ Michael Delahoyde, review of “Metropolis,” by Fritz Lang, accessed March 11, 2011. <http://www.wsu.edu/~delahoyd/sf/metropolis.html>.

1.4 Emotion

Emotion continues to be debated primarily because there is not an exact definition of ‘emotion.’ Emotion can be subdivided into multiple realms for the purpose of defining. For a behaviorist emotions are bodily reactions, a feeling theory would argue the mental states, and a cognitive account would use emotions as evaluative mechanisms.²⁶ Yet all avenues agree that emotion is a phenomena that generally follows the sequence of 1) a stimulating event 2) an appraisal or interpretation of that event 3) physiological alterations 4) behavioral modifications and 5) sometimes conscious awareness. What has been stated in all frameworks of the emotional debate is that emotion modulates perceptual processes and influences our judgements. Emotions can also arise without an external awareness. An intrinsic arousal, constituted by a physiological reaction, causes for an emotional response that may surface later on from the internal origin.²⁷ So not all emotions are triggered from environmental cues, but are sometimes simply a result of particular firing neurons, neurotransmitters released, and memories recollected.

It is important to understand emotion in learning how to design for a heightened awareness because of the definitive changes, both psychologically and physiologically, that result. The term emotion throughout this context will lie within the framework of cognitive appraisals, as this research seeks to understand occupant and architecture relationships.

²⁶ Ana Tajadura-Jimenez, “Embodied psychoacoustics: spatial and multisensory determinants of auditory-induced emotion” (Ph.D. diss., Chalmers University of Technology, 2008), 20.

²⁷ Neil R. Carlson, *Physiology of Behavior*, 7th ed. (Massachusetts: Allyn and Bacon, 2001), 359.

Chapter Two: Sensory Physiology

Man's perception and behavior is primarily a consequence of his physiological reaction. Physiology is the branch of biology that deals with the chemical and physical processes that allow a living organism to function.²⁸ The study of physiology has branched out in specification to particular systems. One realm is sensory physiology, which studies how a sensory stimulus is processed by the nervous system.

Sensory physiology is subdivided into two categories, objective sensory physiology and subjective sensory physiology. An objective description is the study of the nervous system in response to a stimulus and subjective is the perception the subject formulates from the sensation.²⁹ Though each category has its' area of interest the two are by no means entirely separate. The phenomena in an environment must always first pass through a sensory stimuli and excite the sensory nerves in order to formulate a sensory impression that results in a perception. The characteristics of the perception is dependent upon the type and combination of receptors that are activated.³⁰

2.1 General Process of Transmission

A sensory receptor is the dendritic terminal of a neuron that is receiving information from the world. The sensory receptors are activated when they are altered by a stimulus. This impression causes the sensory receptor to depolarize, which is called the receptor potential. The receptors membrane is opened and an influx of ions pass through this channel eliciting an action potential.³¹

²⁸ Schmidt, ed. et. al., preface to *Sensory Physiology*. (Berlin; New York: Springer-Verlag, 1986).

²⁹ Robert F. Schmidt, ed. et. al., *Fundamentals of Sensory Physiology*. 3rd ed. (Berlin; New York: Springer-Verlag, 1986), 7.

³⁰ Paul Pagliano, *Multisensory Environments* (London: David Fulton, 1999), 26.

³¹ Dawn A. Tamarkin, "Sensory Receptors," *Anatomy and Physiology*, Springfield Technical Community College, accessed April 23, 2011, <http://faculty.stcc.edu/AandP/AP/AP2pages/Units14to17/unit15/sensory.htm>.

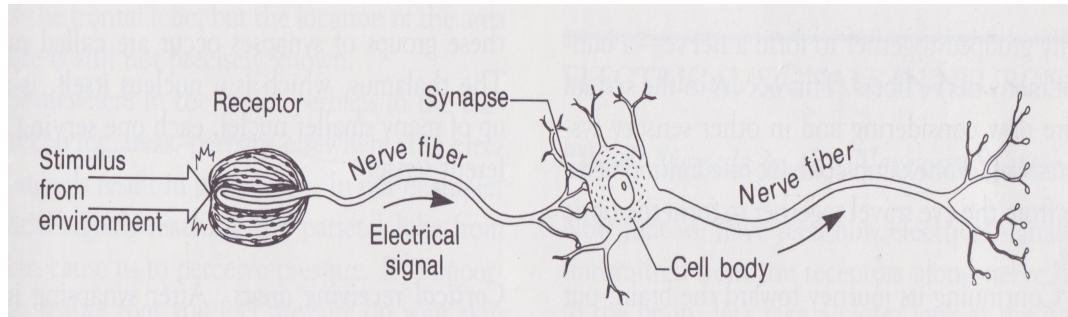


Figure 2.1 Stimulus Travel (Goldstein, 35)

Action potentials generated are carried along axonal pathways up the spinal cord reaching the central nervous system and relayed through the brain. The spinal cord is a tubular bundle of neurons and cells protected by layers of tissue that make the connection between receptors and brain perception possible. Both the spinal cord and brain have specialized areas for specific modalities. In the spinal cord specialized interneurons will synapse with particular modalities making each sense travel unique. In the brain the stimuli is sent to the proper locality.

The brain is comprised of millions of interconnected neurons and is made up of five main parts: 1) the cerebrum, 2) inter-brain, 3) midbrain, 4) cerebellum and pons V-arolii, and 5) the medulla oblongata. The cerebrum covers the most area and is responsible for higher cerebral function and the voluntary movement of muscles. The cerebellum controls fine movement and the pons V-arolii acts as the center for the interconnection of neural tracts. The medulla oblongata controls many reflex responses like breathing. Finally, the inter-brain contains the thalamus which serves as a mediator connecting the sensory paths.³²

³² Jaakko Malmivuo and Rober Plonsey, *Bioelectromagnetism: Principles and Application of Bioelectric and Biomagnetic Fields*, (New York: Oxford University Press, 1995), accessed April 23, 2011, <http://www.bem.fi/book/05/05.htm>.

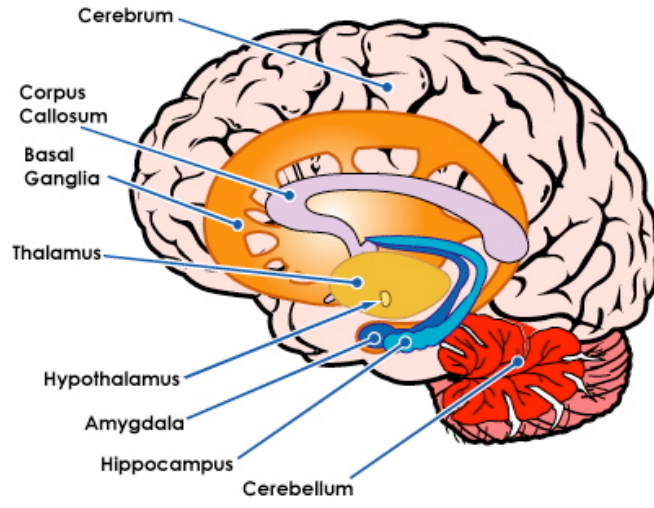


Figure 2.2 The Brain and Limbic System (Rhodo-Dendrites)

Before reaching the brain the sense's nerve impulses converge at the thalamus. It is at the thalamus that the sense is directed for appropriate travel to the complementing receiving area in the brain. The cortical receiving areas consist of the parietal lobe for touch and spatial perception, the occipital lobe for vision, the temporal lobe for hearing and memory, and the frontal lobe for attention and emotions.³³

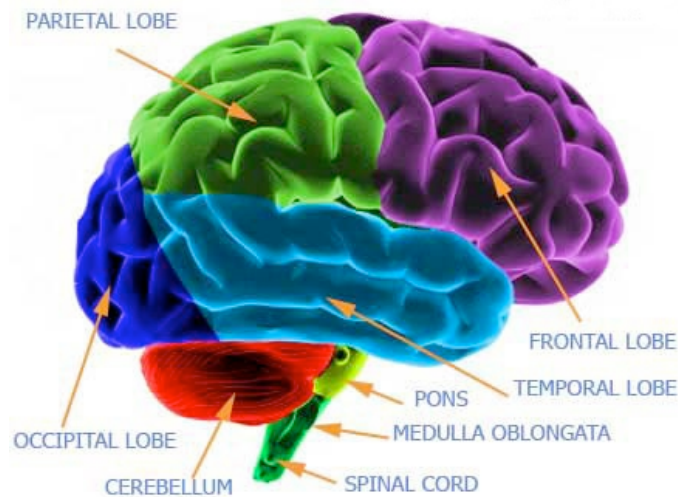


Figure 2.3 The Brain's Division into the Main Functional Areas (Brain Injury Association of America)

³³ Goldstein, *Sensation and Perception*, 36.

It is either at these receiving areas or elsewhere in the brain where signals are formed into perception. Perception occurs through the signal interpretation by the brain, whereas the signal that relays from the brain back toward the receptor organ is for physical reaction.³⁴

2.2 Limbic System

Emotional and memory emergence is often considered from a subjective point of view. For example, the color red makes one feel angry, and the death of a loved one is an unforgettable happening. The question from an objective perspective would be; how are emotions and memories formed, and how could designers use this knowledge to create stimuli that attract the proper mind resources? The answer could possibly lie in the limbic system.

The limbic system has been regarded as the “feeling and reacting brain” inserted into the “thinking” brain. The system’s components are being deemed the primary source for emotional perception and memory formation. The limbic lobe is comprised of the hypothalamus, amygdala, hippocampus, and limbic cortex, which are nestled just below the cerebrum and on both sides of the thalamus. The hypothalamus is the primary output node for the limbic system. This unit maintains homeostasis of the body, it will receive input and then regulate responses so that the body returns to a “set point.” Such regulation includes heart rate, blood pressure, hunger, and aggression. The hippocampus acts as a memory mediator. Although memory is stored in other areas of the brain the hippocampus encodes and also retrieves memories. The hippocampus is particularly active when new environments and surroundings are being explored.³⁵

The amygdala helps coordinate behavioral responses to environmental stimuli. Its’ involvement with the limbic system includes many processes such as what memories are

³⁴ *Ibid*, 37

³⁵ Rand S. Swenson, *Review of Clinical and Functional Neuroscience*, DartMouth Medical School, (2006), chap. 9, accessed April 23, 2011, http://www.dartmouth.edu/~rswenson/NeuroSci/chapter_9.html.

stored and arousal to emotional contexts. The amygdala is particularly responsive to emotional contexts provoking fear, anger, and pleasure.³⁶ The strong correlation with emotion has led many researchers on an investigation of the amygdala's role and consequential effects on the normalcy of man's behavior. One particular study that has potential for related architectural applications was conducted by Harvard's neuroscientists Moshe Bar.

Moshe Bar explored man's preference for objects through functional magnetic resonance imaging. His method used a control object with varying amounts of curved and angular characteristics and then compared the object with those that were of only curvilinear content and others with only an angular characteristic.

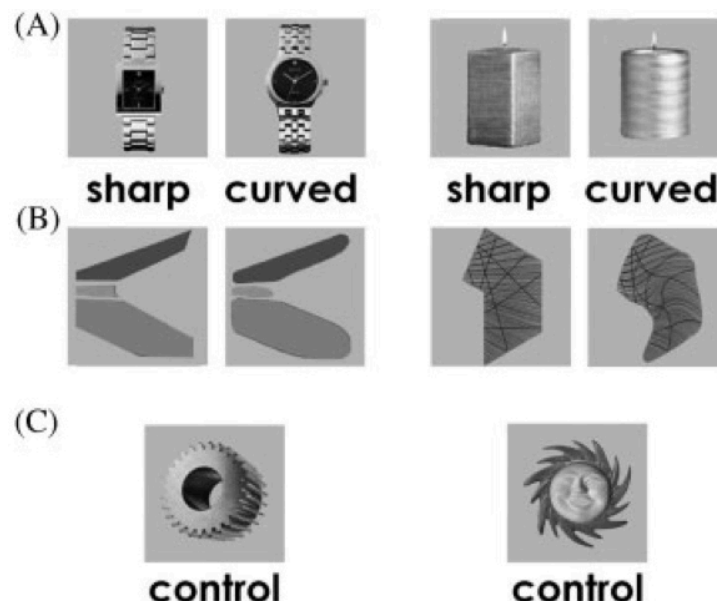


Figure 2.4 Examples of Stimuli used with Varying Contours (Moshe Bar)

The fMRI scans were recorded after each exposure for objective data, and for a perceptual understanding participants were also asked to immediately respond to each object with a “like” or “dislike” opinion.

³⁶ Harvey Black, “Amygdala’s Inner Workings: Researchers gain new insights into this structure’s emotional connections,” *The Scientist* 15 (2001): 20, accessed February 28, 2011, <http://biopsychiatry.com/amygdala.htm>.

While the study has the limitation of whether subject preferences were due to learned experiences and associations with angled objects being in fact more dangerous, the fMRI scans provide some credibility to the survey results. The outcome showed a significantly greater activation in the amygdala for both novel and angular objects, providing support for his hypothesis that angled objects would be liked less, whether consciously or subconsciously. The surveyed results furthered this conclusion with the “dislike” results being significantly higher for angled objects in comparison with both the control and curved objects.³⁷ This study ties in the perceptual features of a space and the influence on our preferences from both an objective and subjective methodology. It’s implications can influence a room’s content and design for a desired physiological and psychological response. This research finding, and others similar, are becoming more widely applied by commercial institutions and designers who must determine architectural details, product design, and furniture concepts.

2.3 Plasticity

The 100 billion neurons located in the adult human brain communicate with each other within the thousands of specialized junctions called synapses.³⁸ It are the external events that elicit synaptic change and cause for the brain’s perceptual response to a neural spatio-temporal pattern.³⁹ The synaptic modification of firing patterns is called synaptic plasticity, and is a physiological phenomenon that formulates memories, alters behavior, and causes for many emotions.

³⁷ Moshe Bar and Maital Neta, “The proactive brain: using rudimentary information to make predictive judgments,” *Journal of Consumer Behavior* 7 (2008), 325-326, DOI: 10.1002/cb.254. <http://barlab.mgh.harvard.edu/papers/Consumer.pdf>.

³⁸ Helmut W. Kessels and Roberto Malinow, “Synaptic AMPA Receptor Plasticity and Behavior.” *Neuron* 61 (2009): 340, accessed April 23, 2011, <http://pharmacology.ucsd.edu/graduate/courseinfo/cell.pdf>.

³⁹ T.V.P. Bliss and G.L. Collingridge, “A synaptic model of memory: long-term potentiation in the hippocampus,” *Nature* 361 (1993): 31, accessed April 23, 2011. http://www.cellbio.wustl.edu/faculty/huettner/BlissCollingridge93_Nature.pdf.

In order for a firing pattern to occur a sense must be stimulated. In neuroscience and psychophysics the smallest detectable level of a stimulus is coined the “absolute threshold.” The absolute threshold is influenced by a subject’s expectations, motivations, cognitive processes, and adaptation to the stimulus. Thus this minimum level is defined at the point at which the lowest intensity is detected 50% of the time.⁴⁰ For example, an experiment by Hecht, Schlaer, and Pirenne in 1942 assessed the absolute threshold for vision as a measure of the minimum number of photons detectable by the human eye. Their results concluded that only 90 photons had to enter the eye for a 60% successful response in a light detection experiment.⁴¹ An understanding of threshold levels of stimuli is significant because a signal must pass through neural filters to the brain for a response to occur.

Receptors are generally plastic in nature, meaning that the more they are stimulated the ease of activation increases. What results is a decrease in stimulus thresholds for that particular receptor.⁴² Furthermore, stimuli that causes neural excitability and synaptic crosses can outlast the event that had originally precipitated the impulse.⁴³ Since these impressionable neurons are modified by environmental cues architecture can play a role in synaptic patterns. In design a determined outcome, or expected response, can be facilitated through the manipulation of sensory exposure so as to decrease the threshold and realize a response.

Neural travel begins at the receptors and travels through nerve fibers crossing synaptic gaps and traveling up the spinal cord to the brain. As synapses are bridged there

⁴⁰ "Absolute Threshold," *Gale Encyclopedia of Psychology* (2001), accessed February 28, 2012, <http://www.encyclopedia.com/doc/1G2-3406000012.html>.

⁴¹ S. Hecht, S. Schlaer and M.H. Pirenne, "Energy, Quanta and vision," *Journal of the Optical Society of America*, 38, 207 (1942).

⁴² Goldstein, *Sensation and Perception*, 27.

⁴³ S.J. Martin Grimwood and R.G.M. Morris, “Synaptic Plasticity and Memory: an evaluation of the hypothesis,” *Annual Review of Neuroscience* 23 (2000): 649-711, accessed April 23, 2011. http://www.neuro.iastate.edu/Uploads/Martin_AnnRewNeros_00.pdf.

can be an excitatory response that will cause a “sustained increase in the efficiency of synaptic transmission.”

This prolonging has been the model of activity-dependent synaptic plasticity and has begun to provide evidence for how memories and behaviors are formed. A major goal of neuroscientists has been to discover how brain synapses are modified by experiences for a behavioral change. Synaptic plasticity can be regulated and changed through the release of neurotransmitters. These neurotransmitters are responsible for getting the message across the synaptic gap between nerve fibers.

2.4 Neurotransmitters

A stimuli is received by a receptor that transmits the action into a nerve impulse. That nerve impulse must pass through synapses by the release of a chemical transmitter that generates a nerve impulse.⁴⁴ That electrical signal makes long distance travel possible. The stimulus travels along nerve fibers, up the spinal cord to the thalamus and then eventually to the brain where a perception is formed. Since the stimuli must travel through a number of neurons and synaptic gaps not all energy input is received by the brain. When the nerve impulse reaches a synaptic gap the transfer from the nerve fiber to the neighboring cell body can either be an excitatory or inhibitory electrical response. An excitatory response would increase the rate of nerve firing while an inhibition would decrease the rate of nerve firing. In an inhibitory state there is a less likelihood of a nerve impulse being generated, resulting in a improbability of a stimulus transforming into a perception. The response is based off the the type of neurotransmitter released.⁴⁵

⁴⁴ Goldstein, *Sensation and Perception*, 35.

⁴⁵ Goldstein, *Sensation and Perception*, 40.

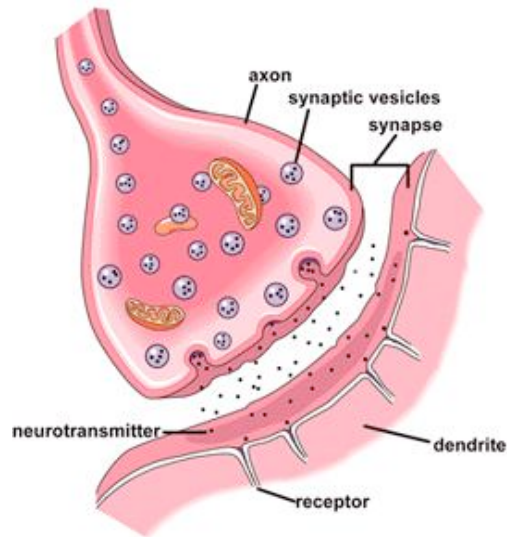


Figure 2.5 Synapse (MindTools)

The most common types of neurotransmitters are: 1) acetylcholine is associated with body functions, like the stimulation of intestinal muscles, 2) endorphins, reduces pain and makes one happy or calm, 3) GABA blocks excitatory neurotransmitters thereby repressing anxiety, 4) dopamine is associated with perception, emotions and movement, 5) serotonin stabilizes one's mood, 6) norepinephrine brings the human body into high alert by raising the heart rate and blood pressure, and 7) epinephrine also increases heart rate and blood pressure but in a response to a dangerous situation.⁴⁶

With knowledge about neurotransmitters designers could create spaces that facilitate activity for the release of a particular type of neurotransmitter. For example, meditative activities, or low-stimulating environments, would contribute to the release of serotonin. When dopamine is released it gives one the feeling of pleasure or satisfaction. Conditional reinforcement has been found to release dopamine levels, such spaces would be casinos and educational spaces. An acquired understanding of science by the architect begins to unravel the unknown to why spaces influence man to the extent at which they do.

⁴⁶ Amna Adnan, "Neurotransmitters and its types." *Biotechnology Articles* (2010), accessed April 23, 2011, <http://www.biotecharticles.com/Biology-Article/Neurotransmitters-and-its-types-347.html>.

Chapter Three: Multi-Sensory Environments

As man experiences architecture he remembers only general representations of the space. Those interpretations are formulated by sensations that are informing the internal context of man about the external environment. Those sensations are interpreted as idiosyncratic because they are intrinsic events that are entirely private.

A sensory impression is the denoted meaning to a sensory experience. A sensory impression would be perceiving the smell of “peppermint” or seeing the color “red.” In the context of architecture there are no pure sensory impressions. The spatial context is submerged in multiple qualities, whether it be of light, color, tones, smells of pine or flowers. Arousal within the individual is based on the best combination, level, and type of sensory stimulation for a particular motive.

Architecture has the power to influence the mind by way of the body’s sense organs receiving stimuli. Sensory cues from spaces and the environment are constantly reaching your receptors and traveling to the brain. Yet not all impulses are formulated into a perception. These instances are the result of low thresholds and a lack of complexity.

A change in stimulus intensity affects the rate of nerve firing. By strengthening the stimulus there is both a consistency and an increase of firing rates.⁴⁷ This increase of nerve firing is correlated with an intensity of pressure upon the senses. However, not all magnitudes are realized accurately by the observer, what occurs is a magnitude experience. This dives into threshold levels as it occurs above absolute threshold. As an example, experimental psychologist S.S. Stevens altered the intensity of light to detect when the participant noticed a change. The magnitude estimation shows that participants perception of light is not a 1 to 1 relationship but rather a 1 to 9

⁴⁷ Goldstein, *Sensation and Perception*, 40

relationship.⁴⁸ This is called a response compression, a perception is not equivalent to the actual intensity of the stimulus. The reverse can also be true in a response expansion, mostly in cases of touch, where the perceived magnitude exceeds the stimulus intensity. What must be managed by architects are designed intensities and magnitudes that realize a desirable threshold, or magnitude estimate, for a preferred goal.

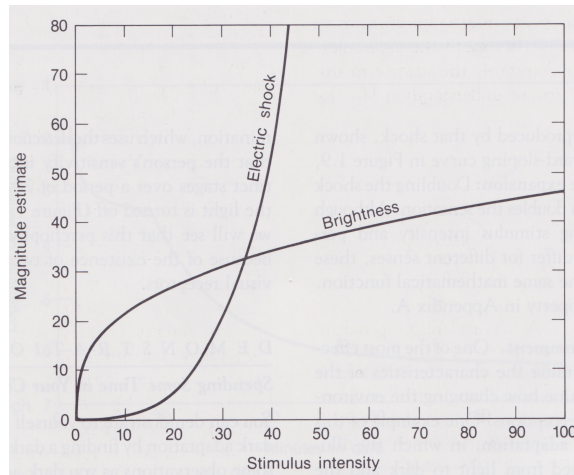


Figure 3.1 Perceived Magnitude and Stimulus Intensity for Electrical Shock and Brightness (Goldstein)

The designed environmental stimuli can only be affective if they have the opportunity to interact with a fitting sense organ. It may seem logical to assume that a single stimuli received by the attending organ would cause for a response. However, information from perceived magnitudes reveal that not necessarily all inputs are received by the brain. For an environment to elicit a nerve impulse that is capable of passing through all necessary synaptic gaps there must be an excitatory reaction.

A study conducted by researchers, recorded hippocampus reactions in rats as they explored their environment. What scientists found was that a combination of stimuli; vision, smell, touch, etc, resulted in a neural response in the hippocampus while single stimuli reacted elsewhere.⁴⁹ Since, the hippocampus plays a central role in the

⁴⁸ *Ibid*, 13.

⁴⁹ Sternberg and Wilson, "Neuroscience and Architecture," 240.

consolidation of information it seems vital that multiple stimuli be present in any one context. A part of the hippocampus is the parahippocampal place area (PPA) which encodes new perceptual information and is best responsive to physical places. The PPA is also most responsive to a complexity of sensations on the body within a space.⁵⁰

Even still multiple stimuli alone won't fascinate the user to the extent that they value the experience or consider the moment memorable. What must be done is a skillful manipulation of environmental effects and the exploitation of the best combination of those sensations. Therefore, a review of the current discourse about agreeable impressions must be evaluated. During the enlightenment period five basic senses were acknowledged; touch, sight, smell, taste, and hearing. An environmental psychologist, J.J. Gibson scrutinized such classifications and proclaimed that the senses were not merely "passive sensation receivers" but actually were "active detectors" within the human mind that sought out information.⁵¹ Gibson added a new category of sense to modern thought, the haptic system. The haptic sense is a twist on the sense of touch to encompass an experience with more than just a hand but the entire body. The haptic system incorporates multiple sensations of the singular sense of "touch" at once, this includes, but is not limited to, pressure, temperature, and kinesthetics.

What is discovered is that even the individual senses are given significance and deemed memorable or pleasant when multiple facets are being incorporated. In the haptic sense the whole body is experiencing a space or object. Even the single sense like vision and sound have multiple facets that determine whether the sensation is stimulating. When a study by architects and psychologists from Pennsylvania and Kent State conducted experiments about what is considered pleasant lighting, they found that people best responded to lighting that incorporated multiple lighting systems.⁵² Another study

⁵⁰ John P. Eberhard, *Brain Landscape: the Coexistence of Neuroscience and Architecture* (Oxford University Press USA, 2008), 75, accessed September 20, 2010, <http://lib.mylibrary.com.eres.library.manoa.hawaii.edu?ID=193090>.

⁵¹ Sarah Fortkamp, "Body. Emotion. Architecture. A phenomenological reinterpretation" (M.Arch diss., University of Cincinnati, 2005).

⁵² Corwin Bennet, *Spaces for People: human factors in design* (New Jersey: Prentice-Hall, 1977), 102.

considered sound, and concluded that pure tones, those sounds that the ear can hear the best, are considered more annoying than complex sounds.⁵³ A complexity of sound is another scenario where multiple dimensions are being appreciated over a single expression.

⁵³ *Ibid*, 122.

Chapter Four: Visual Space

Architecture has been primarily dependent upon the visual environment while being less concerned with the other senses. While this may be true it is not to say that architecture should make a shift to designing for the senses equally. According to MIT's Department of Brain and Cognitive Sciences, and a variety of other sources, nearly half of the brain is devoted to the evaluation of visual information. Vision's complexity of sensory organs has made vision a dominate area of sensory study by psychologists, physiologists, and anatomists. Though not precisely calculated, it has been predicted that the eye can gather much more information than any other sense. Also, at the personal distance and beyond visual information is less ambiguous than the other senses. Many times visual cues give proof or validity to what the other senses are interpreting. For example, a person traveling down an enclosed corridor senses the smell of a gardenia flower, but it is not until one see's the source can one deem it the actual flower or a deodorizing reproduction.

4.1 Light

Light in architecture is often the key ingredient for vision. It illuminates areas to draw out detail, dictates programs, is a tool for productivity, and aesthetically enhances a building. Such an intense measure in architecture is not merely intuition but rather evidence-based when understanding the basic mechanisms of vision. Vision begins with light.⁵⁴ We see through the receptors on the eye that transform the wavelengths into electrical energy that travel along neurons to be received by the visual cortex for perceptual formation. It is the way by which the light rays reflect and bounce off of objects and surfaces that causes for a perception by the observer. For example, light entering a room in one direction can cause for a different experience than light entering from an opposite direction, smaller origin, or even of a different source. Therefore, in architecture, it is unquestionable that light should be an initial design decision.

⁵⁴ Goldstein, *Sensation and Perception*, 69.

When light enters the eye it is focused by the cornea and lens to be received by the receptors located on the retina. The receptors are actually oriented away from the light so as to be in close contact with the pigment epithelium. This pigment epithelium contains the enzymes necessary for pigment construction by selective-wavelength absorption. The receptors cover almost the entire back of the eye, except for where the optic nerve leaves, this area being coined the “blind-spot.” The photoreceptors on the rods and cones form synapses with bipolar cells, which in turn synapse with the ganglion cells. It are the ganglion cells whose axons carry information to the brain by way of the optic nerves.⁵⁵

The ganglion cells are the first neurons that respond to the stimuli with action potentials. Particular ganglion cells will either increase or decrease their firing rate in response to the intensity of light in a communicating photoreceptor. A greater intensity of light will feature increased energy in the ganglion cell. Professor David Heeger of New York University sought out the perceptions formed from ganglion cells. The cells were able to detect the image due to the varying light intensities that were emphasized through the edges. When light intensity was increased so did the contrast, which triggered an immediate response from the ganglion cells. In the following simulated image Prof. Heeger demonstrates ganglion cell responses, with gray having little response and white vs. black a stronger response.⁵⁶

⁵⁵ Carlson, *Physiology of Behavior*, 166.

⁵⁶ David Heeger, “Retinal Ganglion Cells,” (Lecture presented at the Center for Neural Science, New York University, New York, 2006), accessed April 23, 2011, <http://www.cns.nyu.edu/~david/courses/perception/lecturenotes/ganglion/ganglion.html>.

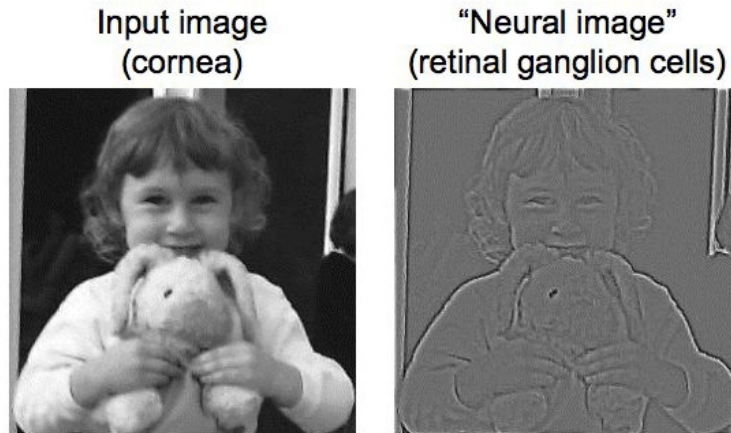


Figure 4.1 Retinal Ganglion Cells Response to Image (Heeger)

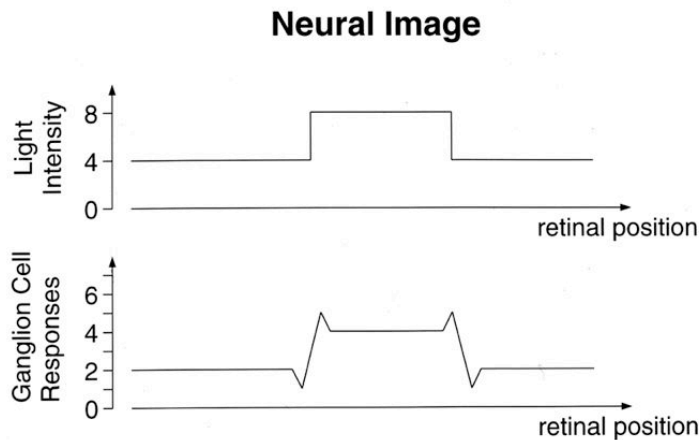


Figure 4.2 Retinal Ganglion Cells Response to Light Intensity (Heeger)

Light, from the architect’s vantage point, has been a driving force of design for centuries due to its’ aesthetic quality, but its’ physiological impact has only recently been investigated. Many institutional and residential buildings are not properly designed for well-lit conditions that our mind and body need. Colleagues from the Netherlands Institute for Neuroscience investigated 12 assisted-living facilities in Holland in concern of lighting’s effect on the elderly’s cognition, mood, and sleep behavior. Tests taken every six months over three and half years reported that residents of more brightly lit buildings reduced symptoms of depression by 19% and had a 5% less cognitive decline. The

brightly lit spaces during the day also improved participants sleep efficiency by 3.5%.⁵⁷ As evidence continues to surface the obligation of the architect will predictably become to include natural light for quality of life standards, much like the recent requirement that all newly built hospital rooms must include a window in response to accumulated medical data.

4.2 Color

Color is determined by the wavelength of a light. Objects are perceived as colored based upon the wavelength that is illuminating the object and those which are being reflected onto the eye. There are three main sources for light: the sun, light bulbs, and fluorescent lights.⁵⁸ While one can look directly at these sources much of the light we see is reflected from our surrounding environment. This leads to the significant relationship between color and wavelength. An object is not colored rather it appears colored. All objects have a hue, and this is because they are absorbing, reflecting and/or transmitting wavelengths. It is through the selection process that an object appears colored. For example, orange juice transmits long and medium wavelengths, therefore it appears orange.

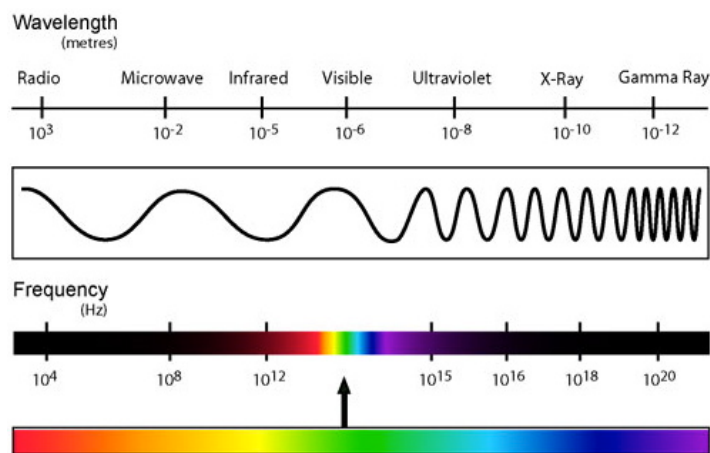


Figure 4.3 The Electro Magnetic Spectrum (Kollewin)

⁵⁷ Rixt F Riemersma-van der Lek, et. al., “Effect of Bright Light and Melatonin on Cognitive and Noncognitive Function in Elderly Residents of Group Care Facilities,” *JAMA* 299 (2008): 2644, accessed February 17, 2010, doi: 10.1001/jama.299.22.2642.

⁵⁸ Goldstein, *Sensation and Perception*, 113.

Alternative medicine is making use of color to treat ailments and bring about emotional and mental balance. The field is called chromotherapy and is believed to be a modern application on the ancient Chinese and Egyptian use of “colored medicine.” In the complex realm of cosmology the Chinese associated certain colors with the five elements; earth, water, fire, metal, and wood. These elements gave color a meaning based on activity and season. The Egyptians created solar temples in dedication to their sun god Re, particular areas in these solar temples were used for patient healing based on the color wavelength that entered. They would manipulate the sun’s rays so that a particular color would diffuse into a room where the patient would bathe to heal his/her particular condition.⁵⁹

Chromotherapy erupted after the findings of biophotons discovered by German researchers. Biophotons are “ultra-weak photon emissions of biological systems ... (biophotons) are weak electromagnetic waves in the optical range of the spectrum.”⁶⁰ This definition translates as living cells being able to emit biophotons that express the functional state of the living organism. German physicist, Fritz-Alber Popp, discovered that whenever a cell was not in a state of balance there would be an increased emission of biophotons. What Popp concluded was that light waves were entering through skin receptors and were communicating faster than electrical impulses to signify imbalance and ailments.⁶¹ Photobiology uses these findings of colored light transmitted through the body as a way of restoring malfunctioning systems.

⁵⁹ Rosemary Bourne, “Color and Light: Ancient Forms, New Paradigms,” Psinergy, accessed April 23, 2011, http://heal.psinergy.info/News_Articles/color_and_light_ancient_forms_new_paradigms.htm.

⁶⁰ Marco Bischof, “Humans Emit Biophotons: The Light of Our Cells,” Heart Spring, accessed April 23, 2011, http://heartspring.net/meditation_biophoton.html.

⁶¹ Bourne, “Color and Light: Ancient Forms, New Paradigms.”

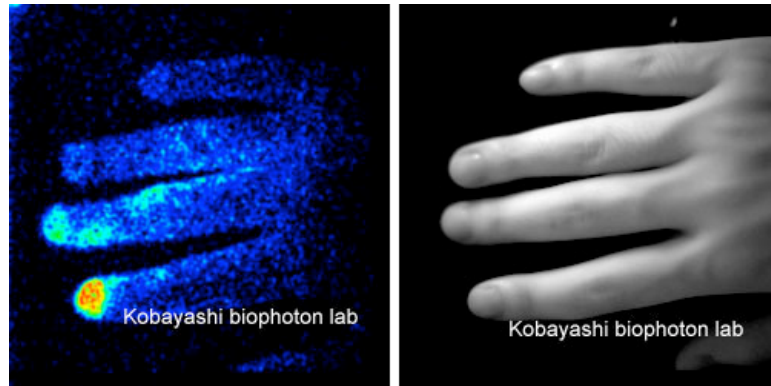


Figure 4.4 Human Biophotons in Cigarette Smoker (Bischof)

Chromotherapy aims to use light and color to transmit along electromagnetic fields to balance the energy of a person’s body, whether it be physical, emotional, mental, or spiritual.⁶² However, this field of alternative medicine is often considered a pseudoscience because of the lack of research and controlled testing trials. The following chart is a listing of the claimed physical and psychological treatments associated with some common colors.

Color	Physical	Psychological
Red	Excites the nerves and Blood Is good for the muscular system Produce Heat that vitalize body	Gives sense of Power Represents Health, Anger Red stimulates, excites
Blue	Stimulates metabolism Contracts arteries, veins Reduces nervous excitement	Soothing emotional conditions Promotes solitude, independence Color of intuition
Orange	Increases Pulse Rate Antispasmodic effect Strengthens Lungs	Color for Ideas and Mental concepts Symbolizes warmth and prosperity Stimulates feelings of sociableness
Green	Muscle and Tissue Builder Dilates the capillaries Acts on the sympathetic system	Color of energy, youth, hope, peace An emotional stabilizer Equalizes the etheric body
Purple	Stimulates kidneys Sexual mechanism	Royalty, dignity Gives authority
Yellow	Motor Stimulant for nerves Purifies the bloodstream Cleansing of liver, intestines	Animating color for life Can create anxiety and mental tension Yellow is color for perception

Figure 4.5 Physical/Psychological Impacts of Colors (Color-Therapy)

⁶² “Colour Therapy,” Worldwide Health, accessed April 23, 2011, <http://www.worldwidehealth.com/alternative-medicine-colour-therapy.html>.

4.3 Visual Angle

There are about 126 million receptors in each eye which are divided into cones and rods, rods outnumbering cones with a 20 to 1 ratio.⁶³ These 126 million receptors must converge onto approximately 1 million ganglion cells which carry the signal out of the retina.⁶⁴ This implies that many signals are inevitably lost because of the far fewer ganglion cells. Therefore, the optimal design solution must be sought to excite the receptors.

Rods are much larger than cones and can absorb more light, contributing to their property of relatively high sensitivity. Yet rods are achromatic and have a low level of acuity, leaving the cones with the responsibility of color vision and detection of detail. There is a field on the retina that contains only cones, the fovea. The fovea is located directly in the line of sight, meaning that when we look at an object within a 0.5 degree angle that object or image is directly received by cone receptors.⁶⁵ It is no wonder then that in art museums paintings are situated at eye level, or why a person directs their line of sight parallel to detail in the freedom of an open space. Architecturally this biological understanding has a huge impact. Consider for example, the paintings in the Sistine Chapel in Rome, Italy. Any visitor would have to explore, redirect, reorient, and focus in on any one piece in order to interpret the detail so as to understand the story.

An object's visual angle is the line that draws from the top and bottom of the object to the center of the observer's eye.⁶⁶ Therefore, the visual angle is always dependent upon its' physical size and its' relationship to the observer.

⁶³ Goldstein, *Sensation and Perception*, 76.

⁶⁴ *Ibid*, 84.

⁶⁵ *Ibid*, 76.

⁶⁶ Mark E. McCourt, "Visual Acuity," North Dakota State University, Department of Psychology, accessed April 23, 2011, <http://www.psych.ndsu.nodak.edu/mccourt/Psy460/Visual%20acuity/Visual%20acuity.html>.

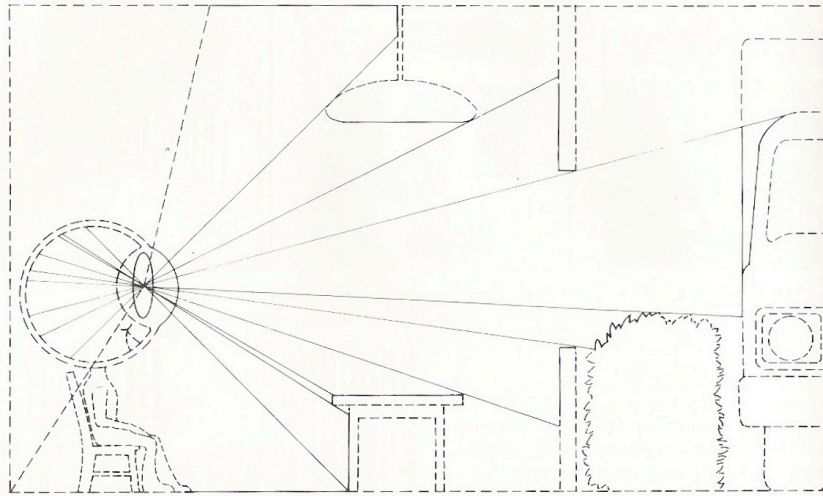


Figure 4.6 Visual Angles: (Goldstein)
Dotted Line - Surfaces unseen, Solid Line - Visible Surfaces

Since visual angle is regulated by these factors it then denotes that two objects with different sizes can cover the same area in your field of view because of their varying distances, as in the experience of covering the moon with your thumb.

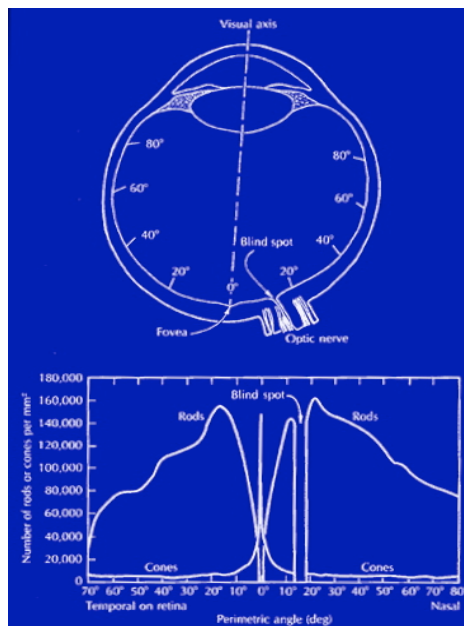


Figure 4.7 Visual Angles on the Retina (CIS)

4.4 Forms and Objects

The environment is a series of objects in particular places that we are interacting with and trying to make sense of. Perception tends to be first about objects as a whole and their location, while secondarily about what color, pattern, or detail is existent. For example, one walks around the counter to set the cup in the dish-rack to the left, while the detail of the counter being marble, or the cup being blue is more of an afterthought.

Architects can utilize this basic principle of perception to strategically locate objects. For example, an object of significant importance should be placed in a sensible location relative to the observer. An even greater awareness of the object would be situating the form in such a way that the occupant must orient themselves around the object, come in contact with, or be immersed within a form, so as to draw out a conscious experiential awareness.

Perception is also a process of organization, an observer will group parts into larger units.⁶⁷ With modifying factors to a stimulus an entire scene could be changed. Gestalt psychologist Max Wertheimer argued that perceptions are dependent on not one part of a stimulus, but the presence of the overall stimulus configuration in order to formulate a true depiction.

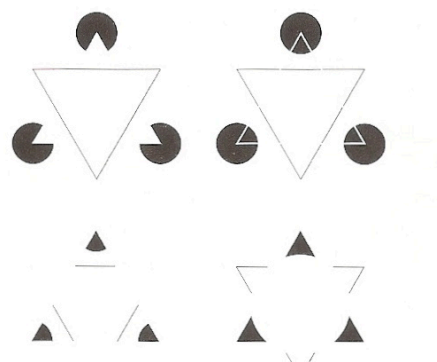


Figure 4.8 The Phantom Triangle (Carter)

⁶⁷ Goldstein, *Sensation and Perception*, 193.

Perceptual grouping occurs because of many different notions. There is the “law of proximity,” in that things near to each-other are grouped, the “law of common fate” states that things which are moving in the same direction appear grouped together, and the “law of good figure,” is that every stimulus pattern is reduced to the simplest structure possible.⁶⁸ For balance, harmony, and understanding to exist within architecture these founding “laws” are ingredients for architects who create objects.



Figure 4.9 “Law of Proximity” (WikiSpaces)



Figure 4.10 “Law of Common Fate” Nutcracker Ballet- similarity in movement (Ballet)

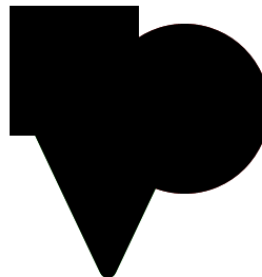


Figure 4.11 “Law of Good Figure” viewed as Square + Triangle + Circle
Not a new composition. (VanSeoDesign)

⁶⁸ *Ibid*, 198-200.

Chapter Five: Auditory Space

The perception of sound is tied into its' localization and association more so than the sound itself.⁶⁹ An advantage of the auditory system is that we can sense outside our immediate surroundings. The sense of hearing can detect sounds from different sources and from different directions without having to physically direct the body to the origin.

Sound results from air pressure either increasing or decreasing. What results are patterns of air pressure changes, which is coined "sound-waves." When an intensity of sound occurs it means that there has been an increased density of molecules in the air, and a decreased sound intensity correlates with a decreased density of molecules in the air.⁷⁰ What happens is that the sound source will push the surrounding air molecules together increasing the density of molecules nearest to the origin. This is an explanation of why in a nightclub sound is loudest right next to the speakers.

5.1 The Auditory Apparatus

The varying air pressures come in contact with receptive cells in the ear and man perceives a sound. This sound is channeled by way of the pinna through the ear canal and into the eardrum, or tympanic membrane, which vibrates the sound.⁷¹ The vibrations are passed through the middle ear via the makeup of the ossicles, (middle ear bones) so that the vibrations can reach the receptors in the cochlea. The cochlea is filled with water and therefore transmitted sound is transferred through a liquid medium.⁷² The receptive organ in the cochlea responsible for auditory reception are the hair cells which are attached to the basilar membrane. Vibrations cause for the basilar membrane to

⁶⁹ Ana Tajadura-Jimenez, "Embodied psychoacoustics: spatial and multisensory determinants of auditory-induced emotion."

⁷⁰ Goldstein, *Sensation and Perception*, 386.

⁷¹ Carlson, *Physiology of behavior*, 202.

⁷² *Ibid*, 203.

physically flex up and down depending on the intensity of sound. Also, the basilar membrane has particular regions that respond to different frequencies of sound.

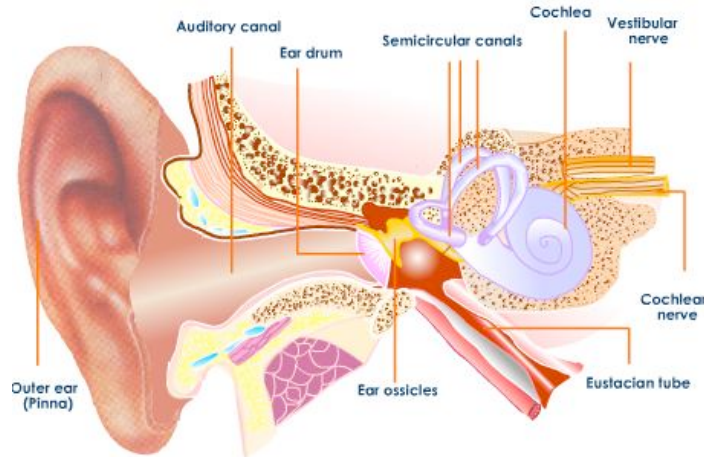


Figure 5.1 The Auditory Apparatus (TutorVista)

From the brief description above on how the body processes sound it is clear that it depends on the vibration quality. The louder sounds will produce more intense vibrations and will trickle through the pathway of the ear with a more intense force on the auditory hair cells, and consequently the basilar membrane. The pressure on the cochlear receptors will result in a greater release of neurotransmitters producing a higher rate of firing by the nerve axons.⁷³ The perception of loudness is signaled by the rate of firing and in the case of frequency, the pitch is dictated by which neurons fire.

As mentioned in the previous chapter vision is a process of organization. This holds true for any sense, and sound interprets tones based on a couple of leading principles. Tones are recognized as belonging to one-another when they are deemed similar.⁷⁴ Similarity is best extracted from the pitch, hence in music there is a progression of notes rather than a sudden alteration that would cause for the melody to seem

⁷³ *Ibid*, 213

⁷⁴ Goldstein, *Sensation and Perception*, 403.

discontinuous and isolated. Although a pitch may be similar they can still be perceived as separate if they do not reveal some proximity or good continuation.

5.2 Localization

Sound localization depends upon our having two ears. The difference of time it takes for a sound to get to the left versus the right ear is a measurement of sound location. Having two ears also allows for localization definitions based on intensity measures. The sound reaching the far ear will receive a less intense sound than the near ear because the head casts a “shadow.”⁷⁵ Origin and intensity are two factors but there is also the earlobe itself that plays a role in determining sound locality. The pinna’s whorls actually reflect sound causing for echoes based on different distances and directions of sound sources.⁷⁶ This explanation defines why people use ear plugs to pass the sense of sound; they are actually stopping the bouncing of sound within the ear, not the sound itself.

We hear through the vibration of objects that move the surrounding air to produce sound-waves that reach a person’s receptive cells in the ear.⁷⁷ In architecture spaces are shaped differently and materials chosen so as to configure a particular reverberation quality. This quality choice is based upon the fact that the sound reaching the ear is not always a direct connection between the sound origin and the ear. What happens to the sound when it leaves the source is extremely significant on the way we perceive a sound. The environment will determine this “what happens” question. Most often we receive indirect sound that often changes the quality. Sound is reflected, transmitted, and/or absorbed through walls, ceilings, floors, furniture, etc. If little sound is absorbed then we hear much indirect sound versus when much of the sound is absorbed thereby receiving less indirect sound.

⁷⁵ *Ibid*, 411.

⁷⁶ *Ibid*, 413.

⁷⁷ Carlson, *Physiology of Behavior*, 201.

The sense of sound informs the occupant of space and geometry as he reflects and realizes a space's spatial depth and acoustic properties that enhances the impression of the environment. These impressions, or soundscapes, inform the occupant of neighboring spaces, the presence of people, the size, material, and voids in a construct. Sound not only informs people of distant environments but also provides feedback about one's own immediate actions, or interaction sounds.⁷⁸

5.3 Perception of Sound

Rasmussen gives a great illustration of the perception of sound in his book *Experiencing Architecture*. The perception of a room being cold might be because of a "hard" acoustical property such that the reverberation of sound is quite high, whereas in the same room an array of rugs and draperies would soften the acoustics causing for a perceived quality of warmth.⁷⁹

The concern with modern architecture is that the quality of material has been so fabricated and manipulated to the extent that the expected sound is something unnatural. There is not a tendency to produce rooms with differentiated acoustical effects but rather a trend toward acoustical handling that shortens the period of reverberation causing for rather solitary places. One might argue that man does not want the noise of architecture to resonate, yet as Rasmussen puts it, "the ordinary human being still enjoys variety... for instance, a man tends to whistle or sing when he enters the bathroom... though the room is small in volume, its' tiled floor and walls, porcelain basin and water-filled tub, all reflect sound... so that he is stimulated by the resonance of his voice and imagines himself a new Caruso."⁸⁰

⁷⁸ Ana Tajadura-Jimenez, "Embodied psychoacoustics: spatial and multisensory determinants of auditory-induced emotion," 32.

⁷⁹ Steen Eiler Rasmussen, *Experiencing Architecture* (Cambridge: The IT Press, 1995), 224.

⁸⁰ *Ibid*, 236.

He then continues to point out the truth of modern architecture which incorporates the same material, tile and porcelain, yet a whistle is not resonated because the space has been acoustically treated so that a sound falls flat. The theory of Rasmussen is letting architecture be heard. If a space allowed its' materials to speak, rather than simply be seen, then there would be a heightened awareness of man being within and knowing space, as all his senses are being enlightened rather than fabricated.

Chapter Six: Olfactory Space

Despite the fact that the nose is an extremely sensitive detector and arouses many emotional reactions the study of olfactory space is rudimentary when compared to the other sense organs. The underdeveloped studies are primarily due to the thousands of odors, and the thousand more concentrations of those odors, that can be recognized by man. The ability for the olfactory sense organ to detect so minute concentrations is a delineating problem for chemists who cannot accurately measure the concentrations, let alone determine its' forthcoming emotional reaction.⁸¹

6.1 Spatial Recognition

The sense of smell tends to elicit strong reactions to olfactory settings. This sensitivity is partially due to the discovery that the olfactory receptors are capable of detecting just one molecule of odorant.⁸² Although the receptors can detect a single molecule of odorant the odors are not detected by their individual components, but rather perceived by its' composition of molecule types. However, if types are mixed together they can still be recognized as different odors.⁸³ For example, the smell of coffee is made up of many molecules, however man cannot define one molecule from another but groups them to form the perception of smelling coffee. If, however, you are in a coffee shop where coffee odor and pastry scents are mixed they do not blend but rather one recognizes them as distinct odors, despite the fact that they have themselves become a mixture. This phenomenon has been transformed into a spatial recognition explanation.

⁸¹ Forrest Wilson, *A Graphic Survey of Perception and Behavior for the Design Professions* (New York: Van Nostrand Reinhold Company Inc., 1984), 189.

⁸² Goldstein, *Sensation and Perception*, 497.

⁸³ Carlson, *Physiology of Behavior*, 238.

Receptors fasten with particular odor molecules. If the molecule fits into the binding site of the receptor then stimulation of the olfactory neuron will occur. Depending on which receptors receive activity determines the brain's perception of a particular odor.⁸⁴

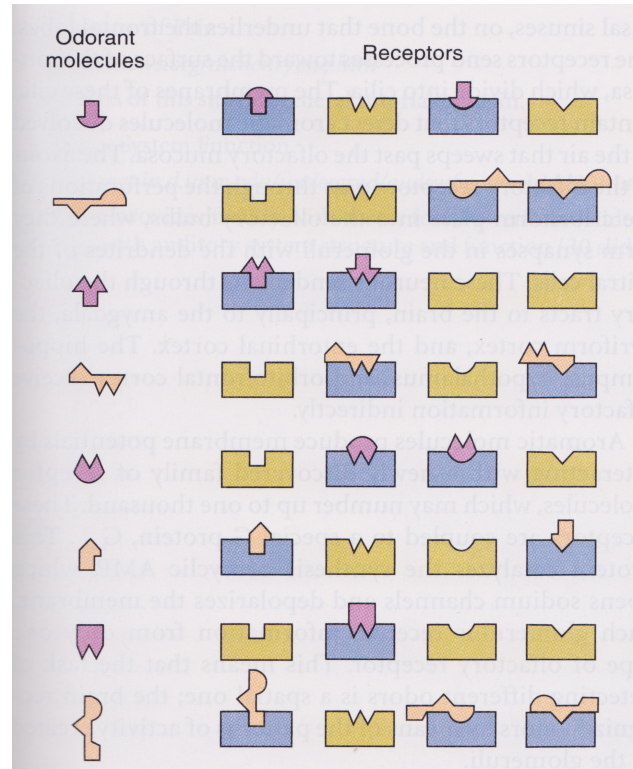


Figure 6.1 Olfactory Coding: different odorant molecules attach to different combinations of receptor molecules. (Carlson)

Molecules in the air contact the cilia of the nose receptors before they are produced into electrical signals that travel along nerve fibers to the olfactory bulb. The olfactory bulb is the location for the first synapses before the fibers split. The olfactory glomeruli is where these synapses take place and though their function is still being researched it is proposed that its' firing pattern is what begins the process of decoding for interpretation.⁸⁵ Each glomerulus receives the same type of receptor molecule, tying into the spatial combinatorial process of odor detection.

⁸⁴ *Ibid*, 239.

⁸⁵ Robert Vassar et al., "Topographic Organization of Sensory Projection to the Olfactory Bulb." *Cell* 79 (1994): 982, accessed April 14, 2011, <http://vosshall.rockefeller.edu/reprints/VassarAxelCell1994.pdf>.

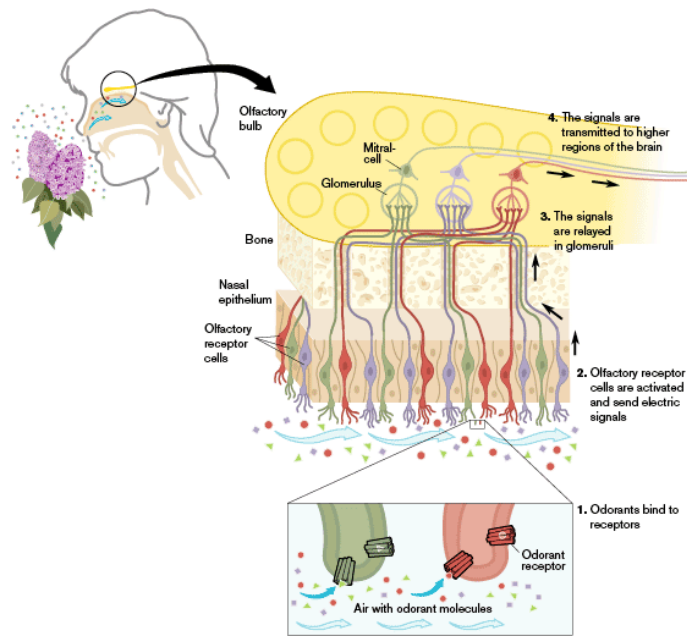


Figure 6.2 Details of Olfactory Receptor Cells with Glomeruli of the Olfactory Bulb (CalmSpace)

The stimulus then travels from the glomeruli through synapses with the mitral cells. Axons from the mitral cells travel to the brain through the olfactory tracts. One circuit travels to the thalamus, as does all the other senses, and the other goes directly through the amygdala, hippocampus, and the hypothalamus. Therefore the olfactory bulb, the area for interpretation of smell, is directly linked to the limbic system.⁸⁶

It is at the thalamus where the perception of odors occurs, but it is believed that it is the limbic system which determines whether an odor is “good” or “bad.”⁸⁷ This limbic system houses the brain structures associated with memory, emotion, and behavior. It is also through these structures that the brain regulates eating, drinking and reproduction, hence smells strong association with food and the arousal evoked when smelling a mate. Such direct connection of sources could have an implication on why the sense of smell evokes strong memories and facilitates emotional reaction.

⁸⁶ Carlson, *Physiology of Behavior*, 237.

⁸⁷ Goldstein, *Sensation and Perception*, 503.

6.2 Scents of Space

Usman Haque, an artist and london based architect, exerts the theory that odor can act as a determinant for design. He considers architecture an “operating system” and has coined a “softspace” and “hardspace” architecture. The hardspace are the boundaries which enclose a space, but the softspace encompasses the spaces: “the delight in architecture comes from the non-tangible, non-physical stuff in-between... it encourages people to become performers within their own environments.”

Haque designed *Scents of Space, 2002*. It is an installation which diffuses smells in controlled zones. The zones then become demarcated not by the “hardspace” but rather by the scent they expose. The areas are controlled by diffusion screens which prevent mixing of smells except by the user’s will of movement to intersect scents. The occupant travels through the spaces in a linear fashion and upon new spaces new smells are elicited. Way-finding through scents then becomes an agent defining location and program, making the possibilities with olfactory space indicative of localization and association. The project is aimed at thinking of architecture through a sensory lens and configuring new ways for spaces to interact with occupants. The installation is focused on new experiences with the olfactory system precisely because of the evidence supporting smell as evoking memories and reshaping perceptual understanding.⁸⁸

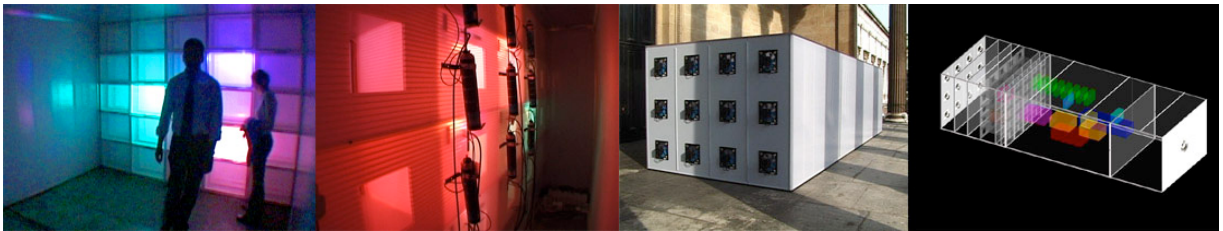


Figure 6.3 *Scents of Space*, by Usman Haque (Langlois)

⁸⁸ “Usman Haque,” La Fondation Daniel Langlois, accessed April 16, 2011, <http://www.fondation-langlois.org/html/e/page.php?NumPage=374>.

Chapter Seven: Tactile Space

Theoretically speaking texture gives architecture its' spirit. The raw character of wood grains nailed together to form stairs, or bricks mortared together to form a wall speaks of vitality and veracity over a mechanically plastered wall refined, leveled, painted and featureless of any detail. Materials are judged not only by its' aesthetic appearance but by its' sensitivity to touch and its' heat-conducting ability.⁸⁹

7.1 Active Touch

Unlike audition, olfaction, or vision, where you can close out the stimuli by plugging your ears and nose or closing your eyes, touch is always there. Touch is unique in that the sense is over the whole body and is a "two-way" street. The physical world in which we touch can actually react. With vision one can see an object but the sense of seeing cannot change the object's shape, form, or temperature. Touch, on the other hand, can create conduction, and with a squeeze, push, or pull, an object's form can be altered.

The tactile environment tends to be best remembered with active touch over passive touch. In a study conducted by psychologist James Gibson there was reported 95% accuracy with active touch over 49% accuracy with passive touch when participants were asked to reproduce the abstract objects they felt.⁹⁰ Therefore, touch can be considered a direct connection into literally "seizing the world."⁹¹

The sense of touch is much more than the act of feeling something with our hands. Touch allows one to run, walk, sit, hug, and kiss. When we consider the sense of touch we come upon the realization that it is an important sense for survival. The sense of

⁸⁹ Rasmussen, *Experiencing Architecture*, 182.

⁹⁰ Hall, *Hidden Dimension*, 57.

⁹¹ Natalie Angier, "Primal, Acute, and Easily Duped: Our Sense of Touch," *New York Times*, December 8, 2008, accessed April 19, 2011, <http://www.nytimes.com/2008/12/09/science/09angi.html>.

touch has been called “the mother of the senses.”⁹² Even in the other modalities the sense of touch is prevalent. For example, when we hear sound waves are vibrated through the ear, and when we see light rays are felt on the retina.

7.2 The Skin

The skin also has an interesting connection to the nervous system. In embryonic development the skin and the nervous system arise from the ectoderm, and upon development the central nervous system differentiates into the brain and spinal cord, while the ectoderm becomes somewhat of an external nervous system.⁹³ The ectoderm then becomes our hair, nails, and location for the other sense organs.

Besides the skin acting as a protective barrier for our bodies it is the informant of stimuli through which we come in contact with. The skin physically comprises about 18 percent of our body, and a quarter sized section of the skin features a few million cells, fifty nerve endings, and three feet of blood vessels.⁹⁴

The skin’s inner layer is the dermis where a multiplicity of nerve endings and receptors reside. These nerve fibers travel from the skin to the spinal cord where they first synapse. The nerve impulse continues up the spinal cord and into the sensory of the thalamus. The thalamus then selectively directs touch stimuli to the somatosensory area in the parietal lobe of the cortex.⁹⁵

Much like the retina of the visual system, certain parts of the skin have higher acuity than others. Different parts of the body have different density levels of receptors. A higher density of receptors, as seen in the fingertips, will have a greater level of sensitivity.

⁹² Tiffany Field, *Touch*, (Massachusetts: MIT Press), 76.

⁹³ *Ibid.*

⁹⁴ *Ibid.*

⁹⁵ Goldstein, *Sensation and Perception*, 471.

Different parts of the body relay information to different parts in the somatosensory cortex based on their level of sensitivity. The following figure is a representation of a man's body allocated on the brain as developed by neurosurgeons over a 20-year period to portray the sensory areas in relation to their responsiveness.

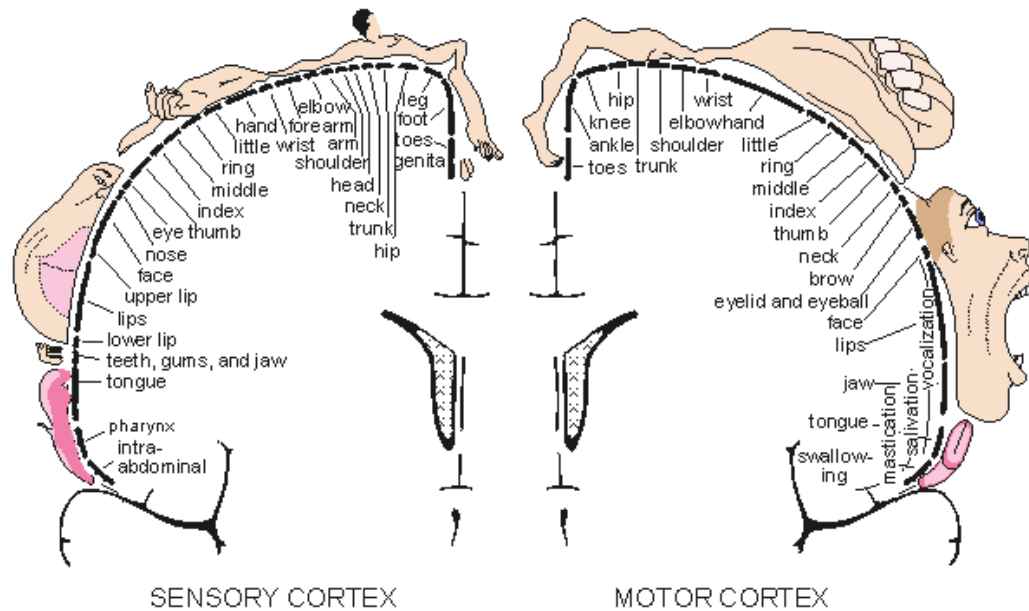


Figure 7.1 Sensory Homunculus (Penfield & Rasmussen)

7.3 Skin Receptors

There are multiple types of receptors in the skin, that are responsive to different tactile qualities. The sense receptors have been categorized into three types: 1) mechanoreceptors, 2) thermoreceptors, and 3) nociceptors. Mechanoreceptors respond when pressure indents the skins and responds more rapidly. Thermoreceptors react to changes in temperature, and their nerve fibers feature an increased firing rate with an increasing change of temperature, hot or cold. Nociceptors are respondent to intense stimulation that pose a threat, whether it be of pressure or temperature.⁹⁶ While these particular receptors respond to particular stimuli there cannot be a judged specificity theory that would dictate a casual perception. While the firing of nociceptors is probably

⁹⁶ *Ibid*, 473.

best correlated with the perception of pain both the thermoreceptors and mechanoreceptors are likely being activated as well, also contributing to the sense of pain.

The nervous system is best visualized when there is a reaction that happens in the context of the thermal environment. Man's response to his emotional state causes for a change in skin temperature, which tends to be of no conscious control. Different emotional states cause for a change in the blood supply to different areas of the body. During this admission there exists swelling of the blood vessels, as seen when people blush.

Man is capable of detecting small changes in temperature differences. Therefore, being within a crowded room and detecting temperature from adjacent occupants causes a different perception of the space than the same space comprised of only you. The temperature detection on the skin receptors not only informs one of his/her emotional state but also can provide clues of attitudes of those around you.

7.4 Association

Designers have the opportunity to contrast materials for an interactive experience with the occupant whom is interpreting his surroundings as he formulates his perceptual experience. When an occupant touches a rough stone surface his physiological response will incorporate the thermoreceptors for experiencing the coolth and the mechanoreceptors will be active as the receptors rub along the edged surfaces. From multi-sensory understanding and its' influence on the hippocampus, an increased response and action potential will occur if more receptors are activated. Therefore, for a distinguished experience to be created there must be a heightening awareness of many receptors.

Touch in the environment is often based on association. For example traveling through nature one might walk on grass and then transition onto gravel. The interpretation that the grass is soft is formulated because it is compared to the gravel

being hard. In the built environment contrast of the tactile environment can be potentially stimulating and enhancing.

Localization is also a key ingredient for manipulating perception. A single texture begins to lose its' significance if not met with a new medium. Man will become adapted to one context if his senses are not stimulated through contrast. In architecture, a stone surface throughout the entire building would not be as stimulating as a stone surface abutting a wood panel.



Figure 7.2 American Folk Art Museum, New York (Todd Williams & Billie Tsien)

Chapter Eight: Experiment

8.1 Concept

Architecture is an art not because it stands like a sculpture but because it has the power to interact with its users. A building elicits a reaction from the senses, whether through smell, touch, sound, or sight, and therefore has an empowering impact on behavior, perception, thought, and memory. From the research presented those influential impacts are first generated by a physiological response. Ironically however, much of architecture has been based on observational and subjective methodologies. The aim of this experiment is to understand those sensations from a scientific standpoint. By understanding physiological responses through perception, designers can generate an environment that has potential psychological results that will formulate an occupant-space relationship.

Thus far the document has provided information about what the psychological impacts are and even the physiological responses to stimuli. However, information gathered has been based on textbook data and the continual bridging of psychological and physiological information. In some instances of research and evidence-based design a new study is necessary to support unknown hypotheses that cannot be otherwise supported or tested through literature reviews.

Throughout this research the question “how does stimuli affect physiological responses” has been continually implied. After a review of the information presented the study of color has presented itself as a rather pseudoscience and void of any real objective data. Rather than dismissing the information as entirely unreliable the experiment is meant to investigate the presumptions made about light and color impacts.

The present experiment explored how might color and light modulate physiological responses. To do this, a 12’x6’ box was constructed with varying colored light bulbs and various openings in order to manipulate the color and origin of light. Participants entered

the box and were subject to these varying mediums while at the same time being continuously monitored for changes in heart rate and blood pressure. If light were to have any influence, the physiological changes were registered.

8.2 Methodology

Participants

The study consistently took place between 11am and 1pm so as to capture the same intensity and direction of light, and lasted a series of four weeks. There were a total of 22 participants whose average age was 26, but ages ranged between 18 and 42. There were a total of 8 males, and 14 females. While subjects varied in personalities, ethnicities, and cultural backgrounds, about 90% grew up in Hawaii and so were use to the everyday intensity of light and climatic data associated with Oahu, HI. In order to ensure the results were not influenced by any prior architecture training, care was taken to make sure that no participant had an architecture background.

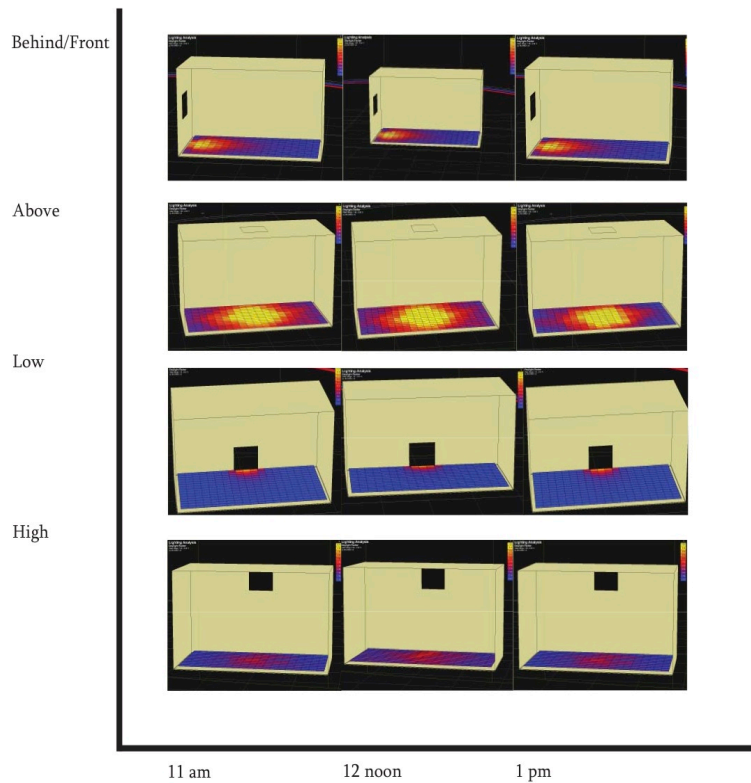
Materials

The experiment presented explores the visual sensation as it relates to color and light. Window locations were located above, in front, behind, top right, and bottom left in direct relation to the seated participant for a response to position relative to self. A series of colored lights (red, blue, and white) are located directly above the seated participant and will be used to discover any change of response to type.

The design of the space was created based on research findings and formulated predictions developed from cited references such as Hall, Fryer, Goldstein, and many physiological references. The window placement was created systematically with each opening the same dimension, 4'x4', and located in the center width of the box, though not necessarily centrally based on height. The time of day chosen was based on Ecotect

software analysis of different daylight measures to derive at the best time of day for the most natural sunlight exposure.

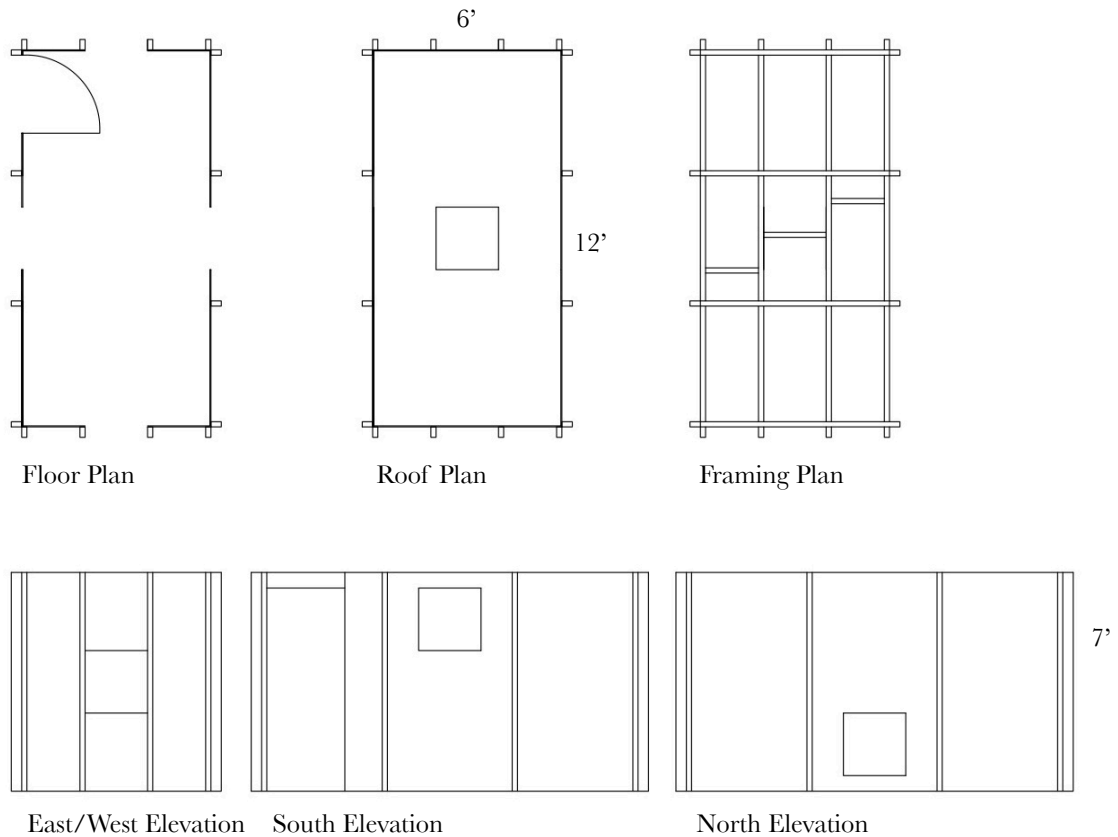
Ecotect Daylight Analysis



Construction was completed over a three week period. The process began with the cutting and assembly of plywood panels. The frame was created with 2"x4"s placed at 48" o.c. with the floor framing bridged in the center. The overall dimensions of the constructed room was 6' wide by 12' long by 7' high. The dimensions are aimed at capturing all zones based on Edward T. Hall's measurement of space: Public Space > 12', Social Space 12' <x> 4', Personal Space 4'<x> 1.5', and Intimate Space <1.5'. For mobility purposes the room has been constructed in modules. Each module screws together to form the overall dimensions, and can be rearranged to make the space smaller, i.e. 6'x8'x7'.

Upon completion the interior was painted black and windows were cut and then hinged appropriately for ease of opening during the experiment. A single light bulb exposing each color (white, red, blue) were drilled to the ceiling directly above the seated participant. Each light was a felt electric 13-Watt twist CFL light bulb with a 2in. diameter. An electrical outlet was connected to the outer facade of the panel to be manipulated with an on/off switch during the experiment.

Plans & Elevations



Constructed Images



Framing is made up of exposed 2"x4"'s



Plywood sheathing is screwed onto framing. The exterior framing allows for a flush interior.



Windows were cut through on five panels and hinged for ease of opening. A door was created to seal off the light during the experiment.



The interior was painted black to allow for a controlled setting.



The 12' long constructed room was created in modules for mobility purposes. There are a total of three modules, the center piece is first disconnected. The center piece consists of a floor panel and two wall panels. The ends consist of a floor panel and three wall panels. The room is pieced on site.

Procedure

Two physiological responses were recorded, heart rate activity and blood pressure. The psychological responses were taken by a written survey delivered by paper and pen, with nearly all questions being open ended for participant reflection (see Appendix). The survey results were then correlated with the physiological data.

The measure of heart rate and blood pressure was chosen because of its' direct link with the hypothalamus. The hypothalamus is involved in homeostasis of the body, thereby it is a regulating mechanism for blood pressure and heart rate. This area also actively receives input from the sense organs that inform the body of high alert so that the hypothalamus might intercede and return the body to its' "set point." The degree of arousal has been correlated with blood pressure reactivity. Blood pressure is an ideal measure that will be taken since it is a direct link to the physiological response caused by stimuli.

Blood pressure is a measurement of the pressure of blood against the walls of the arteries. This stress occurs as blood is pumped through the circulatory system and when arteries are resisting the blood flow. Blood pressure is computed as systolic over diastolic pressure. Systolic is the higher number which represents the pressure of blood while the heart is contracting to pump blood, and diastolic is a lower number that represents the pressure when the heart is relaxing between beats. The optimal pressure levels in adults 18 and over is <120 for systolic and <80 for diastolic.

The second physiological response to be recorded is heart rate activity. Heart rate activity is a measure of attention, arousal, and emotional responses. In the process of this experiment monitoring heart rate activity will be used to correlate data between changes in heart rate, stimuli, and emotional reaction. Information from tests by physiologist P.J. Lang discovered that an increase of attention accompanies a short term heart rate deceleration while arousal evokes a long term heart rate acceleration. Positive and negative stimuli cause an initial heart rate decrease but differ in the long term effects.

Resting heart rate is between 60 and 80 beats per minute. The method for measuring heart rate in the context of this experiment is a count of beats per minute in response to stimuli to be compared with the control heart rate measured after a one minute desensitization period. The variability with heart rate measure is that it is the result of various phenomena, not just a prompting stimuli. Therefore, correlating heart rate measures with blood pressure will lend to better sampling for more credible results.

The process for taking physiological measures involved the principal investigator recording results on a MicroLife monitor from outside the box. The monitor was attached to the right arm of the participant who was solely within the box and simply observed the environment from a center seated position. Once entering the room the participant was immersed in complete darkness for a one minute desensitization period. This period was aimed at gaining a control measure for heart rate and blood pressure. After this time an exposure to four different colored lights and five different locations of natural light occurred. The participant was exposed to each source, window exposure and colored light, for a 45 second period followed by a 45 second black intermission before the next exposure so as to regain a “set point.” Blood pressure and heart rate was taken after the first 15 seconds of exposure. The revealing of different colors and window locations varied by the principal investigator altering the sequence of exposures per participant to reduce variables. The sequence was recorded per subject so as to discover any necessary influences between first and last exposure. The lights were physically switched on/off from the outside, and windows were physically opened/closed by the researcher.

Finally, a survey assessed the participants’ subjective response. Though heart rate and blood pressure might rise, indicating a level of arousal, the quality of that arousal cannot be determined through physiology alone. In other words, an arousal could be from fear or from pleasure. The survey methodology will correlate between physiological data and the subjective perception to extract a connection from the two. Each question was aimed at discovering some element of perception and was primarily open-ended so as to encourage participant analysis of their experience and interpretation.

Variables

Perception is a multi-sensory process in which different modalities are interacting on the body at once. Therefore, in an environmental setting no one sense can be deemed the source of occupant response. To experientially aim for sense testing there must first be a sense deprivation that releases tension from the body. From this point different modalities can be tested for their conclusive response.

Even still, variability such as scent, texture, lighting quality, and the proportion of the space itself must be considered factors in the outcome. Other variables such as participant comfort with blood pressure monitors and relative expectancy of results are also factors. Yet, the greatest uncontrollable variable within the box testing will be variances of participants' experience, memories, and personalities that will influence the way by which he/she will respond to stimuli. The delineating problem to any design goal.

8.3 Predictions

The stimulus is predicted to be given most attention when the stimulus is considered to be having a relationship to the body. One will remember and have an affinity for those stimuli that are seemingly of importance to realizing the self in space. The assumption being that all senses are perceived with the question "what is its' relationship with respect to me?"⁹⁷ This hypothesis is based upon the perception of self and the concept of the "personal bubble."

Findings in this research process have indicated that the brain's primary role is prediction for a behavioral response. Also, the body's role as a protective agent makes one more responsive and aware of objects that might disturb one's equilibrium. The windows will best reveal this theory. Those windows that are in a direct line of vision or contact are

⁹⁷ Ana Tajadura-Jimenez, "Embodied psychoacoustics: spatial and multisensory determinants of auditory-induced emotion," 16.

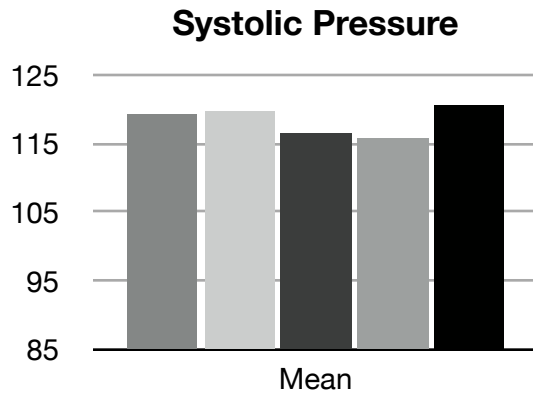
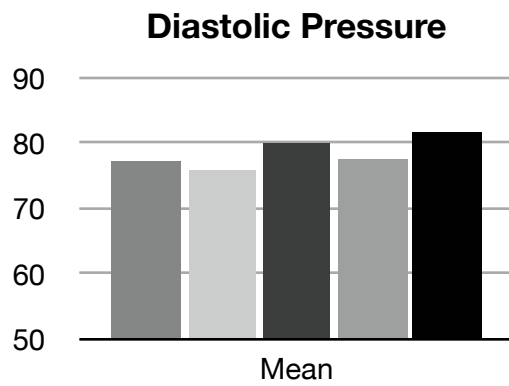
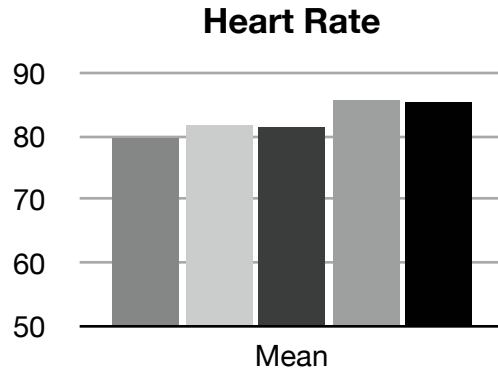
predicted to have the greatest response. The openings that are less obtrusive should lead to a lesser response.

It is also being assumed that the colored lights will result in a stronger response from the participants as it is an unfamiliar light. This supposition is based on the hippocampus discovery that showed it has most activity in unfamiliar environments. An unanticipated change should cause for attention and a heightened awareness of the space.

Upon applicable results, evidence could demonstrate the case for change and occupancy relativity. Stimuli locations could be positioned in relationship to the occupant for a desired subjective response. For a change of the mundane, an application in the design process would be to employ familiar forms that are then unconventionally interrupted so as to catch the spectators view and make them regard the scene more intimately.

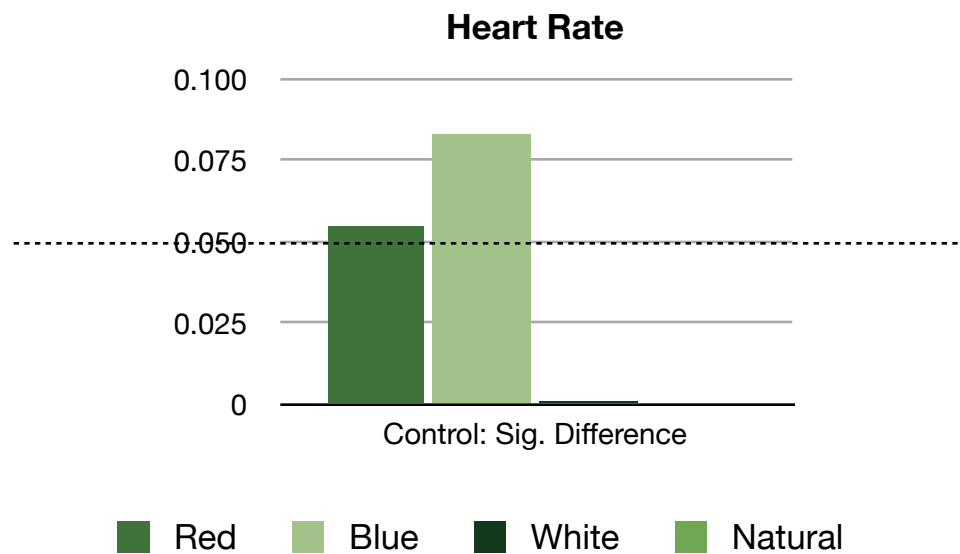
8.4 Summary of Results

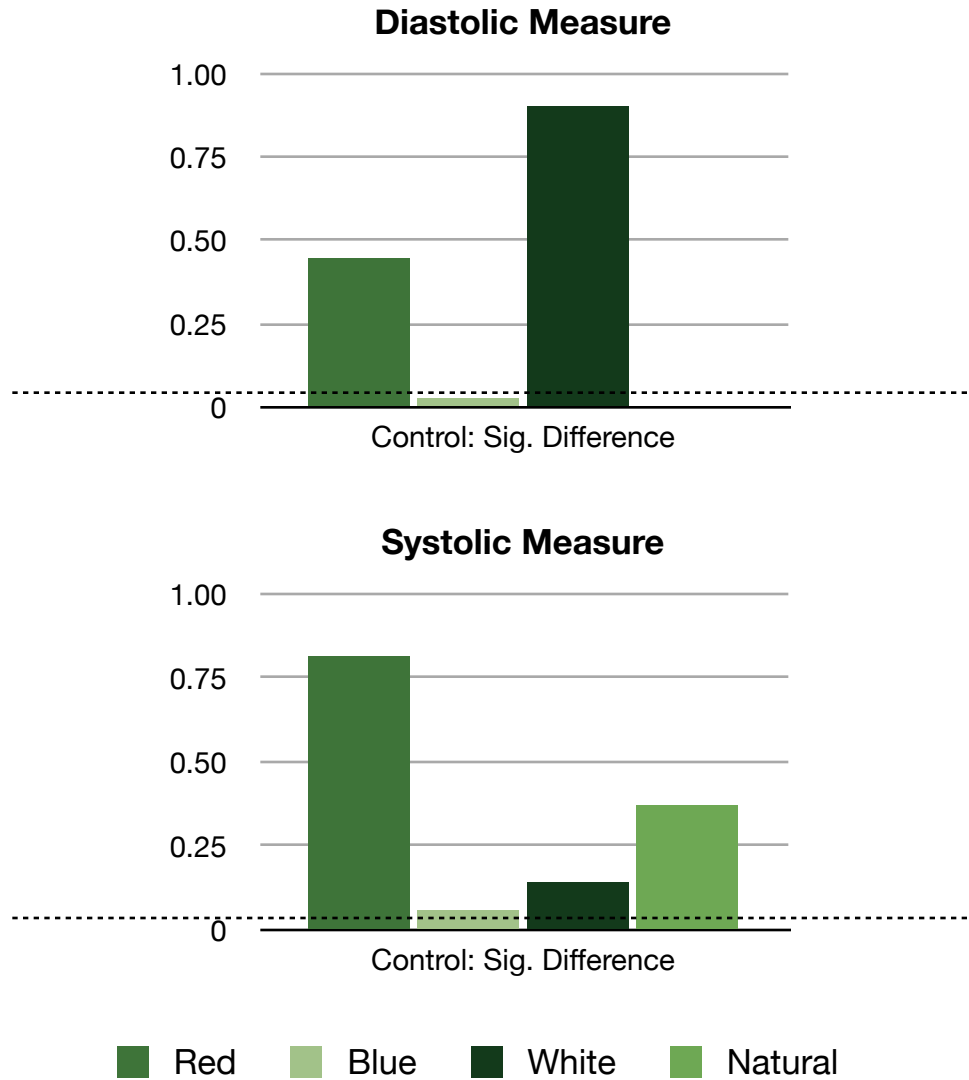
The averages for the heart rate, systolic, and diastolic pressures are portrayed in the graphs below.



■ Control ■ Red ■ Blue ■ White ■ Natural

To truly determine whether there was a significant difference between exposures the data was analyzed using typical software in the social sciences. Briefly, various statistical tests used in the sciences allow for the experimenter to determine whether the results were due to the experimental manipulation, or if instead were due to chance. Typically, statistical tests culminate with a probability value, *p-values* of less than .05 indicate that the results could have happened by chance less than 5% of the time. Accordingly, *p-values* will be provided here to indicate which groups or stimulus types differed from each other at statistically significant levels.





Heart rate was the factor that was most altered by the experiment. Numerically, on average every factor increased relative to the control for the heart rate. The starting heart rate as measured for the control variable averaged 79.7 bpm. The average heart rate slightly increased for red light (81.75 bpm) and blue light (81.5 bpm). Natural light also increased on average with 85.35 bpm and white light showed the greatest change on average with 85.7 bpm. While every measure increased only the white and natural light were significantly different from the control measure (white $p=.001$ and natural $p<.001$). Blue light failed to reach conventional levels of significance ($p=.083$) while the red light was marginally significant ($p=.055$).

Comparatively, the heart rate measure showed a total of twelve significant differences when parallels were drawn upon the entire possibilities for comparisons between lights. Natural light and white light were significantly different from the blue and red light (all p 's < .05) but when compared to each other did not reveal significance (p = .712). Blue light as compared to red light also did not show a significant difference (p = .669). Heart rate most likely revealed the greatest variances due to its' close correlation with arousal, attention, and emotional reactions.

The control averaged a diastolic pressure of 77.25 f/a (force per unit area). The diastolic pressure increased on average in every instance except for the red light exposure (75.85 f/a). Blue light had a mean of 80.1 f/a, white light averaged 77.65 f/a, and natural light increased the most with 81.7 f/a. Whereas the white and natural light showed a significant difference in the heart rate measure, natural light revealed a probability measure less than 5% (p = .001) and blue light was also significantly different (p = .026) for diastolic pressure. Neither white light (p = .903) nor red light (p = .447) reached a level of significance. In this instance blue light did show a significant difference when compared with the red light (p = .025) and with natural light (p = .030). The shift in comparisons when matched with the heart rate results draw attention on the natural light which was significantly different in both cases.

The final measure was systolic pressure, which measures blood pressure when the heart is contracting, and correlates well with the heart rate averages, especially when it comes to natural light. The control measure averaged 119.3 f/a, natural light increased to 120.6 f/a and red light also increased from the control with a marginal difference (119.75 f/a). Blue light averaged at 116.45 f/a and white light had a force per unit area of 115.8. However, the statistical system did not report any significant differences between the control measure and the varying stimuli (all p 's > .05). Though the blue light did not reach conventional levels of significance it was the closest medium (p = .060). Natural light had a p -value of .371 and white light had a p -value of .142. Red light had the greatest level of insignificance (p = .815) in the case of systolic pressure, and is also seen as not reaching levels of significance in either of the other two measures, diastolic or heart rate factors. In

the systolic analysis there was a significant difference between red and blue lights ($p=.023$). Natural light also showed two cases of probability significance when compared to the white light ($p=.007$) and blue light ($p=.009$).

The stimuli most noteworthy from the outcomes of the averages and statistics are the natural and red light. Natural light featured an average increase in all measures and was significantly different 2/3 times to the control, as revealed in the heart rate and diastolic pressure. Natural light also showed a significant difference to each colored light in between all three measures. In no single measure was red light found to be significantly different from the control measure.

Statistical Acknowledgement

The preceding results were based on a statistical program that provided probabilities of the cumulated outcomes as being reliant, credible, and valuable. The Statistical Package for the Social Sciences system is used primarily in fields such as psychology, biology, and medicine, and is less prevalent in the field of architecture and design. However, the importance of this method is to stress the fact that analyzing results as evidence for design requires proper statistical analysis for determining reliability between dependent and independent variables. While the method is unfamiliar to most architects the process should be acknowledged if a design wants to boast being evidence-based.

In research based professions the listing and narrating of probabilities and outcomes is adequate for discussion of results. What is challenging for designer's is their inclination and tendency to comprehend and learn more through visual media. The inclusion of graphs from the statistical outputs are not necessarily required in the parameters set forth by statistics but help to inform an architect of the comparisons made. The significance with using an additional medium is that it does alter a traditional way of putting forth data that some scientists may question, but the purpose is to fuse differing fields of architecture and science. Therefore, it can be proposed that methods of displaying results might soon be altered by different parameters to adjust for the synthesis.

8.5 Discussion/Analysis

In the topic of vision it was discussed that all vision is created by electromagnetic waves that allow one to perceive different colors. In this experiment the two primary colors used were red and blue. Red has longer wavelengths with lower frequencies, while blue has shorter wavelengths but with higher frequencies. The wavelengths and frequencies are also associated with level of energy. The longer wavelengths and lower frequencies indicate red would exhibit less energy, while blue would have higher energy. When compared to the control measure, there was not a single instance where the red light was “significantly different.” In only one instance, the diastolic pressure, was the blue light found worthy of attention. The fact that the color blue was the only colored light that showed a significance plausibly lines up with the frequency energy association.

It was predicted that the colored lights would have the greatest significant difference. Compared to the control, in only the diastolic pressure was a colored light, blue, significantly different ($p=.026$). White light was noteworthy in the heart rate ($p=.001$), and natural light was of importance in both diastolic ($p=.001$) and heart rate measures ($p<.001$). From research there is an increased firing rate of the ganglion cells in the retina with an increased intensity of light. The colored lights reflect more of the black environment and do not create a great contrast. White light and natural light on the other hand reveal a greater contrast to the black environment and therefore value distinction is intensified for the ganglion cells. It is also noteworthy to mention that the rods are more sensitive than cones and are stimulated by achromatic stimuli. Ganglion and rod reaction was probably most dominant in the natural light and produced more intense neural firing. Assuming that this firing apparatus stimulated other neurons for heart rate and blood pressure could be conclusive as to why natural light had the greatest response.

An interesting discovery from the experiment was the correlation with the mind-body conundrum, when comparing data results with survey results. White light was viewed by 18/22 participants as “normal” or “boring” and was associated with activities like “studying” and “working.” Data showed that on average participants heart rate increased

by 6.00. A large increase, as depicted by the heart rate, seemingly contradicts the “boring” description. The mind, or participant’s perception of the light, determined it as simply “normal,” while the body showed a significant difference in heart rate. This could be due to the contrast of light quality as mentioned, and also the observation from psychologist Douglas Fryer that a familiar environment is not as subjectively exciting as a new environment. Also, since the hippocampus encodes and retrieves memory from new events it would be predicted that though this white light had a “significant difference” it might not be best remembered if participants were to be later asked about the experiment.

Another mind-body example is the red light. The red light had the most universal reaction from participants. Many agreed that the red light was “stressful” and caused them to be “angry.” The common activity that people associated with the color was “partying.” Yet the body showed no significant difference to red light in any measure. The media tends to convey that red makes one mad, and bars do commonly feature red lights. So while red may speak to the mind it may not speak to the body as much. This relays back to the beginning when the question was posed about which piece, mind or body, does the interpretation?

Participants were also briefly asked to rate their favorite and least expected window position. This question was aimed at exploring the idea of proxemics in architecture. It was predicted that those stimuli which would gain the most attention would be those which were nearest to the body. Also, it was assumed that the windows which were in a direct line of vision would have the greatest impact. The survey results showed that 64% of people favored the window above, and 60% found the window above to also be the least expecting. This supports the idea that unfamiliarity prompts the greatest response. The other positions varied with reactions. The favored position for the front window was 18%, left high 8%, low right 5% and behind 9%. The least expected ranged with the front, 0%, 18% left high, 14% low right, and 9% behind.

The closest windows to the participant were the low and high openings. Yet these showed little favoritism. This could be in part due to human territoriality. As predicted stimuli close to the body would elicit the greatest reaction, and though there wasn't a positive reaction, it does reveal something about proxemics. As mentioned the body wants to keep protection and balance, the nearness of the openings could have posed a discomfort to this balance.

The front window was the only direction which had a vote of zero for expectancy. Once again tying into the familiarity concept. Also the visual angle at which it is presented could have had an impact. In every other circumstance the body had to direct itself to the opening to see the exposure. The redirection of the head is a whole-body sensory design manipulation and could have been a factor into the results.

The data conveyed that differing environments do have varying impacts on the physiological response. The evidence supports the significance of natural light in architecture from more than just instinct. The survey results revealed the truth that no man perceives a space the same. Experiences, memories, personalities, and cultural backgrounds were all factors in determining participant's response to stimuli.

Chapter Nine: Design Applications

9.1 Case Study

There are currently no examples of a facility being systematically designed based on an accumulation of neuroscience data. The examples that have been inserted into this dissertation are conclusions based on objective data that result in recommendations for architectural applications. The initiation of a design based on systematic intervention from architects, neuroscientists, and researchers is a project of the future since more data is needed and an ordered programming based on the multiplicity of results has been created. The closest example of an institution being developed based on objective data are those places designed based on evidence-based methodologies. Some conclusions from evidence-based design is accumulated from observations, surveys, and case studies. However, in addition to these processes evidence-based tactics also gather information from science, experiments, and objective physiology to discover the best means for a design outcome.

The most notable of facilities to be incorporating evidence-based design methodologies are healthcare establishments. EBD began in the healthcare department as a tool for scientists and practitioners to accumulate clinical data for the best treatment of their patients. What emerged was an attention to architectural detail that influenced a patient's psychological and physiological healing process.

The Pebble Project came about as an initiative to create healing environments that would improve the quality of care, safety, health, and operational duties of healthcare facilities.⁹⁸ Healthcare organizations and professionals participating in the pebble project revealed post-occupancy evaluations and data that have been made available for influencing the transformation of medical centers for improved healing accommodations. The results have been valuable expressions of how architectural design can influence occupant well-being.

⁹⁸ "Pebble Project," The Center for Health Design, accessed February 16, 2012, <http://www.healthdesign.org/pebble>.

Bronson Methodist Hospital

The Bronson Methodist Hospital in Kalamazoo, Michigan is a Pebble Partner which in 2000 began a \$210 million complex based on evidence-based design methodologies.⁹⁹ Researchers for the Pebble Project are still currently collecting data for the recently completed project. The results which are filtering through is proving Bronson Methodist Hospital as a leader in evidence-based healthcare design.



Figure 9.1 Bronson Methodist Hospital (ArchRecord)

In its' new facility Bronson incorporated single-bedrooms with windows as the standard, making the hospital among the first in the nation to incorporate private patient rooms. This lead was embarked by it's director of epidemiology and infection control, Richard Van Enk, who through research and literature reviews hypothesized that patients are best healed when they occupy their own space. The results proved this hypothesis when a comparison between Bronson's old multi-rooms and new single rooms, studied over a four year period, showed that the hospital-acquired infection rate decreased by 11%.¹⁰⁰ In addition, the single-room implementation reduced patient transfer costs, due

⁹⁹ "About Us," Bronson Health, accessed February 12, 2012, www.bronsonhealth.com/AboutUs/FacilityDesign/page3218.

¹⁰⁰ Ibid

to roommate problems and infection control issues, by \$500,000 per year when compared to the old facility.¹⁰¹ Thus lies the argument for the upfront costs in comparison to the overall savings of a single room design.

In privacy there exists a freedom of behavior and activities that are otherwise influenced by a roommate. Doctors noted that patients seemed to prefer the single-patient rooms because of the sense of autonomy it provided. These results, surveyed by Bronson practitioners, strongly support the psychological space discussed by Edward T. Hall. Hall mentioned the idea of the “personal bubble” and how an invasion of a space that one has deemed psychologically theirs results in discomfort. That discomfort would unquestionably play into one’s perceived healing. The perception of healing, as influenced by one’s environment, develops through the interpretation of the sensory information. Likewise, such physiological basis such as circadian rhythms, light and noise sensitivity, and temperature all affect how one feels physically. In the private setting sensory stimuli can be individualized and controlled for preference and healing.

In 2007 Bronson opened the new Neonatal Intensive Care Unit which converted a 45-bed nursery into private NICU rooms. The NICU was given significant attention in the conceptual phase because of its’ role as the first influencing environment on a baby’s sensory organs. The decision for the private NICU rooms was entirely evidence based. The hospital directors gathered evidence from leading hospitals and literature reviews upon making a decision.¹⁰² A leading study for these private rooms was research done by Doctor Stanley Graven and his analysis of environmental design’s correlation with newborn neurodevelopment.

The chemosensory exposure was observed and found that amniotic fluid, breast milk, and the mother’s sense is most soothing to a newborn, whereas noxious odors

¹⁰¹ Habib Chaudhury, Atiya Mahmood and Maria Valente, “The Use of Single Patient Rooms versus Multiple Occupancy Rooms in Acute Care Environments,” *Coalition for Health Environments Research*, January 2005, accessed February 10, 2012, http://www.healthdesign.org/sites/default/files/use_of_single_patient_rooms_v_multiple_occ_rooms-acute_care.pdf.

¹⁰² “About Us (Bronson Health).”

(cleaning solutions, alcohol, etc.) showed an unhealthy increased heart rate and slowed respiratory rate. Stanley Graven and his team also discovered that when infants were exposed to inappropriate noise levels and direct ambient light it impaired the development of the brain.¹⁰³ Bronson reacted with private rooms that allowed for individual dimmer controls, silent alarms, and individualized thermostats. Bronson Methodist Hospital is now one in less than twelve hospitals in the country to have a private NICU design.



Figure 9.2 Bronson Private NICU (Bronson)

The Bronson's Children's Center was planned with a multi-sensory environment methodology. The design includes a complexity of colors and murals that cover the walls. The nurses' stations are built at child's eye level accommodating the visual angle of a minor. There are also activity centers filled with toys and books that cater to those patients with an extended stay.¹⁰⁴ This activity center is significant because it caters to an active experience. The study by James Gibson demonstrated that the experience through active touch is most stimulating and best remembered with a 95% recollection rate. The combination of interior decor, textures, and light also has the potential to influence the healing of a child because of the evidence supported through neuroscience that the

¹⁰³ S. Laudert, et. al., "Implementing potentially better practices to support the neurodevelopment of infants in the NICU," *Journal of Perinatology* 27 (2007): 90, accessed February 12, 2012, doi: 10.1038/sj.jp.7211843.

¹⁰⁴ "Bronson's Children's Center," Bronson Health, accessed February 12, 2012, <http://www.bronsonhealth.com/FindALocation/Locations/page1854>.

limbic system, region in the brain for consolidating information, is most reactive to a combination of stimuli. Evidence from research on children with disabilities also supports a multi-sensory environment when a study by several scholars recorded that handicapped children gained new skills at a rate of .81 per multi-sensory visit. Those skills included, but were not limited to, an awareness of self, social behaviors, and object manipulation.¹⁰⁵



Figure 9.3 Bronson Children's Hospital (Bronson)

The healthcare facility not only considered a multi-sensory environment in terms of child care but incorporated variations in sound, light, color, and texture throughout the complex. Bronson used glass metal/glass curtain walls, precast concrete, wood finishes, tiling, and carpeting to vary the textures being used.¹⁰⁶ The incorporation of large windows and skylights permeates natural light throughout the building while at the same time casting playful shadows. Despite the awareness Bronson may have had toward the physiological effect of light and shadow, their design choices correlate well with the biology of visual cells and action potentials being created through contrast and edges as discovered by Professor Heeger in his research of ganglion cells.

¹⁰⁵ S. Houghton, et. al., "An empirical evaluation of an interactive multi-sensory environment for children with disability," *Journal Of Intellectual & Developmental Disability*, 23(1998): 267.

¹⁰⁶ "Bronson Methodist Hospital," *Architectural Record*, accessed February 13, 2012, <http://archrecord.construction.com/projects/bts/archives/healthcare/bronsonmethodist/specs.asp>.



Figure 9.4 Bronson Light Aesthetics (Bronson)

Bronson's multi-story atrium contains trees, garden paths, water features, and an abundance of natural light. The incorporation of nature into the renovation was based on the variety of evidence and studies supporting the biophilic restorative hypothesis. The belief that nature is psychologically healing has been in theory for over 100 years, particularly in western and asian cultures. The psychological benefit is that natural scenes help to reduce stress which promotes healing. The incorporation of biophilia in healthcare can be costly in development and maintenance, and so during the early 1900s inclusion became scarce. However, evidence behind the theory of nature's healing effects have began to influence architects and developers to rethink how hospital design is fashioned.

In an experiment by Roger S. Ulrich 120 participants were randomly assigned to a recovery period accompanied by either a natural setting or built setting. The results recorded physiological measures such as blood pressure, heart rate, and muscle tension and discovered that those exposed to the natural setting recuperated faster and featured

lower activity in the sympathetic nervous system.¹⁰⁷ Evidence-based physiological studies, like the one conducted by Ulrich, are bringing factual information to hospitals like Bronson who are recreating based on the best restorative information available.

The hospital's atrium is also unique because of its' aesthetic contour. It has been said in theory that a curvilinear edge is more "soft" or "pleasing," than an angular edge. While Bronson may not have designed based on this prophecy the evidence towards a physiological impact of the curvilinear contour is existent. The fMRI scans conducted by Harvard's Moshe Bar exist to demonstrate that perhaps the curve is better received than the angle as interpreted by the brain. As mentioned, his results showed a higher activity in the amygdala, center for perception of fear and arousal, with exposure to angular objects. The growing research into curvilinear objects being more comforting than angular objects makes the architectural decision for the atrium's interior a step in the right direction.



Figure 9.5 Bronson's Atrium (ArchRecord)

¹⁰⁷ Roger S. Ulrich, "Health Benefits of Gardens in Hospitals," (paper presented at the Plants for People Conference, Netherlands, 2002) 4, <http://greenplantsforgreenbuildings.org/attachments/contentmanagers/25/HealthSettingsUlrich.pdf>.

The Bronson Methodist hospital is also advantageous in its' ease of navigation as designed through evidence-based principles. The design focused on shorter traveling distances for patients with incremental seating along the way for reduced stress levels. There are also touch-screen information kiosks implemented at every main entrance for a direct map to a desired destination.¹⁰⁸ Furthermore, the entrance's proximity to the open atrium provides lines of sight and view enhancing possibilities to vertical circulations, and expectations of directional routes for the levels of above. The designers also did not steer far from a simply stacked floor plan, which as shown through the experiments triangulating cognition, neuroscience, and spatial syntax by Dr. Christoph Holscher supports an ease of way-finding.

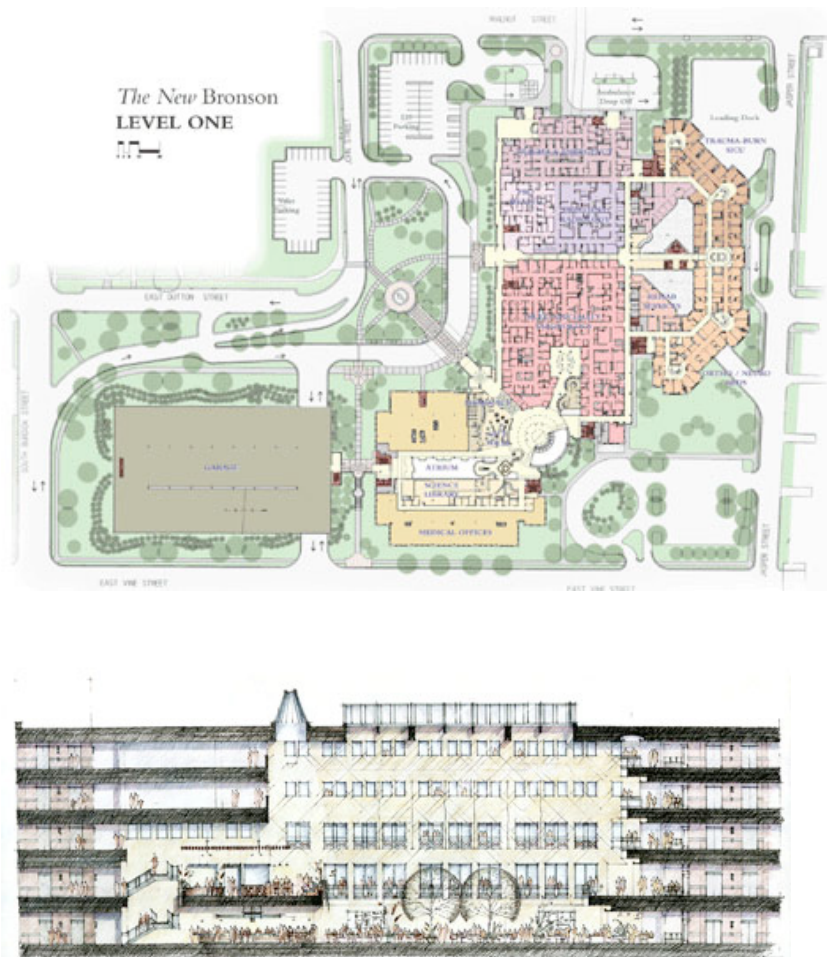


Figure 9.6 Bronson Plan & Section (ArchRecord)

¹⁰⁸ “Evidence-Based Hospital Design Improves Healthcare Outcomes for Patients, Families, and Staff,” Robert Wood Johnson Foundation, accessed February 18, 2012, <http://www.rwjf.org/qualityequality/product.jsp?id=21765>.

After the new building’s completion the hospital was awarded numerous awards, gaining it prestige and national recognition. The hospital’s market share increased by 1% between 2000 and 2001 which led to over 1,000 more admissions. Development also reduced nursing vacancy rates so that in 2001 they were recorded at half the State average.¹⁰⁹ Evidence-based design not only increased the quality of care for patients, but turned over results for the investor and satisfaction of the staff.

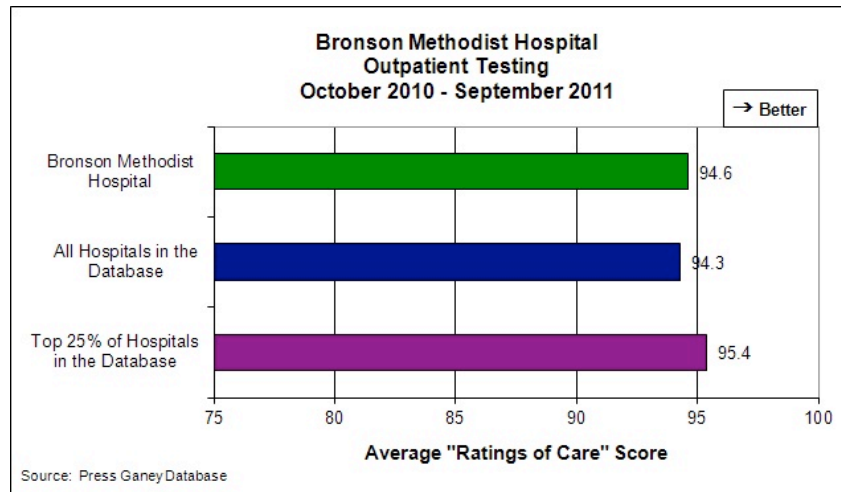


Figure 9.7 Bronson Outpatient Ratings (Bronson)

Bronson Methodist Hospital has taken evidence, data, and observation from research, reviews, and case studies and has created a state of the art complex. The Bronson healthcare facility has implemented architectural design techniques on the basis of suggestive information, recommendations, and examples rather than a mere duplication of a predecessor. The compilation of information into a program has been the work of many who foster the value of evidence-based design in the belief of its’ contribution to the well-being of patients and staff. While the statistical results are still being accumulated, patient reviews, workforce, and facility design are receiving honorary awards, confirming this evidence-based design outcome a successful example of an ideal healthcare design. The following is a list of a chosen six of the 55+ awards and recognitions that speak to perception and the relationship to space in which the Bronson Methodist Hospital has achieved.

¹⁰⁹ “The Hospital Built Environment,” U.S. Department of Health & Human Services, accessed February 16, 2012, <http://www.ahrq.gov/qual/hospbuilt/hospenv.htm>.

Thomson Reuters 100 Top Hospital (2006,2010, 2011)

Awards the top performing hospital based on “patient safety, length of stay, expense, profitability, patient satisfaction.

HealthGrades’ Outstanding Patient Experience Award (2009, 2010, 2011)

Through Hospital Consumer Assessment of Healthcare Providers and Systems survey data discovered Bronson Methodist Hospital as in the “top 15% of hospitals in the nation for patient satisfaction.”

Distinguished Hospital for Clinical Excellence from HealthGrades (2009, 2010, 2011)

Bronson was placed in the top 5% in the nation for clinical quality. The study estimated that 150,132 lives could have been saved and 13,104 complications could have been avoided over a three year period if patients were treated at hospitals that possessed the same caliber and quality of Bronson.

Consumer Choice Award (2003-2011)

In the National Research Corporation Survey consumers recognized Bronson Methodist Hospital as the best hospital in the Kalamazoo area based on overall quality, image, and reputation.

Interiorscape Magazine’s Best Project Award (2001)

Bronson Methodist Hospital became the only hospital facility honored with this award that recognizes garden-scapes in architecture.

Associated Builders and Contractors Construction Award (2001)

An award recognizing excellence in design and construction.¹¹⁰

¹¹⁰ “Awards & Achievements,” Bronson Health, accessed February 12, 2012, <http://www.bronsonhealth.com/FindALocation/Locations/page1854>.

9.2 Prototype Design

Research has made obvious that the environment shapes, alters, and modifies the brain and how one perceives the world and themselves. The concluding portion of this dissertation will seek out architectural applications for the evidence.

So far scientists have focused neuroscience and evidence-based tactics mainly on healthcare and educational institutions. While these establishments are in need of intuition, intellectual, and scientific data for the best design outcome so is everyday architecture that encompasses most of our being for most of the time (retail, workplace, residential, etc.). The challenge comes in gathering a broad amount of information from a limited number of studies and generalizing that information for a programmatic application. If neuroscience and architecture want to prove value in design the research and recommendations must go beyond paper and into building applications.

Evidence-based design is not just possible in new construction. The process of basing design decisions on research can happen in large or small buildings, and within new construction or a renovation. Renovation projects do however tend to pose some additional constraints since the parameters, and materials have for the most part been pre-determined. However, innovation through data still can occur.

After having compiled material from neuroscience, perception, cognition, and evidence-based information I have attempted to put forth a renovation to an existing project I designed in the 500 level studio. The project is a visitor's center located in the Jiangsu Province of China. Originally, the building was created based on intuition, site analysis, and my intellectual development over the years I spent in architecture school. Yet now there exists another realm of reason and influence, and that is the science of an occupant's physiology and how that plays into the perception of space. Thus far this document has been about gathering information, learning, and discovering another method and tool for design. The purpose for the revisit of my previous design is to

explore what I would have done differently based upon the knowledge I now have. The hypothesis is that some, but not all, aspects will change, demonstrating that architecture can be influenced by science but is still an art that possesses qualities of intuition and creativity. Typical of design studio the program was produced through research and case studies that led to a proposal of rooms, areas, circulation, and other spatial requirements. Upon review my proposed program became as follows:

Program

Basic Information:	
Occupancy Type: A-2 Assembly with 50+ occupants	
Type of Construction: 11-A: 1-hr fire resistant	
Building Height: min. 11'	
Functions	Area (Sq. Ft.)
Level 1	
Snack Shop	382.7
Implemented for the quick grab of a drink, picnic items, medicine, bug spray etc. that may be needed or had been left behind by visitors traveling long distances.	
Office	129
This space is meant for the storing of appointment books, activity calendars, human resource department, and the day to day activities involved with management.	
Bicycle Rental Shop	2298
The visitor center is on the outskirts of a busy city whereby most visitors will be arriving by train. The travel distance is long enough that visitors will want to spend an entire day in the 100+ acre park in the presence of fresh air and nature. The bicycle rental shop allows for exercise and exploration of a scenic landscape.	
Bicycle Repair Shop	125.6
Predictably bicycles will need cleaning and new parts after wear and tear of repeatable use.	
Retail Space	1993
Weather is not always predictable and leisure for people differ. The retail space is meant to provide the coat or shorts that were not brought, and/or provide another form of leisure for those who have a limited tolerance for an outdoor lifestyle.	
Loading Dock	211
An accommodation for the loading and unloading of ordered items from the snack shop, retail stores, and restaurant.	
Mechanical/ Storage	448
Provided for janitorial necessities and electrical breakers.	
Total Area Level 1	5587.3

Program cont.

Functions	Area (Sq. Ft.)
Level 2	
Lobby	288
This space is meant to act as a starting point for visitors, to orient themselves and become familiar with the facilities program.	
Orientation Space	1339.6
This area is a gathering space for group visitors on guided tours and those visiting individually to gain an understanding of the park through maps and activities offered.	
Gift Shop	430
Since most visitors will view the park as a day's outing from the big city it will be a trip remembered. A gift shop is necessary for souvenirs and to communicate what the center and park is conceptualized for.	
Restaurant	1802
This space features both indoor and outdoor seating and is another means to provide for the needs of visitors. Besides the travelers from the nearby city district there are also local residents who would be attracted to the center for its' dining amenities.	
Kitchen	1072
Restrooms	
men (2 stalls, 3 urinals)	169
women (3 stalls)	257
Total Area Level 2	5357.6
Accessory Space	2900
This space includes circulation and covered seating that is less defined but must be included in the calculation of total area square footage.	
Total Area	13844.9

Concept

The site is conducive to meditative and exploratory interactions between man and nature. Most visitors to the location will be traveling an hour by train from the second largest commercial center in East China. The city does not boast much green space, thus this park has become a sanctuary from a bustling metropolis. Climatically, Nanjing, the capital of the Jiangsu Province, has a hot and humid climate with high summertime temperatures and damp conditions throughout the year.

Month	Mean Temperature °C		Mean Total Precipitation (mm)	Mean Number of Precipitation Days
	Daily Minimum	Daily Maximum		
Jan	-1.6	7.0	29	7
Feb	0.0	8.4	48	9
Mar	4.4	13.5	69	11
Apr	10.3	20.1	87	12
May	15.7	25.3	96	10
Jun	20.4	29.0	159	11
Jul	24.6	32.0	188	13
Aug	24.2	32.2	124	11
Sep	19.1	27.2	95	10
Oct	12.6	22.1	60	8
Nov	6.1	15.9	56	8
Dec	-0.1	9.7	25	6

Figure 9.8 Nanjing, Jiangsu Province, China Climate Data (WorldWeather)

The building was created as a reflection of its' site, with organic lines that fashioned the curvilinear structure. The structure then became multi-purposed serving as a figure embracing its' setting and also a form for sustainability. The curvature creates a natural shading device for the more populated north end of the building with its' east and west wings acting as fin barriers. The building is also narrow enough to penetrate natural light and views to the deepest corners. Natural ventilation was a dominant driving force in the design ensuring that on appropriate days nature would dominate mechanics.

Since the visitor's center is meant for the user to experience the park, not necessarily another building, the architecture was conceptually constructed such that circulation allows for the park to be experienced at different levels. The progression from the lobby through the exhibit and arriving at the deck the building slopes upward. This alignment is meant to take a visitor from below the trees, to within the trees, and finally above nature such that exploration becomes multifold. The ramping of the exhibit is also meant to encourage movement with anticipation as an occupant foresees reaching the highest point. The orientation deck is to serve as a final arrival point that maximizes views of the park to serve for a visual mapping and expectation of the park's recreation.

As the design progressed details such as materiality, light, and shadow were manipulated. The harsh sun angle coming from the south end adjacent the front facade was played with by a sun screen that not only shades the interior but creates shadows that support a 3-dimensional depth. The structure is comprised of a steel frame with poured in concrete and an exterior stucco finish for contrasting textures and visual aesthetic. Ceilings differ from suspended gypsum board, exposed steel beams, and a wooden trellis that varies spaces with different programs. Each program is meant to encourage a different behavior, whether it be an exhibit to elicit anticipation or dining to foster community, and so dimensions and heights were altered accordingly.

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Original Images Insert 11x17

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Intuition Preceding Science

As mentioned, the curvilinear structure was in response to the organic environment in which it is oriented. As the form developed I began to use what I have learned of geometry, in order for the curves to properly intersect and be visually balanced at either end of the structure. Finally, as part of the architect's training, I devised and tested the orientation through shading analysis, so that the curve would naturally form "fins," shading devices, for the more populated north end of the structure. While the shading analysis can be argued as a piece supportive of evidence-based design as it relates to climatic data, primarily the composition was created without any influence from scientific data.

Beyond the environmental response the curve also spoke to the design sense of "peacefulness" "harmony," and "tranquility," that I, as the designer, sought to represent in this park setting. This illustration came as part of my intuition that curves are more amicable than angular structures. However, to simply say my design is tranquil because I used curves is presumptuous and assuming. Yet, a review of the literature shows that in fact curves are more harmonious and better received by an audience. The experiment previously discussed by Moshe Bar and his use of fMRI scans that revealed greater activity in the amygdala when a participant was exposed to novel and angular forms is supportive evidence to the curvilinear design choice being indeed more congenial. Had I known, I could have further argued the subjective interpretation of curves being more harmonious through supportive physiological data such as this one reviewed.

The function of the "Visitor's Center" and its' locality within a park speaks to the designer's mind of the play with natural light. In an attempt to stick with the original concept of being within nature rather than within building I created a floor to ceiling height glass curtain wall along the north facade to allow for natural light to penetrate the interior, and maximize views to the park. The south facade has smaller openings to control the intake of light and heat due to the direction and low sun angle in the Jiangsu

Province. This direction was under the belief that natural light would encourage a more stimulating environment.

After having conducted a literature review and the lighting experiment I have realized an argument for having large windows and natural light besides the remark of “I want views,” or “I want natural light.” In experiments conducted by such authors as sociologist E.O. Moore and environmentalist Roger S. Ulrich natural views were proven to aid in healing, stress relief, and composure. My concept for a tranquil place away from the city and the design choices that followed, such as large windows with scenic views, would have been better supported had I highlighted these objective studies.

Natural light is an important topic in design studio. As students we learn about the effects of natural light, like its psychological healing power and sustainable profitability. Thus, I designed based on this knowledge. An increase of natural light could mean I lower the costs of electricity and occupants would better enjoy my building. From the experiment I conducted the question was whether this hot topic of “natural light” was actually “better.” The results showed a favoritism towards natural light because of its’ significant difference from the control variable in measure of the heart rate, indicating arousal, attention, and plausibly emotional reaction. The surveyed results also showed a favoritism towards natural light with 18/22 participants voting the natural light as most pleasurable. Yes, it accommodates building performance and the psyche but it also has an impact on the physiology of man. Circadian rhythms are in response to natural light, neural action potentials and firing rates for perceptions react to an intensity of light, and heart rate and blood pressure also respond to exposure. Thus, architecture can play with light and argue its importance beyond the intuition of designer philosophy.

This visitor’s center also manipulates light through the use of shadow play. As mentioned the curvature form acts to shade the high-occupancy zones. There is a trellis system over the outdoor dining area that not only provides shade for guests below but also

reflects the structure through shadows. A third element is the shading screen on the south side of the building. The screen not only provides shade for the interior but visually connotes three dimensionality through the shadows it casts. The form was created primarily for this purpose of being visually appearing. At the time I did not have any scientific sense of action potentials and neural firing rates. If I had I would have argued to my reviewers that the screen is also an element of visual attraction as perceived by the brain, since ganglion cells respond to the intensity and contrast of light. Postulating a heightened awareness of the building from an influence of light and shadow.

Once the conceptual framework was developed the materiality and construct-ability had to be conditioned. I sought to create a neutrality of materials and maintain a relatively low-stimulating environment to encourage the idea of tranquility. The defense of the design decision was to not take away from the natural environment. From an evidence-based approach the neutrality of materials could be argued as an encouragement for the release of serotonin. Serotonin stabilizes one's mood and is released during meditative and low-stimulating activities. Once again, a neuro-scientific application for architectural design choices so as to fashion a particular concept beyond subjective methodologies.

The Potential with Science as a Tool for Design

Architects are educated with a dominant predisposition for the visual sense. Yet from science and other objective methods it is becoming clear that the brain is most reactive to a combination of stimuli. An integrated environment involving vision, smell, and touch would cause for a neural response in the hippocampus. This hippocampus consolidates information, encodes new perceptual information, and though does not serve to store memories it does encode new memories. Thus encouraging the value of multi-sensory environments as effective design mediums for perceptual influence.

Memories are formed from a stimulation of neurons in a particular pattern that recollects a past experience. Those firing patterns are the result of a stimulus, and that stimulus is excitatory and best received with a combination of sensory input. Furthermore, memory is strongly formed with a relatable identity. From many studies on way-finding and exploration it is becoming undeniable that active observation and involvement puts forth a better retained experience.

The failure of the original design for the visitor center is that it is primarily based on the visual sense. The curvature, light, and even incorporated textures from such objects as the trellis and sun screen all appeal to the visual sense rather than being an active integration with multiple senses. If indeed, my concept is a center for occupants to experientially explore their environment and be a memorable place of refuge from the city then a multi-sensory environment should have been better developed.

A designed environment can only create for the potential cognitive effect because each visitor will perceive the center differently based on past experiences and individualized interpretations of sensory information. Another challenge is that much sensory input is lost through the neural travel to the brain. Thus, in order to strengthen the awareness between self and building, routine behaviors need to be interrupted with novel tasks that extracts a reactive mind. The following images and diagrams are a series of renovations and developments that are based on evidence towards the creation of a better design through active sensory integration and occupant encounters. While each space featured incorporates a level of multi-sensory design the categories for discussion are divided based on the individual senses to encourage an in depth understanding of how each sense could be fathomed in an architectural application. The following table has been developed for a general understanding of how intuition/intellect, data reviews, and the personal experiment conducted in the research portion of this document has contributed to the design development.

Prototype Design Applications Table

Intuition/ Intellect	Evidence-Based	Personal Experiment
<ul style="list-style-type: none"> • curvilinear design for sense of “peacefulness” • orientation analysis for shading & natural ventilation • natural light • maximize views • play with shadows • neutrality of materials • texture exemplified through structure (beam, columns, etc.) • curvature slopes towards destination (orientation deck) • dimensions of spaces vary based on program’s desired formality 	<ul style="list-style-type: none"> • angular objects influence greater activation in the amygdala • natural views aid in healing & stress relief • serotonin released during low-stimulating activities • memories are formed with “mega-patterns”(wayfinding) • hippocampus is active with new environments • localization and association a key factor in perception • “law of proximity” • “law of good figure” • combination of stimuli causes for neural response in hippocampus • ganglion cells respond to intensity level of light • visual angle of $x < 0.5$ degrees goes directly to cones (detail, color) • intensity of sound correlates with increased density of molecules in air (reverberation quality) • public distance, $x > 12'$, sense of smell & touch is lost • active touch scores higher for recollection than passive experience • higher density of receptors located in the fingertips • smell is directly linked to the limbic system (center for memory, emotion, behavior) 	<ul style="list-style-type: none"> • natural light showed a significant difference in diastolic measure • natural light showed a significant difference in heart rate measure • 18/22 survey results favor natural light • white light showed significant difference in heart rate measure • 0/22 participants favored white light • blue light had a significant different in diastolic pressure • 14/22 people favored window from above

Vision

Though the visitor center's strength currently lies in its' visual appearance, the appreciation of its' design and detail has not been fully reached when considering what has been learned from science. From an analysis of perception it has become clear that people first interpret objects as a whole and secondarily about the detail it holds. Perceptual grouping occurs as a result of things being in close proximity and moving in the same direction. In light of these principles the design has been enhanced for the creation of visual boundaries that clarify way-finding.

Primarily through vision one navigates and assumes direction making way-finding important when considering the visual sense. The control of way-finding is significant through both subjective and objective understandings. The brain must learn the new environment through neural firing and creation of new patterns, which has been previously coined "mega-patterns." After the first exposure to an object or element the neural pattern that was created will "re-fire" upon a second visit. This perceptually orients a viewer and gives predictability to way-finding. Thus, the incorporation of architectural landmarks and boundaries help inform the occupant about direction.

Originally the design featured a curvilinear form as a response to the organic setting it resides. However, what can be further reckoned is that the curvilinear design begins to aid as an architectural landmark allowing the occupant to view either end of the structure for orientation purposes. To further the design a response has been to incorporate features such as an extension of the deck's roof line for maximum height and dominance in elevation as an indicator of a final destination point. Also, lifting the lobby's skylight above the relatively flat roofline serves as an indication of an arrival space. The incorporated fountain in the rear additionally supports the "mega-pattern" concept through not only visual recollection but also the sound that will reverberate from the source.

Vision in this design proposal is also strongly considered as it relates to an occupant noticing detail. In the design review I recall that no critic had noticed the detail I had put into the ceiling. At the first level the beam structure is exposed and the outdoor trellis system is actually an extension of the hidden beam structure from within the restaurant. As discovered the cones are responsible for detail and color vision. Yet the cones are far fewer than rods, and so locations of objects must be manipulated in order to attract the attention of the cones. When an object is located in a direct line of sight, less than or equal to 0.5 degrees, the image is routed to the fovea containing the highest concentration of cones. In response I have reshaped those detailed elements which require attention to be within the line of sight of a viewer.

The play with shadow and light has been a constant driving force in the development of the visitor's center. Whether it be intuition, intellect, or evidence, vision begins with light and a light's direction and origin can vary an experience. The concept was that light and shadow would enhance the visual depth and experience of the building. So while designer's can manipulate this natural feature it can be further supported through a scientific review. As discovered the ganglion cells are responsible for carrying information to the brain and feature an increased firing rate in response to the intensity of light. Thus, a greater intensity level of light, light vs. dark, will fire action potentials for a conscious awareness of a designed space.

Vision Insert 11x17

Vision Insert 11x17

Vision Insert 11x17

Texture

Upon completion of an assorted and varied textures there begins to emerge a unique quality to each space and an overall higher quality of design. Previously, the design was a visual aesthetic with little excuse for the occupant to actively engage with the building. Variations in texture were chosen as a method for enhancing design as it relates to integrative human responses. The incorporation of actually feeling textural change and interactive mediums require a physical exploration that is not only working to heighten an awareness of the spatial context through multiple sensations, but is also effecting the plasticity of the brain through novel tasks and memory formation.

The concept of novelty is also significant as it relates to associations. A single texture will lose its' significance if not met with a new medium that requires a higher functioning of mental awareness. Therefore, while staying in tune with the neutrality of materials from the original concept, constituents are now varied for originality. Finally, a minimizing of the separation between self and object gives a stimuli power since those things which are upon or adjacent to ourselves are most often dominant. Hence, an integration of elements that require active involvement, such as the wishing pond and stepping stones necessitates a conscious awareness. Even visual integrations, like the entry way shadows and the proxemics of plant placement, begin to formulate a presumed textural quality.

Texture Insert 11x17

Texture Insert 11x17

Smell

Olfactory stimulation is often disregarded because of the ambiguity it poses to the architectural designer whose goal is too often to visually appease an occupant. However, from the scientific review it is made clear how important the sense of smell is to triggering strong reactions, memories, and emotions. The original design, like much of modern architecture, is missing this sensory component and so an evidence-based application for the sense of smell has been incorporated.

Vegetation has now been featured within the building and along the building's edges to enhance the multi-sensory environment. The plants are strategically located so that when naturally ventilated the aromas can fuse through the structure. Material choice has also been manipulated for an olfactory perception. The exterior walkways and deck are of an older rustic quality that when paired with the smells of nature exemplify a garden interpretation. Upon entering the lobby space the nose can also be a detector of programmatic function, where on one end the dining room will elicit smells of food and refreshments and the other a more aromatic fume ventilating through the exhibit hall.

What is also significant to reiterate is the fact that the hippocampus is best responsive to novel scenes. Material's textures, visual planes, and acoustic characters are often quantified to some degree in projects, so by instilling a sense of smell into spaces the scenes and experiences take on an innovative character.

Smell Insert 11x17

Sound

As discovered sound results from the patterns of air pressure changes with an increased intensity correlating with increased density of molecules. The perception of sound is also significantly tied into the localization and association of the sound itself. Being able to detect different sound sources informs an occupant about origin and the self in relationship to the building and program. In the original design the sound quality is unchanging from space to space because of the same materiality that draws out a conformed reverberation quality that is interpreted similarly by the auditory apparatus. The importance of the new development in regards to audition is that spaces begin to become varied based on sound for a diversified experience with the architecture.

Texture of materials begin to play into these sound qualities. Material choice has the potential power to influence a behavior from the sound quality it evokes. The perception of loudness, an indication of activity, is signaled by the rate of neural firing that is directly related to the vibration quality. Thus, in the exhibition hall I incorporated carpeted flooring for sound absorption and in the dining hall a reflective quality to encourage social gathering. The spaces materials and barriers begin to audibly respond to the occupant informing about size, activity, and voids that heighten an awareness of man's role within a space.

Sound Insert 11x17

Sound Insert 11x17

9.3 Evidence-Based Design Evaluation

The nature of this thesis is evidence-based methodologies, and the renovated design proposals were created based on an amalgamation of physiological data, observations, surveys, and case studies. To test whether the improvements were perceived as preferable, an experimental simulation methodology was used to analyze responses from a group of participants.

Survey Method 1

The sample group consisted of 32 subjects who were of the 300 level architecture studio. This sample group was chosen because of their familiarity with architectural terminology and their general understanding of space. While some may regard this sample group as limiting due to an unfair representation of the general public, I have regarded this sample group as suitable. The students are undergraduate level in the seven-year architecture program and thus do not have as much knowledge as a more experienced graduate student, but at the same time they are capable of imagining spaces in 3-dimensional form which would typically be restricting if a general audience was used.

The participants were shown a total of four different scenes. In each of the four scenes were different levels of development. Some participants were shown an image prior to evidence-based implementation, others were shown a changed environment based on data, and the third group was shown a reductionist image that stripped the space of EBD and the original scheme as designed through intuition and architectural training. The purpose of this division was so that I may draw upon a comparison of images for an analysis of whether space influenced by an architect was voted with higher quality than a less intervened space, and furthermore if an evidence-based design was more impressionable than the original design.

The survey was delivered via paper and pen and therefore posed the challenge of being visually based. Once again using architecture students could help to begin to eliminate this limitation. The instrument featured one image at the top followed by five questions that required a 1-5 scaled response (see Appendix). The scaling methodology was limited in the fact that it did not motivate a reasoned response to the vote. However, this approach was used because it encouraged an initial reaction without much analysis to elicit first impressions. There was space left at the end of each page for optional comments if the participants wanted to leave any remarks.

My hypothesis is that the spaces influenced by EBD will rate higher in novelty, stimulation, and potential for occupant integration. This assumption is based on the research that has suggested that a multi-sensory environment, an unfamiliar setting, and active exploration produces a greater awareness between man and his environment. While I believe that science is another tool for the designer to use for bettering a space, I am also convinced that an architect's training and intuition is equally valuable in the creation of spaces. Therefore, images that are in their simplest forms, without EBD and stripped of architectural detail, are predicted to be less favored than its' opponents.

Derivation of Questions

The questions for each image were the same so as to reduce variability and allow for a more simplistic process for the participant. Determination for the inquiry was based on the research and the goals from the prototype design. The following is a table of questions with the corresponding reasons for the inquiry according to evidence, intuition, and hypothesis.

How intense did you find the utilization of light?	
Intuition	Shadow and contrasting edges create a visual depth that attracts an occupant to one space over another.
Evidence	The intensity of light (shadow, edges, etc,) is directly correlated with the firing rate of neurons that determine whether an awareness of light is recognized by the brain.
Hypothesis	Those images which convey a greater contrast will not only score higher but also influence the scale of the other questions since vision begins with light and the test can be only relied upon through visual cues.
How conducive is this space to recreation and amusement?	
Intuition	The higher ceilings, greater spatial dimension, and inclusion of plants will encourage a sense of entertainment.
Evidence	A self-awareness is conditional upon the body's relationship to the surroundings in terms of psychological space (Hall) and acoustics that inform the senses about the spaces formality and program.
Hypothesis	Prototype is meant for recreation and thesis objective is to explore man's interpretation of his environment. Those images which have a greater dimensionality in space and more multi-sensory elements will score higher.
Considering these four senses (smell, sound, touch, and vision) how stimulating do you predict this space to be?	
Intuition	When multiple senses are activated in any one space the quality and depth of design is enhanced due to the greater level of connection with the occupant.
Evidence	The combination of stimuli has the greatest potential for a neural response in the hippocampus.
Hypothesis	Images that include added elements for the predictability for the sense of smell, touch, and sound will rate higher than those which only foster the sense of vision.

How would you rate this architectural scene based on novelty?	
Intuition	Original design breaks the predispositions and expectations of typical archetypes so as to consciously engage the viewer.
Evidence	The hippocampus (encodes and retrieves memories) is particularly active when new environments are being explored.
Hypothesis	The images with a unique shading pattern, unfamiliar object, and/or a combination of sensory elements will rate higher for novelty.
How well do you imagine this space's potential for integrating the occupant?	
Intuition	A greater awareness of a space/object would occur when the occupant is directly oriented or associated with the space/object.
Evidence	The senses are "active detectors" and show a greater accuracy of comprehension when spaces/objects are explored with direct involvement rather than passive viewing.
Hypothesis	The spaces which demonstrate potential for placing the viewer within a shadow or architectural element will better score for potential integration.

Survey Results and Scene Analysis: Method 1

Lobby

The following are three images for the development of the visitor center’s lobby space and the concluding results of the survey based on the average percentage scores.

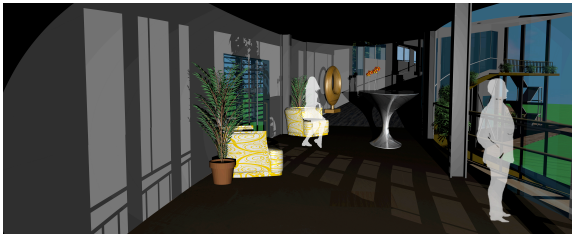


Image A: Lobby Reductionist



Image B: Lobby Original

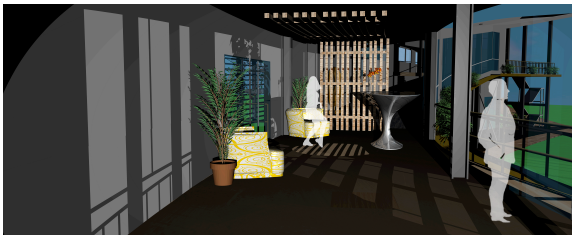
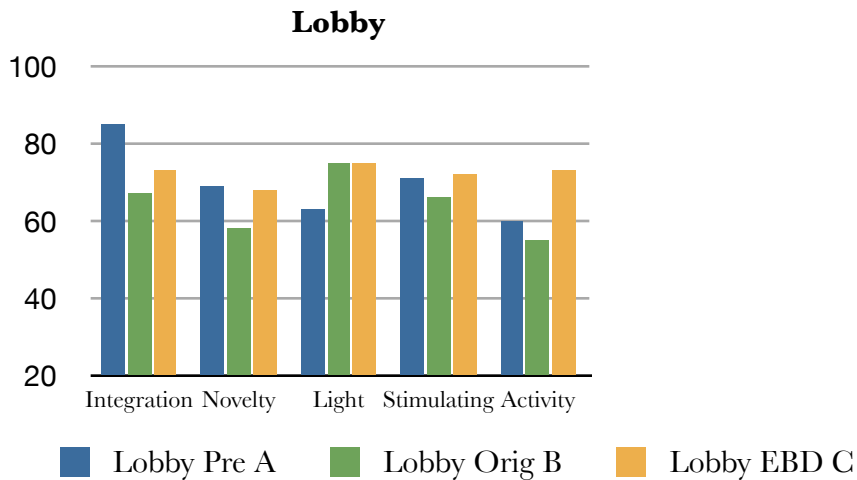


Image C: Lobby Evidence-Based



The focus of the lobby space development was to particularly enhance the sense of vision and touch. The reductionist image did not include any boundaries and only filtered light through the typical window facade. The incorporation of the skylight in image B was purposed to create novelty and reflect upon the experimental results regarding participants preference for natural light entering from above. Finally, the EBD approach was meant to add texture by incorporating the screen at the exhibit entrance which would simultaneously cast shadows from the skylight above and serve as a sound barrier between programs. The hypothesis was that each development would score higher for novelty, utilization of light, and stimulation.

However, the results scored the reductionist image as highest in novelty, the EBD development as highest for stimulation, and image B & C tied for the utilization of light. The EBD development scored well for stimulation as hypothesized predictably because of the added elements that allowed the participant to imagine texture, sound, etc. The fact that both image B & C scored 75% for the utilization of light is seemingly accurate because the light is deriving from the same source. What is significant to note is that the EBD image did score higher in areas of stimulation and activity which could speak to the shadows casted on the floor below.

A surprising result of the survey was that while the EBD scenario was given a 72% stimulation rate, image A followed close behind with 71%. This difference is identically switched in the novelty scenario as participants voted image A with 69% and image C behind one point at 68%. Assessing the high scores for image A it can be speculated that because the barrier was excluded there was greater depth and prediction in the image. The participant was given the opportunity to look beyond the lobby scene and into the exhibit perhaps providing the perception of being more novel and allowing for more possibilities for occupant integration. However, the fact that the participant was not physically within the space is a confounding variable that could vary the results.

Entry

The following are three images for the development of the visitor center's main entrance and the concluding results of the survey based on the average percentage scores.

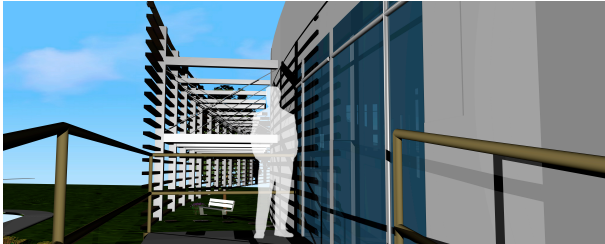


Image A: Entry Reductionist

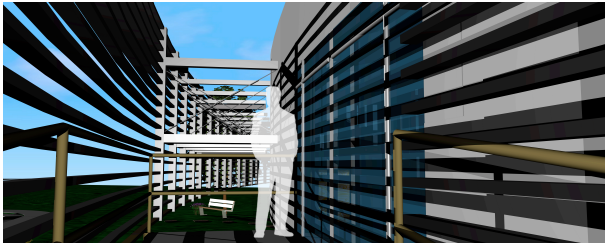
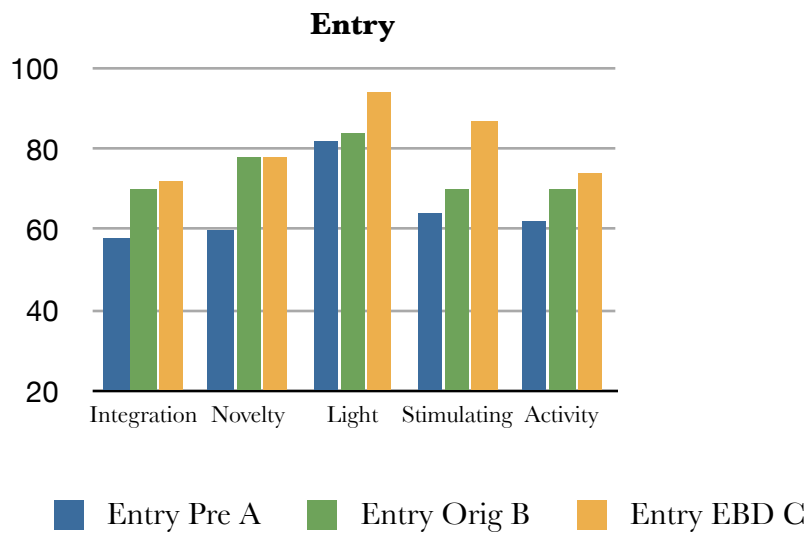


Image B: Entry Original



Image C: Entry Evidence-Based



The entry scene featured results that correlated well with the predictions. Both the original design and EBD design scored higher in all categories compared to the reductionist image. These results may have greater accuracy than the other surveyed images because of the narrow focus of the scene.

The main purpose of using this image for testing was to discover participant's perception of integration and stimulation. Intuitively the screen was conceptually designed to embrace the occupant upon entry so as to encourage a physical engagement between man and space. The survey begins to validate this idea since votes for integration increased with each development. Although the shading device is in the same position in image B and image C the added device of vegetation could predictably be better for integration as it encompasses the sense of smell as well. This is also seen in the stimulating response being 7% higher for EBD implementation than the original design.

What is ironic is that although the light was treated the same in image B and image C, the EBD scene was given 94% good utilization compared to the original design at 84% and image A followed close behind at 82%. The rating in image A could be due to the 2-dimensional image that is better interpreted with less shadows. However, the reasoning behind image B is less predictable. A speculative response is that the vegetation in image C added clarification as to what function the empty space between wall and screen served lessening the confusion of the image that might otherwise be present in image B.

Courtyard

The following are two images for the development of the visitor center's rear courtyard and the concluding results of the survey based on the average percentage scores.

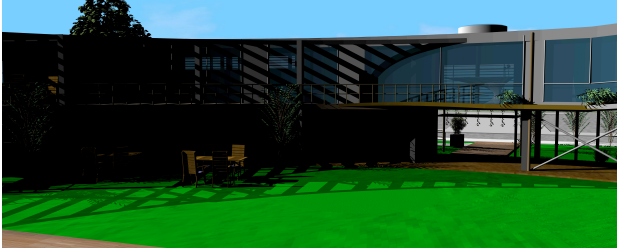


Image A: Courtyard Original

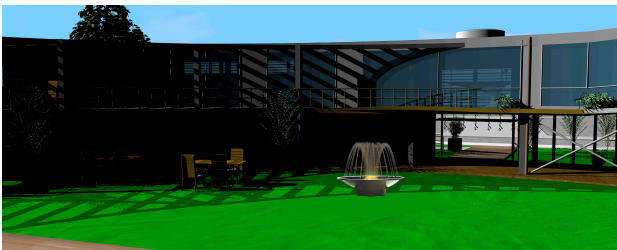
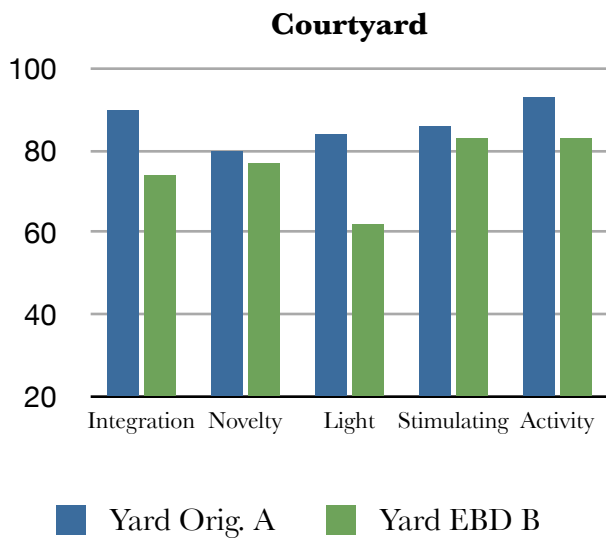


Image B: Courtyard Evidence-Based



The courtyard was developed with EBD principles to inspire activity and encourage a multi-sensory environment. However, like the orientation deck scene the courtyard produced less favorable scores for the EBD implementation. Once again this is predicted due to the fact that the participant is interpreting the 2-dimensional scene from the visual sense only.

A failed hypothesis is actually conceivable particularly in this image. The intensity of light vs. dark and the cast of shadows is so dominant that it is predictably straining to the sense of vision which is trying to interpret the image. The results supports this prediction since the EBD scored a significant 22% less for light than its counterpart, despite the same manipulation of light. Therefore, the simple added element of the fountain may have been a rather disruptive detail that was contending with the shadows for attention. What is promising is that while the EBD on average scored 11% less it was only three points behind for the stimulation factor. Therefore, despite the visually demanding picture the predictability of sound and texture may have presented itself in response to the fountain.

Orientation Deck

The following are three images for the development of the visitor center's view from the orientation deck and the concluding results of the survey based on the average percentage scores.

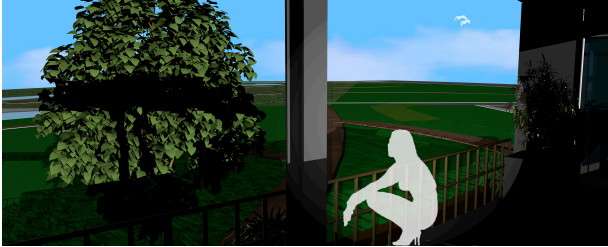


Image A: Deck Reductionist

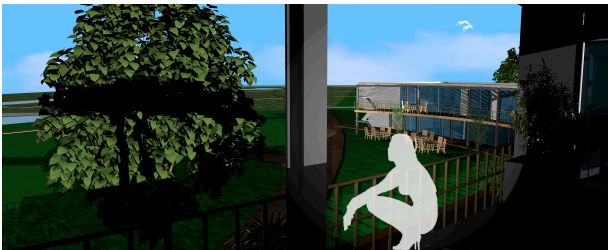
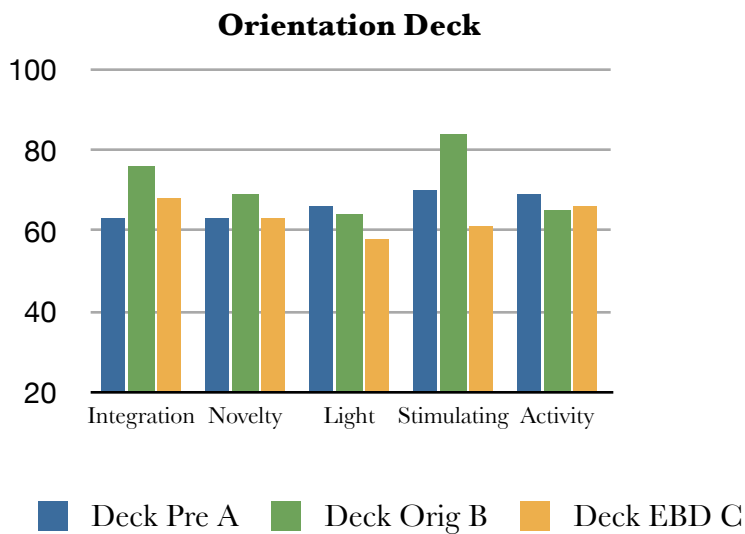


Image B: Deck Original



Image C: Deck Evidence-Based



The purpose of using this image for testing participant perception was to discover whether architectural landmarks allowed for predictability of integration and activity. However, contrary to the hypothesis the EBD scored less in not only these categories, but all categories. A couple variables are assumed that may have influenced the outcome. The figure in the image may have been misleading directing the participants view to the park rather than the architecture. Secondly, the distance of the view may have caused a muddled interpretation. Finally, the idea of “less is more” may have come into effect as the scene may have had too many elements with little focus that caused the reductionist image to score higher in most instances. In reflection I think that if the question served to direct attention to seeking architectural landmarks the results could be better predicted. However, the intent was to keep the questions the same so as to not create biases and added variability.

Concluding Analysis Survey Method 1

The survey results were not entirely supportive of my hypothesis. In most instances the evidence-based design image did score high in all categories, but not necessarily higher than its' counterpart. This could have occurred due to a variety of reasons.

The driving variable within this method was the fact that the participants were deriving answers based on their visual sense. While some elements were meant to evoke the sense of sound and smell the interpretation was based solely on vision. Thus the question, " Considering these four senses (smell, touch, sound, and vision) how stimulating do you predict this space to be?" cannot be accurately scored unless the prototype was constructed to scale. Also, since these images are alluring the visual sense it is plausible that the reductionist images scored higher because simplification of a scene was less stressful on the visual interpretation. For example, in the yard scene the original design (without the fountain) scored higher in all categories although the implementation of the fountain was meant to be a multi-sensory element that would encourage the sense of sound and touch. This variation could be the result of the participants appreciating the more simplistic visual scene that allowed the eye to focus on a single aspect. This interpretation comes from such remarks made by the participants like "too many different pattern arrangements," (response to fountain) vs. "like the light play," (response to original yard design) despite the fact that in both images the manipulation of light was exactly the same.

As mentioned, participants were provided with only one of three variations of a space. The benefit of this is that participant responses are not manipulated, and the subject is responding based on an initial reaction rather than a formation of comparative analysis. However, the negative effect of this method is that had a participant known of an alternative design they may have chosen the substitute. This comparison would provide further support, or criticism, for evidence-based design to discover whether certain elements added value. Therefore, a second part to these results are needed to test the validity and provide greater reliability.

Survey Method 2

While in survey Method 1 the aim was to encourage initial reactions, the second part of this survey method is to allow for a comparative analysis. The same sample group, a total of 33 participants for this portion, was used so as to limit variables. However, this time the survey instrument was delivered via surveymonkey.com. The change of media does pose some inconsistencies when comparing results with Method 1, but the online instrument does help in that participants could zoom in on images. Had a paper medium been used the images may have been too small for proper interpretation because in this survey method each page consisted of 2-3 images in the same location as the single image in survey Method 1 (see Appendix).

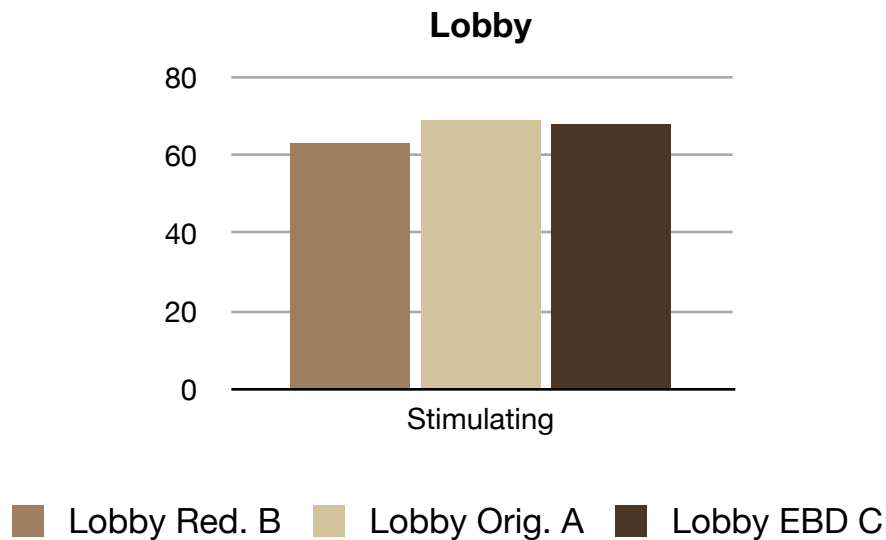
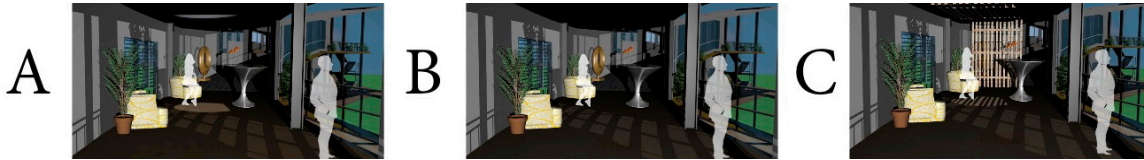
Each survey page (total 4 pages) consisted of one scene that posed 2-3 development phases; reductionist, original, or evidence-based. At the bottom of the images was posed only one question “considering these four senses (smell, sound, touch and vision) how stimulating do you predict this space to be?” Since the participants were the same sample group they had seen at least one of the development phases in the prior test. Having a single question encourages the participants to focus on the 3-dimensionality of the space and limit the wearisome of monotony. The response was fashioned in the same way as Method 1 with a 1-5 scale.

This supplemental survey is less controlled than that in the first method because participants may feel the pressure to choose the image that has more. However, upon factoring results from this survey tactic the outcomes can be correlated with that of survey Method 1 to draw upon a comparative analysis that would begin to validate both results. The goal of this prototype design process has been to prove that evidence-based design complements an architect’s intuition and hypothetically would result in a comparatively better design outcome.

My hypothesis is that in most instances the evidence-based design scene will score higher. However, I do not predict it will necessarily score higher in all instances because of the realization from the first survey that the reductionist image is often preferred because of the simplicity for interpretation by the visual sense. I have narrowed my question to focus on the “stimulating capacity” in belief that in all scenarios the EBD images should better allow for predicted sound, smell, touch, and vision sensations.

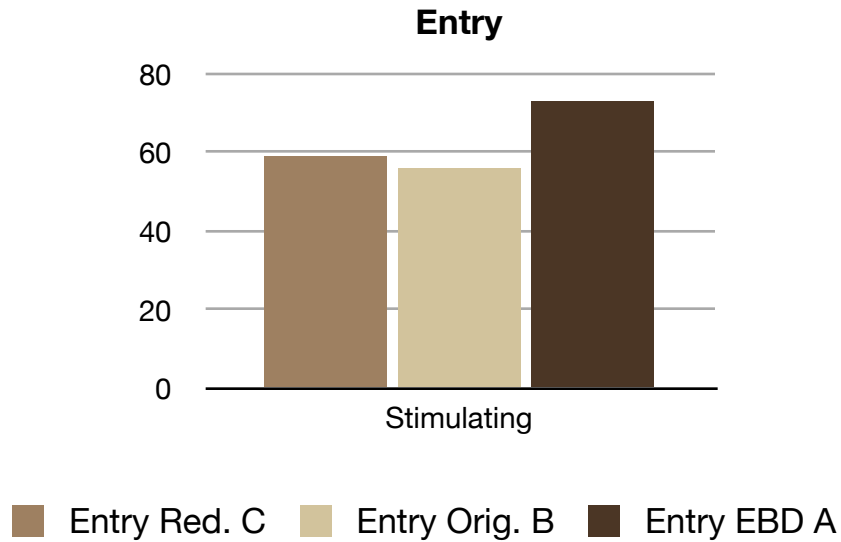
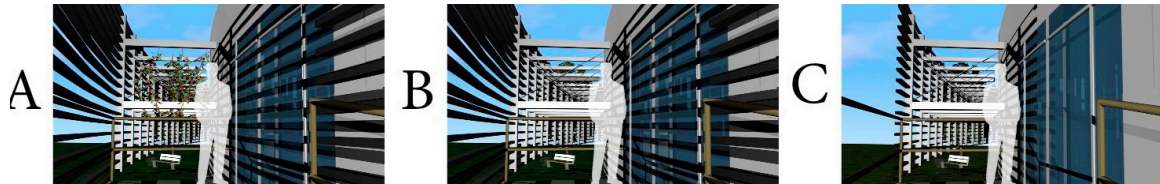
Survey Results and Scene Analysis: Method 2

Lobby



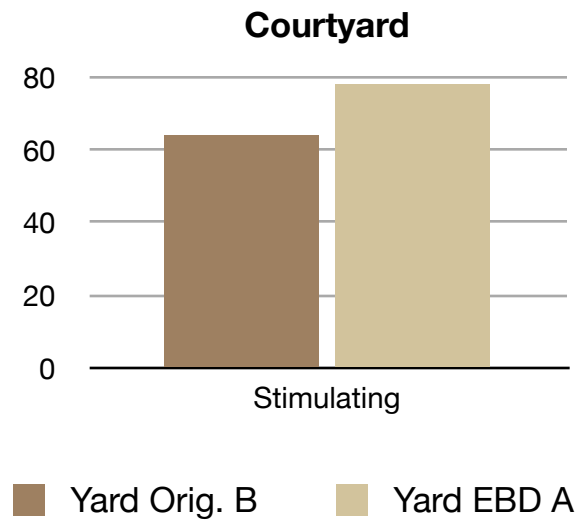
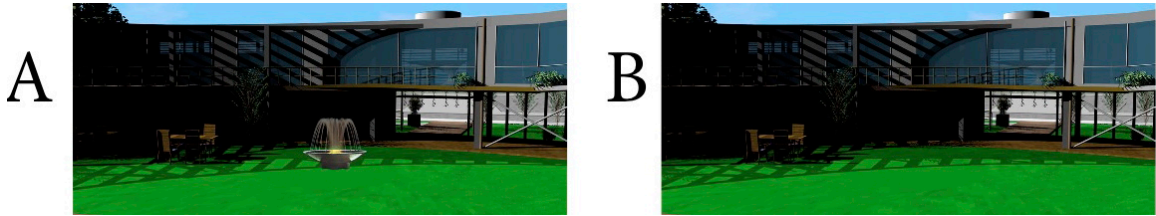
As predicted not all images with an evidence-based development would score higher. The lobby image is the only scene of the four scenarios in this comparative survey method in which the EBD image has not ranked highest. In this particular scene the original image is leading. As previously mentioned survey tactics pose the limitation of being visually based and in this instance it can be assumed that the sense of vision is overpowering all other elements. In Image A, the original rendition, there is an intense spotlight on the floor as reflected from the skylight above. This spotlight does not exist in the reductionist image and is diffused in the EBD image, causing for a much more dominate light scene in the original lobby design. Hence the plausible explanation towards a higher score for the original image.

Entry



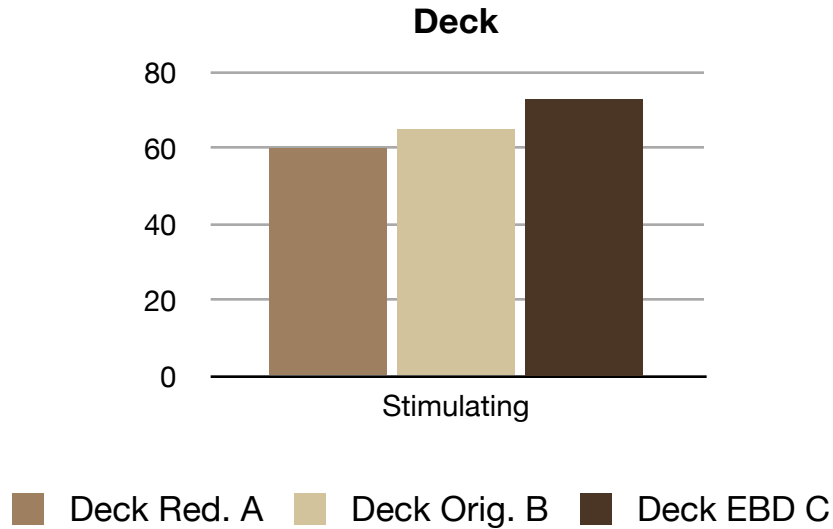
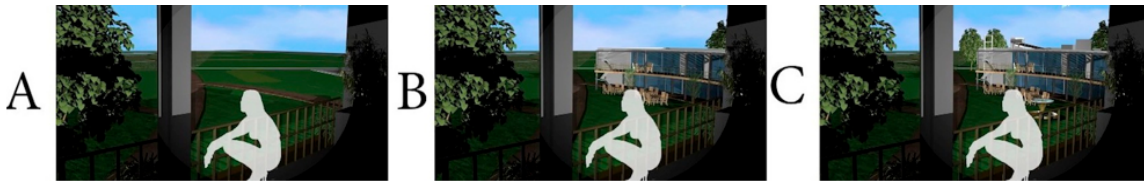
While the evidence-based design scene scored higher as hypothesized what is unique in these results is that the reductionist image scored slightly higher than the original. This could be due to the simplicity of the scene and also the comparative difference apart from the other two's similar repetition making the reductionist image unique and thus better scored. At the same time the introduction of plants in the EBD Image A possibly made it score higher than either of the two alternatives because it led for predictability on part of the participant searching for cues that would stimulate particularly the sense of smell, which is lacking in both the reductionist and original design.

Courtyard



In this design scenario the EBD image scored higher. These images are both visually intense due to the extremity of shadows. This scene is probably most skewed and influenced by the survey question “considering these four senses (smell, touch, sound, and vision) how stimulating do you predict this space to be?” as it hints to choosing the image which has more sensory cues, and in this scenario only the addition of the fountain causes for change. While this may seem as a limitation in the study it can also credit the results as more probable to the likelihood of responses in the actual built construct since the participant is now having to think beyond vision as they compare scenes, and the simple addition of one element allows for an ease of comparison.

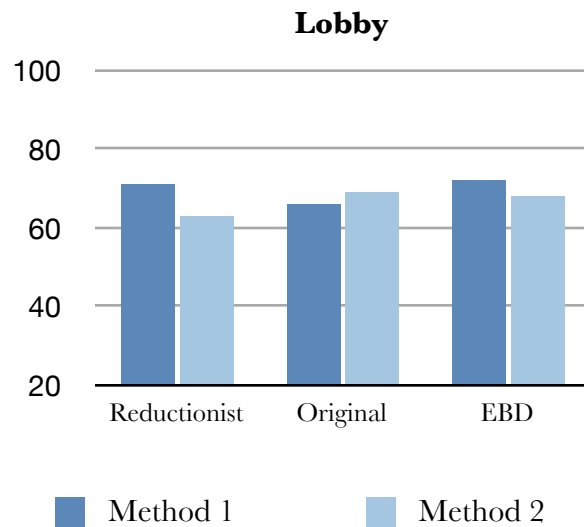
Orientation Deck



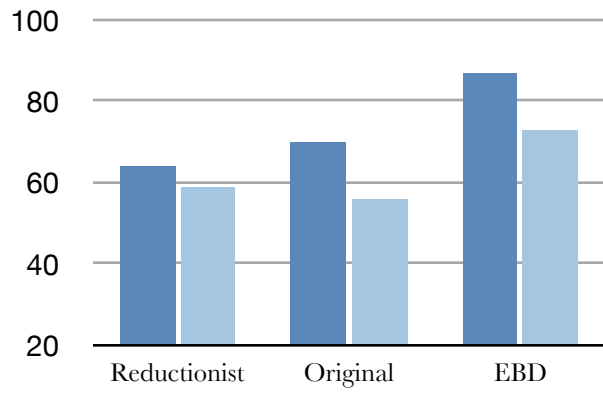
The rankings for this scenario scored precisely as predicted. What is unique for this particular sequence is that those elements which are added or subtracted are placed in the distance. Therefore, there had to be obvious comparisons made on part of the participants who had to seek out differences. The direct view are those elements which are nearest in the picture, like the steel column and tree, which do not change. Items in the background however are what cause for differences, and while the reductionist image is obviously different than the other two, there are not so apparent differences between the original image and the EBD image. This meant that participants had to clearly analyze the differences while scoring scenes, which lends credibility to the aim of survey Method 2 as encouraging participants to consider alternative scenes when predicting sensations.

Concluding Survey Comparative Analysis

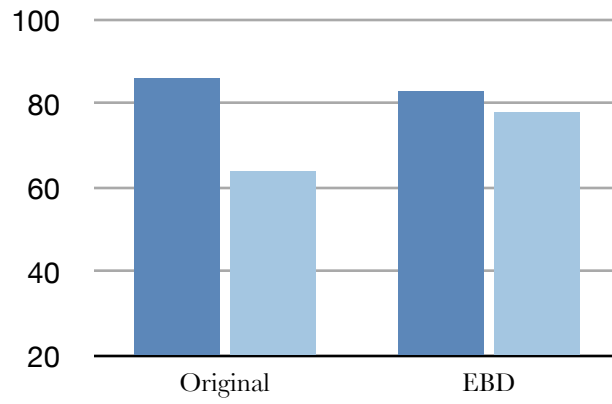
Survey Method 2 has demonstrated that when participants are able to compare scenes, even in the 2-dimensional realm, there exists a greater possibility for realizing one images capacity to manipulate the senses over another. While the weakness lies in the fact that participants might be subject to choosing those images which have more, the strength ironically lies in the same realm. People are being asked to relate a 2-dimensional scene to a 4-dimensional cause, therefore they would be prone to choosing an image that has more in the prediction that it would trigger greater sensory reactions. While survey Method 2 has better supported the hypotheses than survey Method 1 it is now important to compare the two studies to average results for a more comprehensive look at reductionist vs. original vs. evidence-based development.



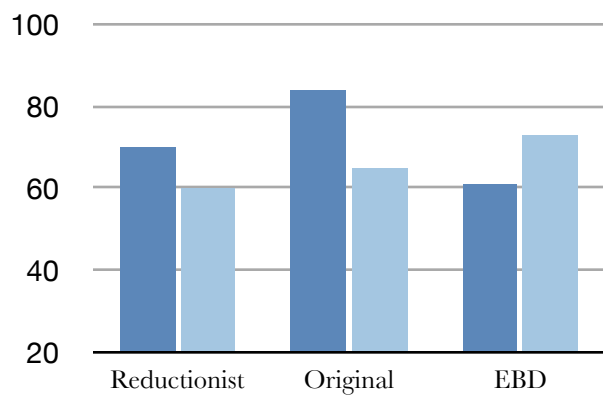
Entry



Courtyard



Deck



■ Method 1 ■ Method 2

On average survey Method 2 had an overall decrease in ratings of 9% when compared with those of Method 1. However, in Method 2 there was a steady increase in scores, averaging a 10% increase respectively between each scene as images proceeded from reductionist to original to evidence-based development. This is in contrast to Method 1 which was $\pm 9\%$ between images. Therefore, as predicted Method 2 did reveal an overall steady increase of scores presumably because of the allowed comparisons to be made. The overall decrease in ratings can also be explained by the permissible comparisons since people may be more inclined to choosing a rating of “1” since they realize an alternative option in a scene where they can vote a “4.”

The purpose of survey Method 2 was to correlate with Method 1 on the basis of whether an analysis would influence a better rating for evidence-based development compared to the original and reductionist comparisons. In Method 1 on average the EBD scene increased by 3 points from the reductionist image, and in Method 2 the average was 11.5 points. The EBD as compared to the original image for Method 1 increased by 1/2 point on average and in Method 2 increased by 8.5 points. Finally, the original when contrasted with the reductionist image showed a mean rating increase of 5 points for Method 1 and 3 points for Method 2. Overall, the hypothesis was correct in that Method 2 would find a gradual rise in ratings for the scenes based on development, despite the marginal difference of Method 1 scoring 2 points higher for reductionist vs. original.

For both methods the average scores between scenes did increase. While a statistical analysis is the next step in investigating whether there truly was a significant difference between developments and individual scenes, the averages speak positively towards evidence-based design having a greater stimulating potential.

Statistical Acknowledgement

These survey methodologies were used to simply gain a sampling of average results. The next step for interpretation would be to statistically analyze the significant differences between reductionist, original, and evidence-based developments. To truly indicate variances and probabilities of results a computer programming for survey authoring should be conducted as demonstrated in Experiment 1. However, for the purpose and scope of this project the average graph sampling suffices as representation of a starting point for occupant's perceptual judgments.

Chapter 10: Conclusion

10.1 Methods for Evidence Based Design

Evidence-based design is a process not a product and so the importance of methods is critical to research. There exists three main types of research in an EBD project. First, design concepts can be developed based off of implications of data collected by others. However, sometimes necessary data for a particular question is not available and so the second method consists of the designer/researcher performing his own research study. The third type of research is that which is conducted after a project's completion for evaluation of its' performance.¹¹¹

Kirk Hamilton, FAIA, developed a model for his former firm WHR Architects in Texas that outlines the process of evidence-based design. His nine-step process does not abandon traditional methods of design but rather adds elements that can be easily understood by design professionals making an EBD transition.

	Task	Activity
1	Identify the Client's Goals	Note most important and facility-related global and project-based goals
2	Identify the Firm's Goals	Understand the firm's strategic, project and evidence-based design objectives
3	Identify the Top 3-5 Key Design Issues	Narrow the possible choices; work on high impact decisions
4	Convert Design Issues to Research Questions	Reframe statement of design issues to become research topics
5	Gather Information (Benchmark Examples, Literature Sources, International Studies)	Infinite possibilities must be narrowed; limited perspectives must be expanded
6	Critical Interpretation of the Evidence	No direct answers; requires open-minded creativity, balance, and critical thinking

¹¹¹ Kirk D. Hamilton and David H. Watkins, *Evidence-Based Design for Multiple Building Types* (New Jersey: John Wiley & Sons, 2009), 205.

	Task	Activity
7	Create Evidence-Based Design Concepts	Based on creative interpretation of the implications of research findings
8	Develop Hypotheses	Predict the expected results of the implementation of your design
9	Select Measures	Determine whether your hypothesis is supported

Fig. 10.1 WHR's Nine-Step Evidence-Based Design Process (Hamilton)

The first step is to understand the client's objectives for a project which then leads into the firm making sense of their own vision for the concept. Once goals are stated the issues that are critical to the design solution are pinpointed. Typically those key matters are stated as intents rather than research questions. An example of a key design issue listed by the author is "the design must provide an attractive and well-used public space near the entry in order to create the right image." This idea is translated into a research question, "what makes a public space attractive to this specific clientele?" or "what size of space is conducive to public use?"¹¹² Thus, the fourth principle in Hamilton's plan requires new skills of the design team to rephrase key issues into specific questions that permit the possibility of an answer.

The next step in the EBD process would then be to answer the design questions through literature research, observational studies, and/or one's own research. Collecting data can come from a number of resources including client's information, literature, statistics, field studies, virtual environments, mockup environments, etc. The important point to remember is that the research findings must be reliable, replicable, and valid.¹¹³ This evaluation is the critical interpretation of the evidence and can be challenging as it may often test a designer's insight and former preconceptions.

The method utilized for conveying evaluations and results should respect statistical parameters of analysis because without it results tend to be incredible and analysis rather

¹¹² *Ibid*, 212.

¹¹³ *Ibid*, 242-243.

imaginative. The application of probabilities provides the research with validity. However, architecture is not science and science is not architecture. This implies that one method defined with a set of parameters and restrictions for a profession might have to be fragmented and redefined to reach its' fullest potential for the other profession. Evidence-based architecture is about a fusion of research and design that will inevitably shift the way experiments are conducted and results and analyses are displayed. In this sense a new field almost emerges as a new framework is created when the dominant left-sided brain of scientists collaborate with the predominantly right-sided mind of the architect.

Step seven is the development of concepts that returns the practitioner to the familiarity of practice. However, now those concepts lend itself to credibility since ideas must be a byproduct of results discovered. The eighth step requires the designer to document the predicted results of a design implementation. By stating a hypothesis that can be shown to have been achieved conveys rigorous investigation and study rather than simply reporting the results of a project.¹¹⁴ The final step is to choose and undertake measures that will test the hypotheses. Most often in architecture the test comes in forms of post-occupancy evaluations and case studies that evaluate the effectiveness of design choices.

Evidence-based design does require more time than a conventional project and therefore research needs to begin at the pre-design phase. The design team should be composed of multiple disciplines that challenge each-other's thinking and believe in the value of research for the product.

10.2 Process Reflection

Through the process of this dissertation I have ran into many challenges that have enhanced my architectural education. My inquiry began with the question of how designers could create environments that would heighten man's awareness of the space

¹¹⁴ *Ibid*, 215.

about him. I then undertook the three steps of research in an evidence-based project; research, own research study, and evaluation of a created project.

The research led to my discovery of the importance of multi-sensory design and key elements that would influence a reaction from a single sense. Such discoveries informed me of design applications that could intensify a user's experience. While research began to fuse the fields of science and architecture there were many questions that were left unanswered. My goal was to consider architectural applications from primarily an objective interpretation. Thus, one question that arose was the pseudoscience of color perception and chromotherapy. There was no reliable or valid research that dictated how different colors were understood by the brain or whether one color truly was more "relaxing" than another. Therefore, I challenged myself with a new study.

The mockup experiment tested participants heart rate and blood pressure as an indicator of arousal and was correlated with a survey to factor in individual preferences to three colors issued; white, blue, and red. Despite the variability of culture, experiences, and personalities, the experiment began to reveal information about light exposures. This test helped me acquire new skills as an architectural researcher and taught me the process of setting up a new study to help answer an unknown hypothesis.

The final step that I took was a renovation of a previous project I designed based on evidence-based principles, with a comparative look at before and after images. The goal of the design was to test how my research findings could be implemented and whether my proposed EBD project would be perceptually "better" than the original design. Though a more credible assessment would be the collection of data after the project was built, the limitations of this thesis encouraged me to evaluate based on other means. I conducted a series of surveys that questioned participants interpretation of a presented environment. This process instilled my understanding of the value of evaluation rather than leaning on my own biases. I think it is also important to note that analysis and evaluation should begin before a product is built through multiple measures so that when the product is complete it will serve to better support a conceptual goal.

The value that this dissertation has brought to me has been a discovery of the methods and procedures that are undertaken in an evidence-based design project. The process has taken me through the steps of EBD practice, from a literature review, to a new study, and an architectural application. Originally my bias was that EBD could be easily incorporated into firms and was personally bewildered by any objections. However, this exploration has led me to understand that while EBD is valuable it is also challenging in that it requires an architect to put on an unfamiliar hat as researcher. This transformation simply requires time that an office sometimes cannot accommodate. Therefore, this thesis has personally given me a new edge to design and acquired skills that I might have not otherwise so easily grasped in an architectural office.

For the public I feel this dissertation is also beneficial. The direction of design is continually changing and the competitive market is always demanding. Evidence-based design provides the value and reliable concepts that consumers are seeking. Yet while EBD has been around for some time the skills needed for EBD are often not well acquired in most universities. A unique aspect of this document is that it undergoes the three main types of EBD research, serving as a framework for the beginnings of evidence applications. This thesis can serve as a guide for architect's seeking direction for how to begin an EBD process. It can also enlighten the reader of the value of evidence-based design and serve as a proponent for the future of the architecture profession to be critically assessed.

10.3 Value of the Fusion of Science and Architecture

Architecture has continually been called a “jack of all trades,” because of the demanding profession and widespread knowledge that a practitioner must acquire for design and business. Architecture has always been a competitive market with challenges in design, costs, and collaboration. Ultimately the product is within the control of the client. With so many options made available the client is now demanding more dependable and predictable outcomes from the design that will result in an investment that will make the

sizable costs of building worthwhile. The architect in today's market is thus posed with a further challenge; to create beautiful buildings that produce results.

Today's technologies and available data make design opportunities endless allowing for refinement and improvement of the architect's abilities to create form. The promising aspect of evidence-based design is that this form-making goes beyond an aesthetic appeal to potentially offering the power to positively influence human well-being and effectiveness. The challenge to traditional architecture practice is that design choices become transparent requiring, in most instances, an explanation to the client rather than agreements based on acts of faith in the designer's intuition. Therefore, evidence-based design is sometimes considered a prescriptive methodological agent that does not allow for the freedom of innovation.

The value of evidence-based design can only break the traditional mindset when assessed in the context of contributing value to society. A client and the public may find value in an aesthetically pleasing space but the bottom line that drives client and developer investment is the return to their organization or institution. Then the value soon becomes how well the design motivates, heals, and reaches financial targets.

Evidence-based design markets a firm because it provides methods to achieving those results. Often times architects correspond with a client by stating that they "understand your (client) business and can design buildings that can help you continue to expand." A more research acquired architect might contrastingly respond, "I understand what outcomes drive the success of your business, and I can design buildings for you that can help you improve those outcomes."¹¹⁵ The second example demonstrates design knowledge and promises a greater potential for results than the first.

The value of hiring an architect is beginning to die down in modern society. Engineers, contractors, and even the layperson can design spaces through new programs,

¹¹⁵ *Ibid*, 252.

publications, and resources that are making the architect struggle to prove his worth. We have seen this “death of the architect” in history as the sole practitioner defined by fifteenth-century humanist Leon Battista Alberti as the man who could “devise through his own mind and energy” transform into a group of partners who collaborate with multiple disciplines, making architecture an attainable trend. The value with evidence-based design is that it offers a way to re-evaluate the importance of an architect. An architect who can use his intuition and intellect accompanied with evidence gives more value to a client seeking beautiful space with results rather than simply an aesthetically pleasing space which can be too often easily reproduced. Therefore, designers who can offer more and deliver more are hired.

Architecture has always been a knowledge-based practice that has to some degree been influenced by research. The term “evidence-based design” has been around for a long time but the buzzword is just now beginning to transform itself to encourage exploring unknown domains. Evidence-based design is about gaining power to influence design and the outcomes of design decisions.¹¹⁶ Firms who can credibly document their work can make known to the public that they are able to positively predict results that will attract clients and recognition within their own field. An architect who embraces EBD will ultimately have greater influence over a product increasing her competitive advantage.

10.4 Concluding Summary

Critical thinking in design is about designing from available evidence to create the proper relationship between man and his surroundings. Usman Haque says it best, “encourage people to become performers within their own environments.” The world of neuroscience is unraveling and is revealing many discoveries about how human’s interpret space. Architectural practice should bridge with science to create purposeful and meaningful environments. The design profession can regain acknowledgment for being a

¹¹⁶ *Ibid*, 258.

vital source for the built environment rather than being perceived as an optional elite craft when concepts and methods result in effective outcomes.

The understanding of space is formed by the mind interpreting signals from the body. Those signals are transferred through the millions of sensory nerves that are receiving information from the outside world. Despite the cultural and experiential differences among people those sensory impressions universally are what forms a person's behavioral choices and perceptual experience. Therefore, the potential value that architect's can contribute to the social good is boundless because he is the artist that shapes the environment.

Therefore, it seems rather obligatory that an architect knows how to access and accumulate knowledge of the available information out there to create for the most influential environments possible. Evidence-based design is a leading advocate for this type of responsible design and so the process and methods should continue to be developed and explored by the profession. A new medium for this familiar term could be the advancements in neuroscience and its' leading-edge studies that are becoming interpretable for the architecture profession. The challenge is that neuroscience can be simply alluring, and because of its' scientific acclimations be automatically viewed as proof. Therefore, the architect must beware of claims and gain the best available data before confirming any information as factual. This process is time-consuming and transformative, but vital in a profession that holds the responsibility of an influential social power.

A famous quote by Winston Churchill is "First we shape our buildings, then they shape us." Building and people repeatedly evolve and thus new ideas must be embraced to maintain balance between humanity and architecture. The sciences are not a systematic threat to architectural methods but rather another design tool that architect's should take advantage of in order to stay in the current of building transformation.

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Appendix

1. Experiment Survey Instrument

University of Hawaii at Manoa

**School of Architecture
Mind & Architecture: Stimuli Localization Survey
Subject Code Number: _____**

Your participation in this survey is appreciated, and is entirely voluntary. All of the information provided within this survey will be kept confidential. The results will be aggregated and your identity anonymous.

Please respond to the following 10 questions to the best of your ability, if you are unsure about a question please feel free to ask any research assistant for clarification.

1. What is your Gender?

Male
Female

2. What is your Age? _____

3. Where did you grow up?

Hawaii
Mainland
 East Coast
 Central
 West Coast
Asia
Other _____

The following questions regard your own personal perspective, there is no right or wrong answer.

1. During the experiment, what was your favorite light position?

In Front
Behind
Left Low
Right High
Above

2. Which location was the least expected or most surprising?

Right High
Left Low

Above
Behind
In Front

3. What was your favorite light?

Natural Daylight
Blue Light
Red Light
White Light
No Light (dark)

Why?

4. Can you describe any emotional/personal reaction to each light?

Natural Daylight

Blue Light

Red Light

White Light

No Light (dark)

5. If this was a real space with larger dimensions, what activity, or lack there of, would you envision yourself doing in accordance with the the following colors?

Example: Black - sleeping, hide and seek, meditation

Blue Light

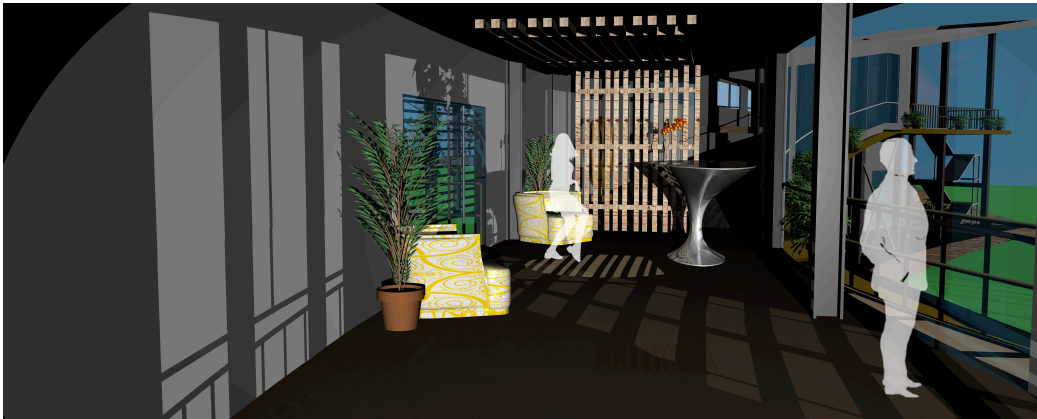
Natural Daylight

White Light

Red Light

6. Do you have any additional responses to this experiment concerning your experience, favorite stimuli locals, favorite lighting modality, or response to the lighting experiment?

2. Survey Instrument Method 1 (sample sheet)



How would you rate this architectural scene based on novelty?

SCALE: 1 low - 5 high _____

How well do you imagine this space's potential for integrating the occupant?

SCALE: 1 low - 5 high _____

How intense did you find the utilization of light?

SCALE: 1 low - 5 high _____

Considering these four senses (smell, touch, sound, and vision) how stimulating do you predict this space to be?

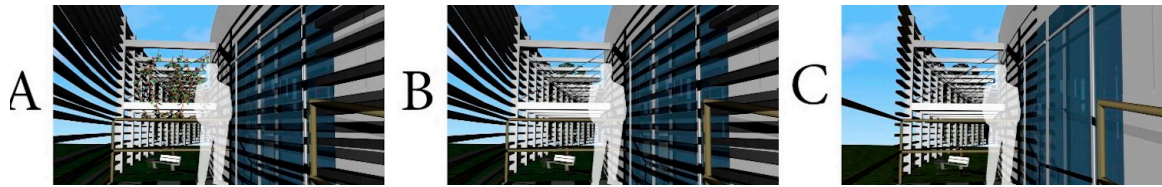
SCALE: 1 low - 5 high _____

How conducive is this space to recreation and amusement?

SCALE: 1 low - 5 high _____

Comments:

3. Survey Instrument Method 2 (sample sheet)



1. Considering these four senses (smell, touch, sound, and vision) how stimulating do you predict this space to be? (1 low - 5 high)

	1	2	3	4	5
Image A	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Image B	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Image C	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>