The Integration of Interior Design and Neuroscience: Towards a Methodology to Apply Neuroscience in Interior Spaces

Assoc. Prof. Dr. Maha Mahmoud Ibrahim
Associate Prof. Interior Design & Furniture Dept. Faculty of Applied Arts – Helwan Univ. Egypt.
Drmaha.ibrahim@gmail.com

ABSTRACT

As we know architecture and neuroscience were two separate disciplines, until it was found that the brain responds to stimuli and is constantly shaped by the environments we are living in. In the last decades, the rapid growth of functional brain imaging methodologies allowed neuroscience to address open questions in psychology and social sciences. At the same time, new insights from neuroscience research have begun to influence various disciplines, leading to a turn to cognition in the fields of planning and architectural design.

Neuroscience is beginning to provide us with an understanding of how the brain controls all of our bodily activities, and ultimately affects in our behavior. In addition, neuroscientists study sensation and perception, how the brain influences decision making, emotion. For example how we interact with our environment and how we navigate through it, how we hear, taste, how we store the information received and how we can recall the same information, and how we react to various situations.

On the other hand, new field of design called "neuro-architecture", driven by research on how factors like light, space, and room layout affect physical and psychological well-being. The idea is to understand how each feature of a person's architectural environment influences brain processes involved with stress, emotion, and memory.

Neuro-architecture is a discipline that seeks to explore the relationship between neuroscience and the design of buildings and other man-made structures that make up the artificially created environment that most human beings live within. The underlying purpose is to assess the impact that various structures have on the human nervous system and brain. More specifically, 'neuro-architecture' addresses the level of human response to the components that make up this sort of built environment. Examining how external and internal environmental settings can change emotional processes, such as stress and memory, is one aspect of neuro-architecture.

Through all of the above the research aims to use neuroscience principles to input them in the design of interior spaces, assuming that learning how our brain works with perception will lead to new developments on behalf of users in design, and more specifically the field of interior design. It is therefore of paramount importance for designers to understand the effect various designs have on our emotions and then on our behavior to use it in the design process.

Keywords: Neuroscience, Neuro-Architecture, Perception, Neuro-Interior Design Methodology.

الملخص:

كما نعلم أن العمارة وعلم الأعصاب هما مجالان منفصلان ، حتى تم اكتشاف أن الدماغ يستجيب للمؤثرات ويتشكل باستمرار من قبل البيئات التي نعيش فيها. و في العقود الأخيرة ، سمح النمو السريع لمنهجيات تصوير الدماغ الوظيفية لعلم الأعصاب بمعالجة الأسئلة المفتوحة في علم النفس والعلوم الاجتماعية. في الوقت نفسه ، بدأت رؤى جديدة من

أبحاث علم الأعصاب في التأثير على مختلف التخصصات ، مما أدى إلى تحول في الإدراك في مجالات التخطيط والتصميم المعماري.

بدأ علم الأعصاب بتزويدنا بفهم حول كيفية تحكم الدماغ في جميع أنشطتنا الجسدية ، ويؤثر في النهاية على سلوكنا. بالإضافة إلى ذلك ، يدرس علماء الأعصاب الإحساس والإدراك ، وكيف يؤثر الدماغ على صنع القرار والعاطفة. على سبيل المثال ، كيف نتفاعل مع بيئتنا وكيف نتنقل من خلالها ، وكيف نسمع ، نتذوق ، كيف نخزن المعلومات التي نتلقاها وكيف يمكننا أن نتذكر نفس المعلومات ، وكيف نتفاعل مع المواقف المختلفة وكيف نقييم نتائج أعمالنا.

من ناحية أخرى ، هناك مجال جديد من التصميم يسمى "العمارة العصبية" ، نشأ من البحوث حول كيفية تأثير العوامل مثل الضوء ، الفراغ وتخطيط الغرفة على الصحة البدنية والنفسية للانسان. تكمن الفكرة في فهم كيف تؤثر كل سمة من سمات البيئة المعمارية لأي شخص على عمليات الدماغ المرتبطة بالتوتر والعاطفة والذاكرة.

العمارة العصبية هي نظام يسعى إلى استكشاف العلاقة بين علم الأعصاب وتصميم المباني وغيرها من الهياكل التي صنعها الإنسان والتي تشكل البيئة المصطنعة التي يعيشها معظم البشر. الغرض الأساسي هو تقييم التأثير الذي تحدثه الهياكل المختلفة على الجهاز العصبي البشري والدماغ. وبشكل أكثر تحديدًا ، تتناول "العمارة العصبية" مستوى الاستجابة البشرية للمكونات التي تشكل هذا النوع من البيئة المبنية. إن فحص الكيفية التي يمكن بها للإعدادات البيئية الخارجية منها والداخلية تغيير العمليات العاطفية ، مثل الإجهاد والذاكرة ، هي أحد جوانب العمارة العصبية.

من خلال كل ما سبق يهدف البحث إلى استخدام مبادئ علم الأعصاب لإدخالها في تصميم الفراغات الداخلية ، على افتراض أن تعلم كيفية عمل دماغنا مع عملية الإدراك سيؤدي إلى تطور جديد- نيابة عن المستخدمين- في التصميم ، وعلى وجه الخصوص مجال التصميم الداخلي. لذلك من الأهمية بمكان للمصممين فهم تأثير التصاميم المختلفة على عواطفنا ومن ثم سلوكنا لاستخدام ذلك في عملية التصميم.

كلمات البحث: علم الأعصاب ، العمارة العصبية ، الإدراك ، منهجية التصميم الداخلي العصبي.

Introduction

Neuroscience is beginning to provide us with an understanding of how the brain controls all of our bodily activities, and ultimately affects how we think, move, perceive, learn, and remember. In an address to the American Institute of Architects convention in 2003, "Rusty" Gage made the following observations that set the core premise of the relation between the brain and architectural design : (1) The brain controls our behavior; (2) Genes control the blueprints for the design and structure of the brain; (3) The environment can modulate the function of genes, and ultimately, the structure of the brain; (4) Changes in the environment change the brain; (5) Consequently, changes in the environment change our behavior; and (6) Therefore, architectural design can change our brain and our behavior.

The use of neuro-architecture to inform building design is highlighted in the 2003 Fall issue of Society for Neuroscience, where Eberhard and Gage explains why architects and neuroscientists are beginning to work together.

“Architecture has the most impact when the ideas used in building design reflect our understanding of how the brain reacts in different environments. Neuroscientists can help architects understand scientifically what have historically been intuitive observations.” - Eberhard

"Neuroscience has reached a point in its understanding of the brain and how it is influenced by the environment that neuroscientists can work with architects in their designs for environments that enable people to function at their fullest within those environments." – Gage (27).

Changes in the environment change the brain, and therefore our behavior changes also. The growth of new neurons occurs constantly in part of the brain by a changing environment (1). Due to advances in technology within the sciences; machines are able to peek into the human brain in order to understand how we understand the world. These advances in technology allow scientists to understand how the brain reacts to a variety of stimuli, and therefore allowing architects and interior designers to design for effective buildings. Neuro-architecture is not simply a design inspiration or a concept; it is a design tool and another stepping-stone in the evolution of architectural design and interior space.

1- An Overview about Neuroscience

Neuroscience is concerned with the study of the human nervous system, the brain, the biological basis of consciousness, perception, memory and learning. It discovered that the brain is a three-brain structure, and our brain is a reality consisting of three brains as fowling: The lower brain or Hindbrain which controls the basic motor sensory functions, the Limbic brain (Midbrain) which controls emotions, memory, biological rhythm (Biorhythms), and finally the Cerebral Cortex (Forebrain) which controls knowledge, reasoning, language, and higher intelligence.

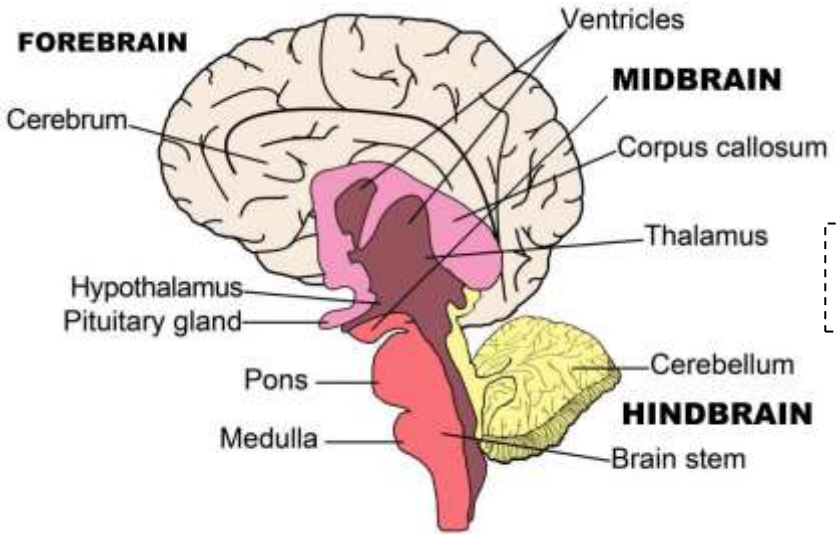

Figure1.
The structure of the human brain

The brain is not a computer. The structure of neural correlations is characterized by its relative mobility, flexibility, complexity, multilayeredness and abundance. The brain may best be described as a self-regulated information system and connection often changes and develops physically. Our brain changes through use during our lifetime, the mental and stress concentration changes the physical structure of the brain. Neurons are linked to network-like branches called Dendrites. There are about 10 billion neurons in the brain and 1,000,000 trillion connections. And the probability of a combination between the communications is

about ten to one million. When we use our brains, we strengthen patterns of connections and this makes linking work easier in the coming times.

Factors affecting brain functions are heredity; the environment; and social status. We are governed by the genetics of our brains, which are of great importance. In this research the greatest focus is on design methods in how to improve the impact of the environment to raise brain development.

When Perception occurs, an electrical impulse is sent from the senses to the appropriate neuron in the brain. The electrical pulse reaches the dendrites via the axis of the axon. Between the billions of Dendrites there are small gaps and the contact is made through these gaps by the chemical stimuli that are produced from the ends of the nerves. Back in 1949, the Canadian neuroscientist Donald Hib suggested in his work "Behavioral Organizations" his theory, which can be summarized as follows: When the axis of neuron A is adjacent enough and stimulates cell B, by repeating and continuously activating the process, some developmental processes or metabolic changes occur in one or both cells. In other words, if a neuron sends a number of signals to trigger another neuron, the synapses between the two neural cells strengthen and support. The link between the two cells grows and develops; so with each new experience, the individual's brain rebuilds its physical structure.

Other research has suggested that we change the patterns of some of our repetitive movements regularly, because if an individual is familiar with routine tasks, he or she uses little or little of his brain cells. This neglect causes death to many non-stimulated or stimulated cells. The change of routine tasks is a cause of brain stimulation, thus creating new links and renewing connections between nerve cells of the brain. There is evidence to support and reinforce the scientific fact that intelligent stimulation increases the number of active cells in the human brain. A rich environment causes more active neurons than a poor environment. The number of active cells is not constant and is constantly changing, in addition the internal connections between neurons (synapses) are not constant, but are constantly changing all the time (25).

The study of the human brain, or neuroscience, attempts to give meaning or an understanding of the way our brain inputs, stores, and receives information gathered through our senses.

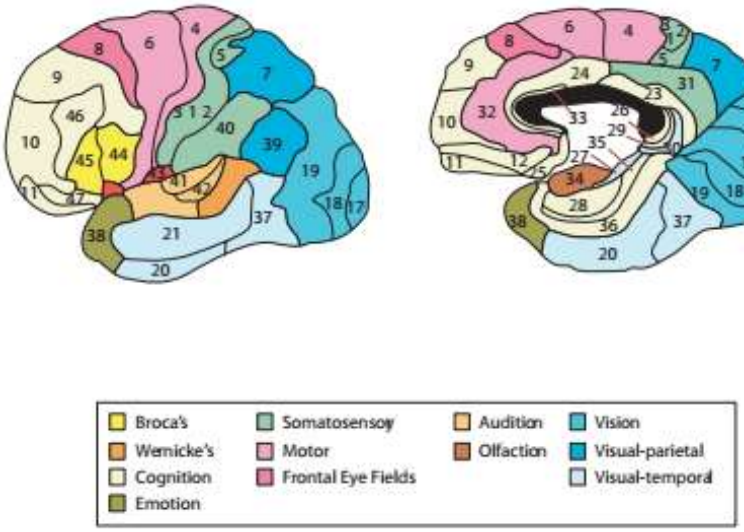

Figure2. A view of the left cerebral cortex showing Brodmann's numbered areas, together with some color coding of

- Hippocampus

Hippocampus is a complex brain structure embedded deep into temporal lobe. It has a major role in learning and memory. It is a plastic and vulnerable structure that gets damaged by a variety of stimuli.

Long term memory is formed in Hippocampus but not stored. Hippocampus also the same area where new cells are born all the time, and our environments determines the rate of the new cells. Most of the activities of forming and recalling memories depend on the hippocampus for processing. In addition, Hippocampus is participated in place and restoring memories, particularly personal ones and those related to finding our way about and spatial perception (14).

1-1 Perception

Our perception changes while we move between different environments. The individual neurons responding to the sense of the place are more than our sensory organs. As our spatial perception depends on strong sense of orientation, different environments relate to different pattern of neural activity. Therefore architectural elements stimulate different activities in our brains, while we realize environments (8).

"Every significant experience of architecture is multi-sensory; qualities of matter, space and scale are measured equally by the eye, ear, nose, skin, tongue skeleton and muscle." – Juhani Pallasma (12).

The human mind and body are in a continual mode of perceiving, looking for experiences that are relevant, meaningful, pleasant, and motivational. Perception is multi-sensory including memory, emotion, visual, and tactile experiences, all of which effect human behavior and response. Perception is a way in which human beings keep track of our relationship to the world, guide our experiences towards things, in an attempt to reveal and understand both the world and our physical environment (19).The interior space has the ability to trigger such responses from us, encourage us to think and understand the relationships created with our surroundings through our experiences (21).

1-2 Memory

Memory differs from perception in that the event or stimulants is not happening in the present moment, memory is the way we make identity and position within the world , but perception is the way in which we view the world (15).

Memory is important in evaluation, decision-making, emotions, interaction, and movement, because it allows for the accumulation of knowledge and the ability to recall events, faces, objects, and places. In the field of neuroscience and related disciplines, the study of memory provides key insights into the physiological workings of the brain in regards to the formation, storage, and recollection of information.

To understand the role and importance of memory in the field of neuro-architecture, we must first understand the process of memory and the mechanics of the brain. Neuroscience researches have concluded that the area of the brain responsible or linked to memory in relation to architecture is the hippocampus. The hippocampus is responsible for analyzing and determining which informational inputs are committed to long-term memory. More specifically, neuroscience has linked the architectural experiences to the Para hippocampal place area (PPA) of the brain which uses the recognition of scenes versus the recognition of

faces or objects, insinuating or fostering a multi-sensory experience in the creation of long-term memory.

Memory process is divided into three parts: encoding, storage, and recall. Memory requires a combination of physiological and neurological processes (7).

1-3 Emotion

Emotion is often applied to a large variety of phenomena, like moods, feelings, anger, and sentiments .These phenomena are a reaction to an experience invoked by the senses due to a specific subject, space, or event.

Neurological theories defined emotion as: Emotion is a primal activity at the very core of human nature. It is the lens through which we engage or perceive the world and the activity within the brain leads to emotional responses. For this reason many neuroscientists like to distinguish between emotion and feeling, emotional processing happen during the perceptual act, while feeling is our conscious awareness of these emotional events. In the architecture, the built environment is initially perceived emotionally—that is, prior to our conscious reflection on its many details. Although the word emotion lacks an exact definition, but neurological theories debate that activity within the brain (20).

The four different affective states include: emotions, moods, emotional traits, and sentiments. Emotion can elicit by the stimulus such as an event in the environment, or some change within us, such as thoughts or memories (6).

- **Mechanism**

Emotional responses to a given stimuli can vary from person to person and culture to culture. Pieter Desmet has created a basic model of emotions in his research, Designing Emotions, which describes the eliciting conditions of emotions with the use of three key variables: appraisal, concern, and stimulus. He uses this model to examine if a stimulus elicits an emotion and if so which particular emotion is happened (19). Below is specific example of how the basic model of emotions works for interior space.

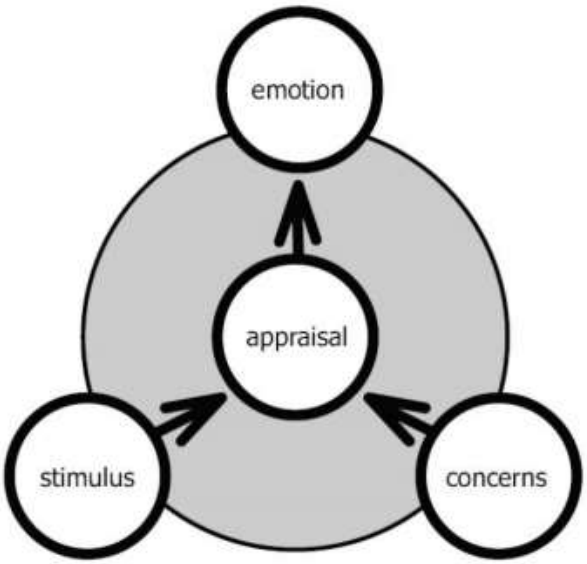

Figure3.
Desmet Model of Emotion

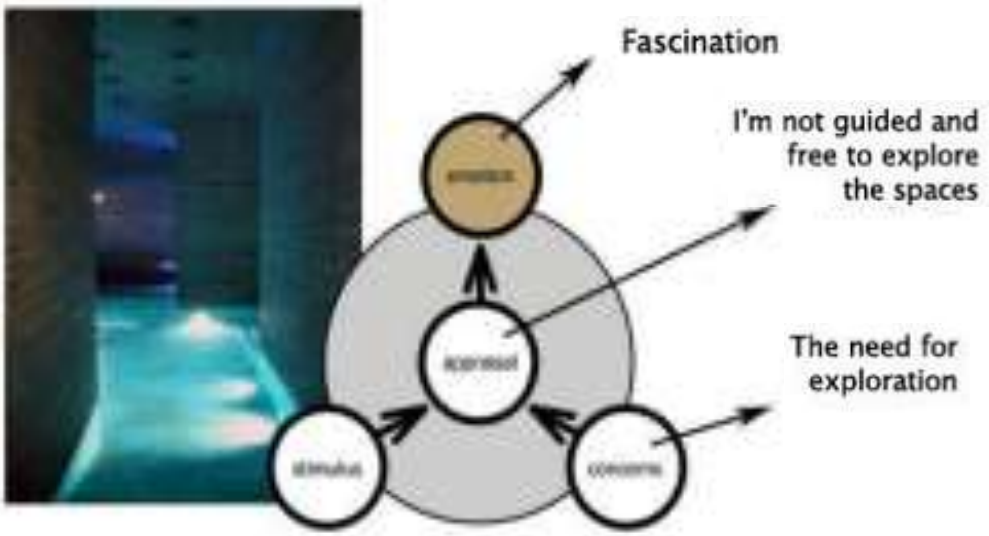

Figure4. An example of how the basic model of emotions applies in interior space

2- The Relation between Neuroscience and Architectural

Architectural design and neuroscience at first glance may appear to be two seemingly different fields, yet they share a common background. There was the famous Egyptian Imhotep, who has been interest in both the field of architecture and that of the sciences and considered by many to be the first architect, doctor, and engineer. Then there is the original Renaissance man Leonardo da Vinci, whose contributions to both science and architecture are well known.

In architecture, new awareness of the complexity of cognitive and emotional processes involved in the daily experience of designed environments has rapidly grown. Such interest also led to the American Institute of Architects (AIA), where John Eberhard founded the Academy of Neuroscience for Architecture (ANFA) in 2003 in San Diego. Since then, various important contributions have emerged from both fields (4,16,17,18).

The mission of this Academy to foster and advance knowledge that links neuro-science research to human responses to the built environment (28). The premise is to consider how each variable of the environment impacts certain brain processes, which in turn alter a specific outcome measures.

There are three Ways to Link Architecture and Neuroscience: The one most addressed within ANFA is the neuroscience of the experience of architecture, the second facet, the neuroscience of the design process, and the third facet is neuromorphic architecture assessing what it would mean for a building to "have a brain" (4). In this research, I will discuss the neuroscience of the experience of architecture and its impact on interior design due to that buildings where people spend much time can influence the fundamental structure of the brain and thus affect people's thoughts and behaviors.

2-1 Neuro-Architecture

Neuro-architecture is a discipline that seeks to explore the relationship between neuroscience and the design of buildings and other manmade structures that make up the artificially created environment that most human beings live within.

The underlying purpose is to assess the impact that various structures have on the human nervous system and brain. More specifically, neuro-architecture addresses the level of human response to the components that make up this sort of built environment.

Neuro-architecture is based on the premise that artificial elements added by humanity have a significant impact on the function of the brain and nervous system. This impact may be beneficial, while in other situations the form and structure of the building may create negative changes to the way the nervous system functions on the long term.

Neuro-architecture defined as built environment designed with principles of neuroscience, which determines spaces that foster memory, improve cognitive abilities, avoid stress and stimulate brain (4). By the merging the two fields of architecture and neuroscience with the scientific goal of earning a better understanding of the relationship between emotions and design by observing people's responses and measuring the related regions of the brain, including the cerebral cortex (which registers and expresses emotions), the hippocampus (which is responsible for memories) and the hypothalamus (which receives messages from other parts of the body).

The importance of study neuro-architecture is to evolution architectural design practices. More specifically, neuro-architecture provides the link between how the brain processes information, the body's responses to external stimuli, and how this information is translated to inform architectural design (5). The evolution of neuroscience, and introduction of neuro-architecture, presents the opportunity to restore perceptual and emotional attributes to interior architectural design.

2-2 Implications for Interior Space

Perceiving spaces is a complex process. It involves sensations such as seeing but also perception. Evaluation, decision making, emotions and affect, as well as interaction, movement all play a part in the neuroscience of architecture and interior space.

2-2-1 Space Perception

Perception is the process of interpreting information gathered from the environment. Bruce Goldstein cleared that "the way in which neurons are wired together in the nervous system influences our perception." In regards to architectural and interior space objects and spaces, visual perception allows for the translate and understanding of spatiality, atmosphere, and visibility.66 Using visual cues, impressions of space, form, surface, texture, color and light are formed and then processed or translated in the brain to provide an understanding of the environment (9).

In 1999, Nancy Kanwisher and her associates published an article in Neuron (7) that established grounds for linking the brain to experiences with architecture. She called the place in the brain where this link is made to the parahippocampal place area (PPA). The PPA is defined as the set of all contiguous voxels within the parahippocampal region that respond significantly more during viewing of scenes than during viewing of faces or objects. They found that PPA activity is not affected by the subjects' familiarity with the place depicted, and

does not increase when subjects experience a sense of motion through the scene, and is greater when viewing novel versus repeated scenes. Also they reported that the PPA was significantly more active when subjects viewed complex scenes such as rooms with furniture, landscapes, and city streets than when they viewed photographs of objects, faces, house (elevations), or other kinds of visual stimuli. By place recognition, the authors mean the matching of current perceptual information to the memories of places that had been encountered in the past and stored in one's cognitive map. They do not use the term disposition, but it seems likely that what are stored in the PPA are the dispositions of past experiences of these buildings (5, 21).

2-2-2 Interior Spaces and Memory

In the experience of the spaces, we use our brain. We see them, we move, we perceive the light and shadow, sound and echo, sense the material, and see the geometry. We realize them with our sensory organs and note them to our brain, where our hippocampus will work on passing them to long term memory.

With the light of our memories the spaces gives us the "feeling" of what they reveal about their types and affect the way we behave. From the functions, planning, materials and orientation of interior spaces, we build up our own database of perceptions. The next step is that anything we perceive from built environment, our brain retrieves a memory, and that's one way of how it affects our brains (4).

As I mentioned earlier, the hippocampus plays a crucial role in the creation of memory of episodes, it is also plays a role for humans in navigation in space as well as episodic memory. This is why neuroscience of the hippocampus and related brain regions become relevant to wayfinding as a particularly component or property of a building.

We experience or remember spaces through a series of connections. Memory offers understanding and meaning through spatial memory, internal sense of space, and orientation (8).

Sensory input is integral to the formation of memory and other architecturally related brain function. In addition reactionary emotions and sentiments are also important aspects in memory. The strength of a memory or the strength of the connection between neurons can be increased by certain factors, producing easier recall and a deeper sense of meaning and understanding (13).

Architecture uses human memory to help occupants both "do" and "learn. The meaning, sense and emotion that an environment helped provide are the most what occupants probably remember.

- **Brain Stimuli and Environment**

In response to appropriate stimuli the brain creates a motive that demands to be satisfied. Environmental installations stimulates our brain, stimulating it perceive, think, understand and write or connect to memories, which makes the brain vitalize, and develop new neurons. So with an enriched environment the brain got more cells- more intelligent (3).

Architecture holds the potential to create new neurons through a process called neurogenesis. Neuron generation in the hippocampal region of the brain is linked to enriched environmental stimuli and exercise (11).

2-2-3 Emotions and Space Perception

Emotions, as we all know, can be of many kinds, but the key point is that emotion is always a multimodal or multisensory experience of someone moving through an environmental field. We take part the world holistically on all sensory levels.

The psychologist Lisa Barrett, notes that when an organism engages with an environmental stimulus the body first produces a "core effect," an initial state of pleasure or displeasure growing from how the sensory properties of the stimulus (perceive the environment) affect the organism's vital condition. The emotions condition our response to specific events or sensory fields (the internal built environment), and they do so pre-reflectively—that is, much of the activity happen before to our "feelings" about events.

The emotional responses are fundamentally embodied, it's mean that emotions also involve or implicate the sensorimotor areas of the brain related to our bodily movements and physical awareness of them. We feel into this world through our bodies in an immediate and multisensory way.

Our response to stimuli is integrated with our peripheral autonomic nervous system-that is, the working of our sympathetic and parasympathetic subsystems that regulate homeostasis. These neural subsystems work in a reciprocal and opposing fashion. The sympathetic system, for example, accelerates the heart rate in response to one bodily situation such as running, while the parasympathetic subsystem slows it down in response to another situation such as rest.

This fact is important because the interior spaces, as every designer knows, can be aligned with these two poles, which is why the different spaces affect us in very different ways. To clear this fact here are two examples; the New National Gallery is rational in its conception, minimalist in its execution, and highly focused on its detailing. The materials steel and glass are perceived as cool to human touch perhaps fittingly, it is a quiet building that allows a place for artistic contemplation. On contrast, Scharoun's Philharmonic Hall design is a multisensory production with a colorful materials, textures, and forms. It is a stimulative environment that demands little in the way of conceptual understanding or analysis (16).

Figure5.
Left: Hans Scharoun, Philharmonic Hall, Berlin (1956-63).
Right: Ludwig Mies van der Rohe, New National Gallery, Berlin (1956-63).

2-3 Applications

There are many linked research conducted in neuroscience towards the practice of architecture. Three main areas of application have been explored and executed by professionals, including facilities for the aging, work environments and sacred places.

1- Trezevant Terrace, an assisted living community with a resident Alzheimer's care home, located in Memphis, Tennessee serves as an example of designing the memory care facility implementations. The applied approach is a therapy gardens involving plants to strengthen the elderly patient's memory, making them suggest the time/seasons with environmental modifications. The main feature of the facility is the easily accessible garden which includes a simple circular path used as a tool to aid wayfinding. That gardens are crucial to helping patients feel more compatibility with time and less trapped .The path allows residents to explore and enjoy the outside while providing a visual element, which helps them back into the facility in case they forget where they are and how to return to their private residence.

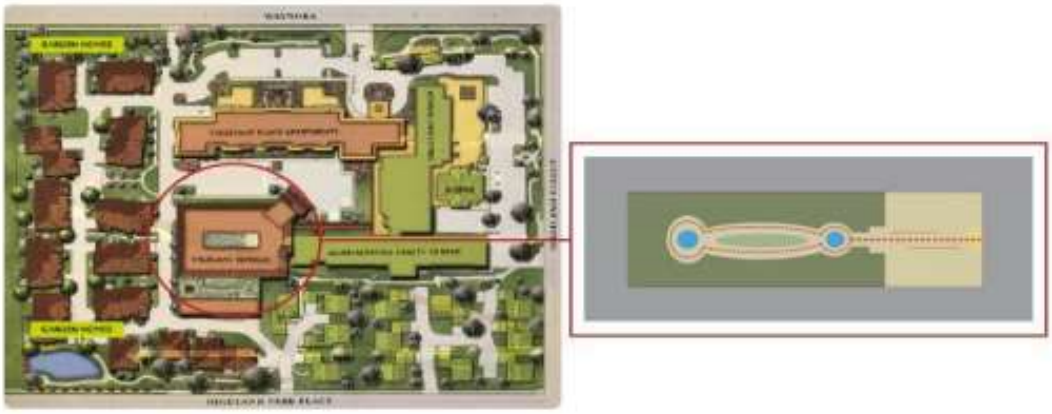

Figure6. Trezevant Terrace Site Plan, an example of designing the memory care facility for elderly patient.

2- One of the early examples includes neuroscience in work environments is Salk Institute, which was designed by architect Louis Kahn as an example for designing workspaces that would enhance creative ability. Salk achieves this by providing vast unobstructed laboratory spaces that adapted to the ever-changing needs of science.

The plan of institute is designed to represent the human body through moving from body to the spirit. The spaces radiate from the exterior service areas (body) inward, and then the biological laboratories (mind), followed by the walkways. And finally to the central courtyard which intersects with a simple stripe of water running its length, representing a place of stillness (spirit). Kahn immersed the laboratories with daylight to creating a welcoming and inspiring environment for scientific research. The selected materials were represent a sense of touch like concrete, lead, glass, teak wood, and special steel which helped in creating the inspiring space.

The water helped in creating a certain atmosphere to stimulate clarity of mind and to guide the eye in creating a visual connection with the surrounding nature. Light and shadow can have a great effect on our emotions and on the way we perceive a space. It affects also our visual impression of the materials, for example concrete that looked white/grey, during midday looked warmer with a light orange hue. (29)

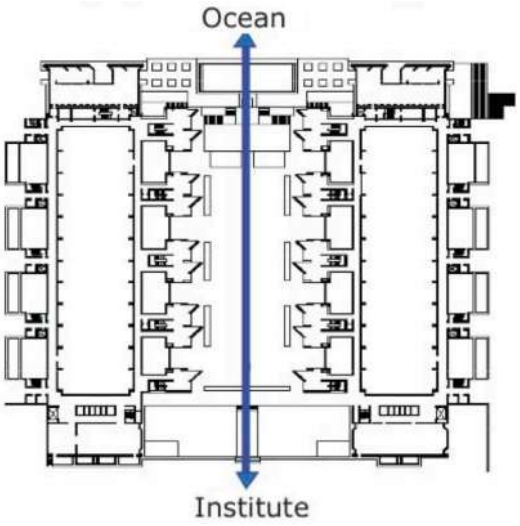

Figure7.
Plan of Salk Institute, view corridor diagram.

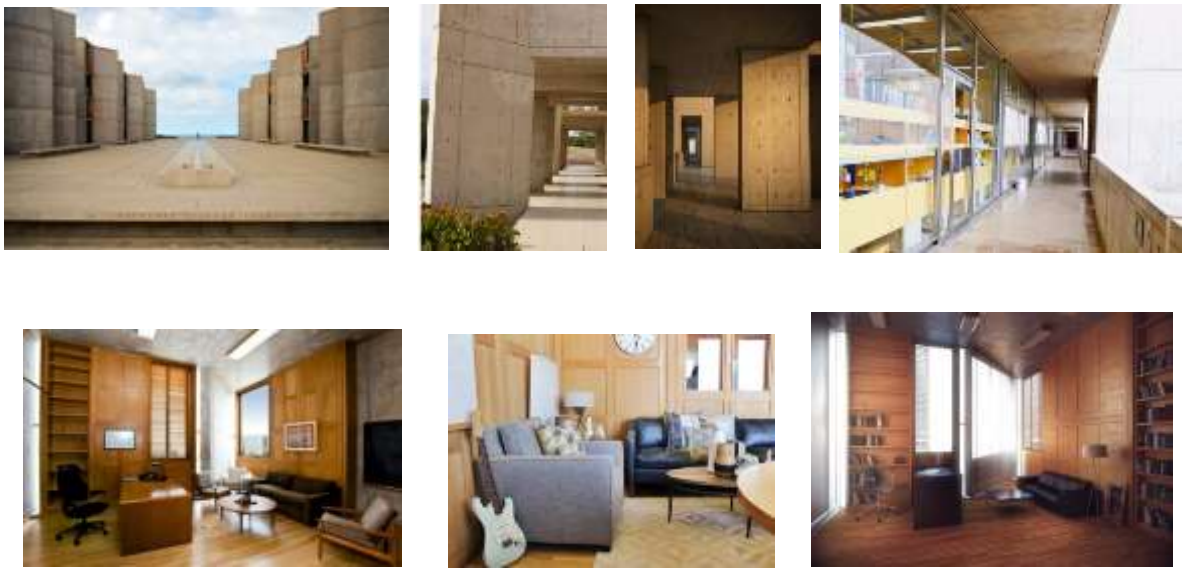

Figure8. The interior and exterior of Salk Institute represent a design feature of neuroscience.

3- Thorncrown Chapel in Eureka Springs, Arkansas, which designed by Euine Fay Jones to be a place for travelers to rest, reflect, and refresh. It considered as an example illustrate how design can impact the human brain and mind. The chapel constructed of organic building materials compatible with nature. With over 425 glass windows and a repeated column and truss structure, the vertical chapel is like a "forest within a forest," reaching 48 feet high, 60 feet long and a mere 24 feet wide. A central skylight allows vast portions of light to spill through onto those below. Special lanterns ornament each column and at night reflect off the glass – as if they were lit somewhere off in the forest. The main important features of the chapel are the glass and the elaborate trusses, which provide a constantly changing pattern of light and shadow throughout the day and creating a space that would stimulate the emotional response in the visitors mind. The play of light and shadow trigger the suprachiasmatic nuclei (SCN) in the brain to influences our alertness and the surrounding nature provides a “quiet” experience for our auditory cortex (5).

Figure9. Thorncrown Chapel Structure, designed by Euine Fay Jones

3- Towards a Neuro-Interior Design Methodology

Research methods in interior design can involve different studies, such as searching through literature, case study, and post occupancy observations. A successful design brings all the research methods together and combines them in the design.

3-1 Design Methodology

The purpose of this research is to studding the findings of neuroscience and promotes their application into interior design, creating a deeper understanding of how the human body relates to the elements of interior spaces. The methodology follows the research typologies used in evidence-based design (EBD).

I assumed that evidence can be a powerful tool used to inform designers' decisions. EBD defines as "a process for the conscientious, explicit, and judicious use of current best evidence from research and practice in making critical decisions, together with an informed client, about the design of each individual project." In short, EBD is when decisions about physical space are based on research and data. "EBD has three main components: doing the research, testing and seeing the results." It's similar to the scientific method, where experimentation and outcomes either support or disprove the hypothesis. (26)

The three components of methodology are: the first is an understanding of the human brain, the senses, and neurobiology as this is the basis in determining the body's primal reaction to interior space stimuli. Second is a literature review of the findings in neuroscience research and their application to architectural design. The third step of the process determining the principles of neuro-interior space in which research findings bridged and reinforce the connection between neuroscience and interior design, resulting in a design that has the ability to elevate the human experience.

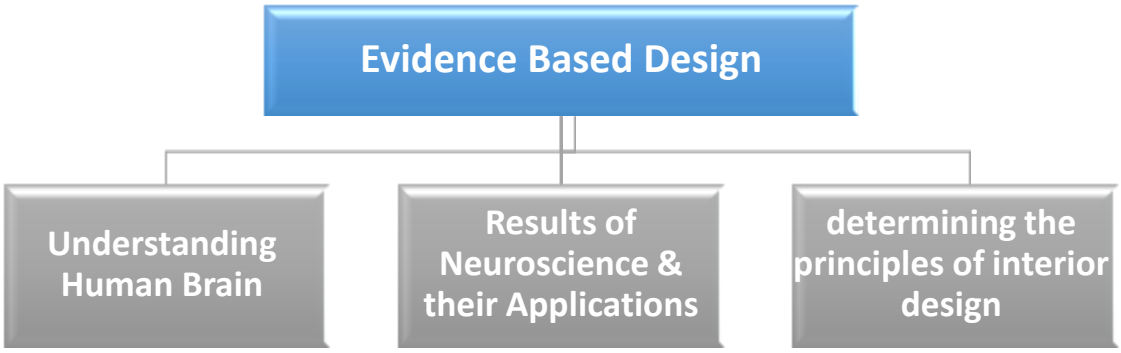

Figure10. Design methodology of neuro-interior design

3-2 Determining Neuro- Interior Design Principles

The best way to approach a methodology to apply neuroscience in interior design is understand and research the results of neuroscience in relation to interior space and the case studies in which these findings implemented. The design process begins with the determining of the different stimuli that require to be achieved in interior space. Also it is important to understanding of the various interior spaces and the key features and applies neuro design principles which have been to evoke inspiration or a sense of enlightenment.

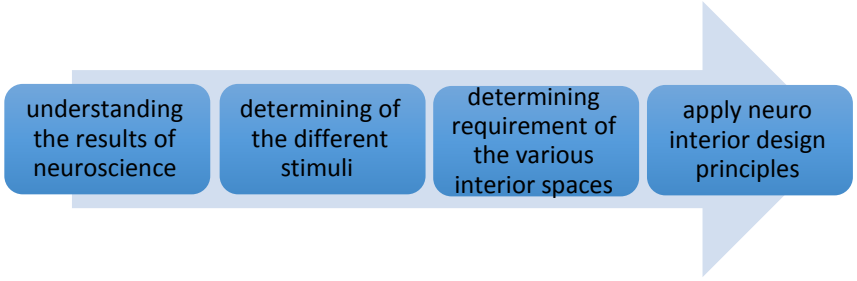

Figure11. Design process of neuro-interior design

In order to understand the relation between neuroscience and interior space, we can start with our basic activities that we use our five senses to perceive the environments. There is no doubt that perception involves properties of space include color, light, texture, smell and sound as well and also with our navigation in space, where the human brain registers sensations through sight, sound, touch and elements of interior design such as form, color, materials, natural light, nature, and sound impact the human psyche (22). Neuroscience explains on how physical environment affects our cognition, problem solving ability and moods. Understanding these principles can guide interior designers to create spaces serving better spatial orientation, reinforcing cognitive abilities and minimizing negative effect in emotions and motivation.

There are numbers of design principles related to interior spaces which affected with neuroscience. Classifying these principles gives a clearer perspective for neuro interior design process, so the designer can adapt them in the different spaces.

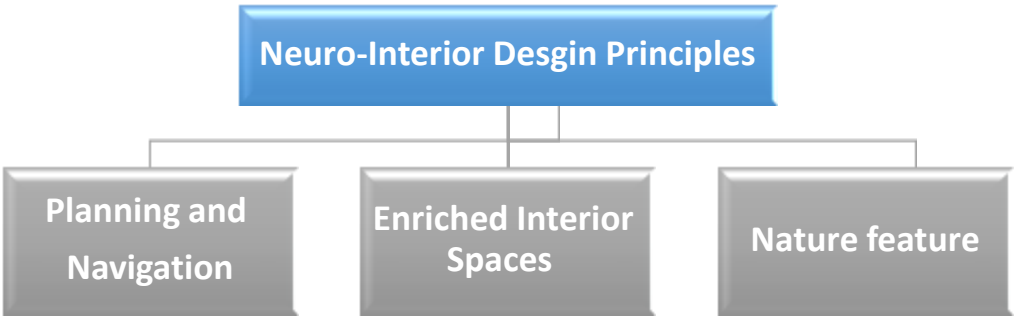

Figure12. Neuro-interior design principles

3-2-1 Planning and Navigation

A good environmental image gives its occupant an important sense of emotional security. Normally we do not lost in the environments that we are used to, or that well-ordered design. Feeling of being lost, hesitation, delay in navigation, causes stress especially in hospitals or work spaces. Clear planning should be a principle in every healthcare ,public buildings, work spaces where users can more capable to find their way, or form a mental map of interior spaces.

As mentioned earlier Hippocampus related with memory is very essential for way finding and navigation. How do we remember our ways in buildings, is either from memories from previous visits to similar buildings or by learning thorough the spatial planning by recalling the landmarks. Hence landmarks don't help when they are used abundantly. It could be using colors as a landmark helps the users to find their way to the target. The use of colors can be a part of the directions lines, signals or lights.

However, the advantage of visual landmarks is that they can serve to keep people "oriented" as they move within and between different environments, such as rooms or hallways, and in so doing provide stability to the spatial representations within the hippocampus, reinforcing a strong sense of place (14).

The stimuli in an environment play important role to contributing a strong sense of place by the consistency of neural activity in the hippocampus in the presence of such stimuli. So by providing prominent landmark that serve to establish uniquely memorable routes, the "memorability" of an environment can be enhanced, and hence a strong sense of place can be reinforced.

It is also hypothesised that the design of spaces with high visibility and connectivity with multiple points help to understand space, and excite curiosity and interaction with the place. Neuroscience research suggests that the neurobiological system that rewards learning, via endomorphin release in parts of the brain involved in memory of place (parahippocampal cortex), may encourage exploration. Therefore, views that hint of the presence of hidden information and accessibility by using curved lines for example may, in fact, excite learning and increase of environmental experiences.

Figure13. Clear and hidden information planning and its effect on interior space

In a study to evaluate the preference of varying areas with different degrees of permeability and occlusion, found spaces that achieved a volume of visual permeability from 20 to 40% were preferred and there is no preference of the most occluded space, in which the total volume of visual permeability was only 13%. Also there is a preference of both visual complexity and order, and desire to understand an ordered, permeable and easy-to-learn environment (30).

3-2-2 Enriched Interior Spaces

Neuroscience researches have referenced the scientific connection between the human brain and environment, which has demonstrated that enriched environments can lead to brain cell growth. Other studies have concluded that interaction with a stimulating environment could be connected to the regions of the brain that are responsible for memory formation. That interaction can happen through integrating necessary components of elements of interior environment in its design, therefore environmental settings can alter emotional processes, such as stress and memory, and form our behavior and mood also.

- Form

Neuroscience and cognitive psychology indicated towards a connection between shapes of objects and feelings. It is leading us to understanding of the way humans perceive different spaces and how the geometry of spaces affects our feelings.

Our preference for objects has been shown to be influenced by many factors including familiarity, symmetry, contrast, complexity, and perceptual fluency (10). It means that the more fluently perceivers can process an object, the more positive their aesthetic response.

It explains the people prefer symmetric shapes, as they contain less information than asymmetric shapes. It also cleared that angular hexagons are less pleasing than round lines or circles. Rounded and curved objects subconsciously make us feel safer than pointy or angular objects. According to Zeisel, “The reason has to do with your peripheral vision and is linked to a primitive part of the brain called the amygdale… If you were to walk down a dark, narrow tunnel lined with sharp rocks, you wouldn't be able to think about anything except avoiding getting hurt.” Using curved elements relax our brain. Furthermore, people with low expertize in the fields of design prefer curved over angular shapes because they are simple (circles and hexagons), while experts prefer the more complex polygons (2).

The volume of space has also other impacts on our brain which influence our behaviors. One of the most dominating elements of volume is ceiling. A change in ceiling height is a large field of study which concerns widely environments for research and productivity. High ceilings reveal freedom and thinking independently. However low ceilings signify confinement therefore it collects the attention to certain point which increases focus. The different effects of heights can be used to strengthen ability of concentration or encourage creativity . For example, Spaces designed with lower ceilings, for rooms involving learning, can help gathering attention. On the other hand when more creativity is desired, higher volumes might support thinking broadly (14).

Figure14. Different interior spaces with different form

- Material

Another key concept that enriches interior space is the rich expression of materiality. Materials influence our sense of touch and the visual impression architecture leaves us with. Through the use of local material such as wood and clay tiles, the user is intimately linked to a sense of place. The contrast between the different materials allow for an emotional connection to the space such as a sense of calmness and tranquility throughout the grounds.

Neuro-architecture through research and investigations has greatly emphasized the importance of touch, even more than sight, in our understanding of the built environment as well as in our psychological state of mind. Using materials that influence our sense of touch serve as a medium, which ties us to our environment, evokes emotion and can at times heal (19).

Figure15. Interior space represents rich expression of materiality

- Color

Color is another area where neuro-architecture has a lot to tell us. Studies have proven that use color in interior spaces design influences people and their thoughts; it can leave a lasting impression on the mind and conveys the message which plays a significant role in creating ambiance or the psychological mood. For example, merging in red environments may

improve performance on detail-oriented cognitive tasks whereas blue spaces associated with enhanced creative thinking.

Perceived color is based on the relative activity of ganglion cells whose receptive field centers receive input from red, green, and blue cones. It appears that the ganglion cells provide a stream of information to the brain that is involved in the spatial comparison of three opposing processes: light versus dark, red versus green, and blue versus yellow (19).

Perceptions of colors differ from age to age, for enriched interior environments it will be a more common approach to determine the colors by their brightness colors instead of grouping them with their perceptions. Brighter colors behave as a stimulus since they are more recognizable, where brains remember the things easily that are more remarkable. If the colors are used in a right way with the spaces, it can strengthen the position in the mental map, and stimulates the memory. However same stimuli is not desired for every function, for example the bright colors attract more attention and if they are used in spaces where attention is not expected, the attention will be collected in the wrong place. The better solution will to involve neutral colors, with less contrast, and preferably light colors to perform with lighting (14).

Figure16. Brightness of colors and their effect on interior space

- Light

Neuroscience researches reveal that exposure to light have significant impact on mental state, cognitive function, behavior and physical health. Recent studies about measures of neuroendocrine levels revealed the correlation between daily fluctuations in melatonin, which modulates sleep and wakefulness, and elevated cortisol levels, which prepare the body for activity. (5)

Consistent with these findings, Edelstein found significant differences in heart-rate variability (HRV) during performance of memory tasks when subjects were exposed to less than 15 minutes of red light, versus bright white (with a blue peak) light. Whereas many studies have focused on the influence of blue and bright white light on melatonin responses, this experiment demonstrated that red light is associated with changes in cardiac responses. In red light, HRV relaxation was appropriate during rest, and activated only during the memory task. In contrast, bright white light with a blue peak was associated with a constantly active heart rate throughout the experiment.

Thus design of light should include the findings that reveal the spectral range, intensity and pattern of light important to human health and function, as well as vision. Lighting design should respond to the specific needs of the users, in addition to the uses of a space, thoughtful

lighting strategies should provide for safety and egress, as well as individual controls to modulate light exposure according to clinical needs, functional tasks and user status. (30)

Light can also have the ability to stimulate higher cognitive brain activity, independently of vision (5).Students who are fortunate to be in a school classroom with large windows and skylights perform better on tests than those in rooms with very little natural light — between 7 percent and 18 percent better.

Natural lighting also has the ability to affect the mood of the user. Daylight is a solution for lighting general spaces, if it is opening directly to outside. However for activities involving attention, for example workspaces or teaching activities, direct day lighting will also bring the problem of glare. But the glare can be prevent by using low transmitting glass , or shadings, or use artificial lighting for task lights to enhance the attention.

Figure17. Natural light can also have the ability to stimulate higher cognitive brain activity

3-2-3 Natural Feature

When it comes to stimuli, nature with varieties in color and geometries is rich stimuli, that we are naturally encoded to be stimulated. In other words nature provides a source of neurological nourishment. Where interacting plants provide visual complexity, which is a source of neurological nourishment. (19)

Likewise, greenery and other natural features in the interior environment may improve mood, enhance working memory, improve focus, accelerate recovery from stress and surgery, and stimulate learning abilities (25).

Neuro-architecture research has shown that being in or viewing nature triggers parts of the brain, which are associated with empathy and love to become more active. For example effect of nature on reducing patient stay has been studied comparing the patients in different rooms according to their view to nature. As stated in the previous example, the presence and ability to see or interact with nature promotes our physical and psychological well-being.

Neuro-architecture has made similar conclusions about water. It is understood that water affects us on various levels. It can also have a therapeutic effect on the mind by placing us back in touch with the balance and harmony of nature. The sound of flowing water, we associate with meditation and relaxation soothes the mind and the body. The sight of water as a feature of nature evokes feelings of delight and serenity.

Furthermore Indoor planting, or even paintings or artworks represent natural elements, can have a positive neuro-interior design impact also (19).


Figure18. Nature provides a source of neurological nourishment.

3- Discussion

Using the neuro-Interior design methodology, research has found a way to assist designers in applying the results of neuroscience within the various interior spaces through the design process and define the main neuro-interior design principles according to the following table.

principles	stimulus		Impact on human experience
1-Planning and navigation	Clear planning		Find the way. Form a mental map of interior spaces.
	Hidden planning		Excite learning and exploration.
2-Inriched interior spaces	Form	symmetric shapes	Feel satisfy and aesthetic response
		Curved line	Feel safety and pleasing(from low expertize)
		Complex polygons	Aesthetic preference(from experts)
		High ceiling	Encourage creativity
		Low ceiling	Strength concentrating
	Material	Rich expression of materiality(sense of touch)	Emotional connection to the space
	Color	Brightness colors	Strength the mental map. Stimulates the memory. Attract attention.
		Neutral colors	less attention
	Light	Natural light	Stimulate higher cognitive brain activity. Effect mood.
		Red light	Stimulate relaxation.
		Bright white light	Stimulate activity.
3-Natural features	Connection with nature		Improve mood Enhance working memory, Improve focus Accelerate recovery from stress and surgery Stimulate learning abilities.
	water		Meditation and relaxation. Evokes feelings of delight and serenity.

Table 1. The principles of interior design and its effect on human performance

Conclusions and Recommendations

The research created an understanding of how the human brain is affected by external stimuli and an understanding of how the information gathered by neuroscientists can be used to guide interior design.

Neuro-architecture is a new field that is rapidly progressing towards the development of guidelines that can ultimately be integrated into the design process.

The research can serve as an example and catalyst for interior designer in gaining knowledge through the methodology of neuro-design to ultimately gaining a better understanding of how every element of interior space can affect the user.

I truly believe that neuro-design is the link that will allow designer to implement knowledge about the human body into future designs in an effort to create interior spaces that is more meaningful, attuned to our needs and can improve our overall wellbeing.

Link neuroscience with interior space will not in any way prevent technological advances or creative thinking. In fact the new methodology will offer interior designer a means to rethink their tasks and provide design with a more secure theoretical basis -because knowing ourselves will help us better understand the people for whom we create design.

Further research is needed in order to use these results and apply them in specific interior spaces like work environment, educational building, health care center....etc.

References

1- Badger, Emily. “Corridors of the Mind.” Pacific Standard. November 5, 2012. http://www.psmag.com/culture/corridors-of-the-mind-49051 (Accessed May 6, 2018).
2- Bar, Moshe. and Neta, Maital. "The proactive brain: Using rudimentary information to make predictive judgments". Journal of Consumer Behavior 7(2008): 319-330.
3- Diamond, Marian C. "Response of Brain to Enrichment". An Acad Bras Cienc. 73 (2001):211-220.
4- Eberhard, John P. *Brain Landscape*: The Coexistence of Neuroscience and Architecture. New York: Oxford University Press, 2008.
5- Eberhard, John P. “Applying Neuroscience to Architecture.” Neuron 62, Issue 6 (2009):753-756.
6- Ekman, Paul. and J. Davidson Richard .*Nature of Emotion: Fundamental Questions*. New York: Oxford University Press, 1994.
7- Epstein, Russel, Alison Harris, Damian Stanley and Nancy Kanwisher. “The Para hippocampal Place Area.” Neuron 24 (1999):115-125.
8- Esther M. Sternberg and Matthew A. Wilson. “Neuroscience and Architecture: Seeking Common Ground,” Cell 124 (2006):249-242, accessed April 2, 2018, http://www.cell.com/cell/fulltext/S0092-
9- Goldstein, Bruce. *Sensation and Perception*, 9th Edition. Belmont, CA: Cengage Learning, 2013.
10- Hekkert, Paul. "Design aesthetics: principles of pleasure in design". Psychology science, 48(2006):157-172.
11- Holladay, April. *How Does Human Memory Work*. USA Today, March 15, 2007.
12- Holl, Steven. and Juhani Pallasmaa. *An Architecture of the Seven Senses, In Questions of Perception: Phenomenology of Architecture*. Tokyo: a+u Publishing Co., Ltd., 1994.
13- Jeffrey Nevid. *Essentials of Psychology: Concepts and Applications* .Boston, MA: Houghton Mifflin Co. 2006.

14- Kayan, Cagil. *Neuro-architecture: Enriching healthcare environments for Children*, Master thesis project, Chalmers Architecture, MPARC 2011.
15- Kirkbride, Robert. *Architecture and Memory*. New York: Columbia University Press, 2008.
16- Mallgrave Harry. *The Architect's Brain: Neuroscience, Creativity, and Architecture.* Chichester: Wiley-Blackwell 2009.
17- Pallasmaa, Juhani.& Mallgrave Harry. and Arbib, Michael. *Architecture and Neuroscience.* Finland: Tapio Wirkkala-Rut Bryk Foundation, 2015.
18- Robinson Sarah. and Pallasmaa Juhani. *Mind in Architecture: Neuroscience, Embodiment, and the Future of Design*. Cambridge: MA: MIT Press, 2015.
19- Ruiz, Mayra. *Hawaiian Healing Center: A Weaving of Neuro-Architecture and Cultural Practice*. University of Hawai'i, 2015.
20- Schwartz, Norbert. *Feelings as information: Informational and motivational functions of affective states*. In Handbook of Motivation and Cognition: Foundations of Social Behavior, volume 2, edited by E.T. Higgins and R. Sorrento, New York: Guildford Press, 1990.
21- Shemesh, AVISHAG.& Bar, MOSHE. and Jacob , YASHA." SPACE AND HUMAN PERCEPTION – Exploring Our Reaction to Different Geometries of Spaces", The Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), Hong Kong (2015):16-19.
22- Sternberg, Esther. *Healing Spaces: The Science of Place and Well-Being.* Cambridge. Mass: Belknap Press of Harvard University Press, 2010.
23- Whitemyer, David. "The Future of Evidence-Based Design". International Interior Design Association. http://www.iida.org/content.cfm/the-future-of-evidence-based-design (accessed October 14, 2018).
24- Zeisel, John. & Nina M. Silverstein. & Joan Hyde. & Sue Levkoff, M. Powell Lawton and William Holmes. "Environmental Correlates to Behavioral Outcome in Alzheimer's Special Care Units." The Gerontologist 43 (2003): 697-711.

Internet Sources

25- Wikipedia the free encyclopedia." Neurology and Education". wikipedia.org. wikipedia.org/w/index.php?title=%D8%B9%D9%84%D9%85_%D8%A7%D9%84%D8%A3%D8%B9%D8%B5%D8%A7%D8%A8_%D9%88%D8%A7%D9%84%D8%AA%D8%B1%D8%A8%D9%8A%D8%A9&oldid=26346780(accessed February 1, 2018)
26- http://www.iida.org/content.cfm/the-future-of-evidence-based-design,(14-10-2018)
27-Neuroscience Quarterly. "Society for Neuroscience". www.sfn.org. http://www.sfn.org/~/media/SfN/Documents/NQs/2003/NQ_Fall_2003.ashx (accessed August 7,2018)
28- ANFA the Academy of Neuroscience. "Neuroscience Healthcare". www.anfarch.org. http://www.anfarch.org/wpcontent/uploadsNeuroscienceHealthCareANFA2004.pdf,(accessed September 15, 2018).
29- Salk. "ABOUT SALK ARCHITECTURE". www.Salk.edu. http://www.Salk.edu/about/architecture.html(accessed August 25, 2018)
30- Neuroarchitecture. "New approaches to the creation of healthy environments". www.worldhealthdesign.com. http://www.worldhealthdesign.com/Neuro-architecture.aspx,(accessed August 1, 2018).