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MEASURING SPACE-RELATED EMOTIONS

Potential usage of modern technologies in the emotional appraisal of spaces

Nader Samir Mahmoud [1,*], Eman H. A. Afifi [1], Ossama A. Abdou [2]

[1] *Department of Architecture, Faculty of engineering at shoubra, Benha university, Cairo, Egypt.*
[2] *Misr International Universit, Egypt.*
** Corresponding author*

E-mail address: ns.ezzeldin@icloud.com , emanhanimafifi@gmail.com, oabdou@hotmail.com

Abstract: The main motivation of this research is to bridge the gap between modern neurological technologies and architecture, mainly on the topic of emotional and psychological response detection. This research conducts a revision of topics such as human perception, visual perception, space-generated emotions, psychological impact, and human emotions, beside a revision of modern technologies currently being implemented in the medicinal field with the purpose of emotion detection such as electroencephalography EEG and functional magnetic resonance imaging fMRI from an architectural practice perspective. Moreover, this research (a) suggested characteristics that are thought to be of great importance if included in any emotion's evaluation tool that is meant to be used in architectural practice, (b) evaluated reviewed technologies based on the suggested characteristics in order to determine the most suitable available technology, and (c) suggested futuristic actions to be taken into consideration by technologies' manufacturers and developers to finally deliver a version of the technology that fulfills architectural practice demands, particularly in detecting emotional responses generated by spaces.

Keywords: Space perception, Psychology, Physiology, Emotions, EEG fiber.

1. Introduction

Architectural spaces are generally known to generate psychological and emotional response in humans due to physical, environmental, aesthetical, cultural, and social factors [1]. Therefore, architects' and interior designers' main goal is to deliver the most convenient and emotionally pleasing space for its inhabitants. Nonetheless, means and methodologies that are used to determine the degree of emotional pleasure and emotional reactions towards spaces are still done in an arbitrary manner or limited to verbal reporting and/or in most favorable cases to conducting questionnaires that are designed to enable the expression of emotional reactions while experiencing the space.

Such means and technologies can be inaccurate, subjective, biased, and can be easily manipulated by the reporter due to the absence of numerical and/or graphical outcome. Additionally, they lack the ability to depict the neural brain activity which is the main source and cause of all human's reactions and behavior whether it is internal or external.

The rise of many advanced neurological, physiological, and psychological technologies that are currently being implemented with the intention of determining the emotional responses generated by various phenomena such as electroencephalography (EEG), functional magnetic resonance imaging (fMRI), and other techniques such as Positron Emission Tomography (PET), and Computerized Axial Tomography (CAT) scan, can deliver a reliable, objective, and an unbiased method to determine the emotional response towards architecture and architectural spaces if such technologies were evaluated and critiqued from an architectural point of view to suit the nature of architectural practice as well as the nature of critiquing and evaluating architectural products. Moreover, such technologies can deliver a graphical representation of the neural activity of the brain while experiencing the emotional response due to space perception in a subjective, accurate, and unbiased manner.

The problem

This research's aim is to investigate and suggest solutions to the following problems: (a) the emotional response to architectural spaces is usually done arbitrarily or using tools such as verbal reporting and questionnaires which are inaccurate, biased, can be manipulated, and subjective in some cases, and (b) the absence of an accurate and reliable tool to detect, depict, objectively represent and evaluate emotions raised while experiencing architectural spaces.

Goals and objectives

This research main objective is to investigate and review current modern technologies that are used to accurately detect human's emotions with the goal to determine the technology that is, or at least, has the best potentials to fulfill architects suggested demands particularly concerning emotion's detection and depiction. Additionally, the research will critique the selected technology from an architectural perspective in terms of advantages and disadvantages and thus suggest future actions and modifications to be applied to the technology to best meet the architecture practice and to facilitate detection of emotions while experiencing architectural spaces.

1.1 Human perception

Perception is the process of developing a hypothesis about what is provided through the process of sensation [2], as in perception information is obtained from the environment to make sense of it [3], or in other words, it is the process which gives meaning to the sensation [4]. Over the past three decades, psychologists and neurologists have accomplished many advances to the study of perception [5].Today, as confirmed by studies, perception is a conscious experience that takes place when electric signals generated by specialized cells (i.e., receptor cells) are received by the brain which translates those received signals into meaningful experiences [6] [7] [8].

The perceptual process is the process in which all senses collaborate to produce a comprehensive and understanding view of the world [2]. Simply, its goal is to take information about the environment then make sense or perceptions of such information [3].

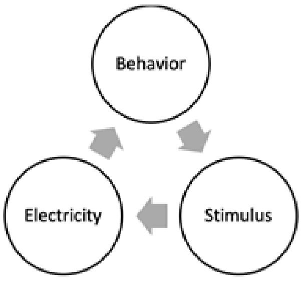


Fig 1. The perceptual process [1]

Stimuli are inside and outside the body; they apply energy on receptor cells that can be in the form of sound or light waves, heat, or pressure which those cells can respond to [2]. According to Goldstein (2010), there exists specialized receptors which can receive stimuli from the environment, then transduce the force exerted by the stimulus into electric energy, thereafter, transmit that energy to the brain to create representations of the stimulus [8]. Therefore, the kind of sensation the stimulus produces refers to the quality of the stimulus [2].

Electrical signals created inside the nervous system are the main source of perception. They are created in receptor cells through the operation of transduction in which energy is transformed from one form of energy - depending on the type stimulus- to electrical energy. Afterwards, through charge exchange between neurons, when connected neurons are activated, a transmission sequence is started until it reaches the brain. Finally, in the processing stage, the brain creates another representation of the actual stimuli [8].

As in Fig 2, light reflects of a butterfly then enters the eye and stimulates the retina light receptors which transduce the light to neural signals that travel through the optic nerve to the brain which processes received signals into sensation and perception.

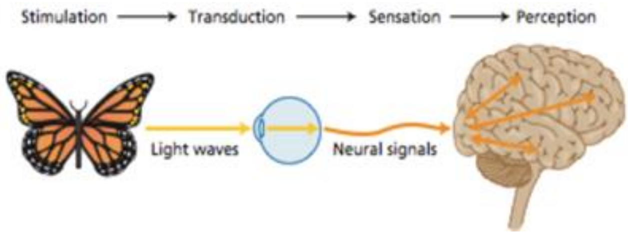


Fig 2. The sequence of electrical operations within the perceptual process [4]

The casual use of the term behavior in every day`s life - as the way or manner with which people act – is different from what the term refers to in psychology. In psychology, behavior occurs when a stimulus in the environment exerts an influence on an individual resulting in an activity or a response [2], and the term refers to: "Anything a person or animal does, feels, or thinks" [9].

Behavior is classified into two types; "overt" behaviors – such as pupils' dilation and sweating - that are obvious and can be easily detected and identified, and "covert" behaviors – such as changes in heart rate and brain`s electrical activity - that are not directly observable and can be detected only using sophisticated instruments [9].

Moreover, behavior comprises all kinds of human activities such as motor activities (walking, speaking), cognitive activities (perceiving, remembering, thinking, reasoning), emotional activities (feeling happy, sad, angry, afraid) [9].

Regarding the characteristics of behavior, there are four major facts about nature of behavior: (a) has a bodily basis, (b) is dynamic, (c) varies from person to person, and (d) is social [2].

1.1.1 Neurology of perception and knowledge

Neurologists first discovered brain functions by examining the brains of individuals with brain injuries or diseases. Injured soldiers, for instance, may sustain damage to certain regions of the brain but still survive, allowing researchers to link the damaged region of the brain to the loss of function in other parts of the body [10].

A brain module is an area of the brain where neurons that respond to similar stimuli are often grouped together [8]. For this paper the area called Parahippocampal place area (PPA) is of paramount importance and is responsible for the perception of places [8].

The (PPA) area is responsible for identifying objects' location and spatial position to guide actions [3]. It is also activated by photos depicting indoor and outdoor scenes as well as responding to both empty rooms and rooms that are completely furnished [8].

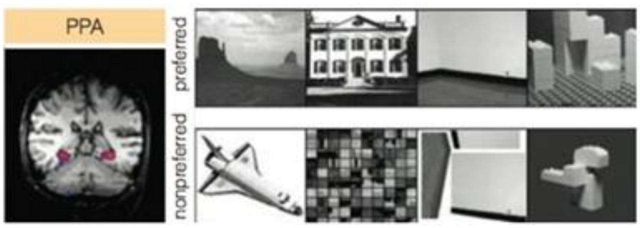


Fig 3. The parahippocampal place area [8]

1.1.2 Space perception

The perception of any space is an objective variable and not a physical one [11]. Thus, the way spaces are arranged, shaped, colored, lighted, and connected can alter one`s perception of spaces. Moreover, it must be emphasized the fact that everyone will perceive the space differently, according to their own set of knowledge and experiences - which will differ from the one that the designer of the space possesses - a characteristic which should be thought of throughout the entire designing process [12].

Within the context of space design, the philosophy and psychology of how space is perceived is a way in which architects can manipulate a certain space to achieve a particular feeling or perception from those who are in it [13].

According to Pop (2013), for a theoretical study regarding the concept of perception, the study of space perception must be filtered through the following sequence:

Fig 4. The proposed sequence of space creation and perception

Meaning that the space created by architects will become reality, and then it will be perceived by a user [12]. During the first stage of the perceptual process, s/he will register just its physical aspects. Then, during a second stage, the individual will be capable of distinguishing the three-dimensional space, while identifying and recognizing its meaning, its function and / or utility - based upon past experiences, namely previously gathered and stored information [12].

An article from the Journal of Research Practice states: "When creating an interior spatial design for various types of uses and experiences, considering both the aesthetic qualities of a space and how people experience interactions and sensations within the spaces is of great importance" [14]. Moreover, stress induced by the physical environment destroys positive moods, also functional and symbolic stressors can degrade performance [13].

1.2 Human Emotions

Human emotion is characterized by physiological arousal, expressive behavior, and conscious experience. The term "emotion" comes from the Latin word "emovere" meaning "to stimulate." [15] [16] [17].

Emotions are how people deal with issues or events that are especially significant to them. It has a wide range of effects on humans. The same emotions can have diverse impacts on different people, and even on the same person under different circumstances. Emotions tend to influence all aspects of the person [18].

Furthermore, the nervous system, which comprises the brain, spinal cord, nerves, and sensory receptors, is responsible for all emotions [19]. And emotional states can last anywhere from seconds to hours and vary greatly in intensity [18].

Emotion is defined as "An episode of interrelated, synchronized changes in the states of all or most of the five organismic subsystems in response to the evaluation of an external or internal stimulus event as relevant to major concerns of the organism" [17]. Moreover, the differential emotions theory defines emotion as; "A complex process with neurophysiological, neuromuscular, and phenomenological aspects" [18].

The term emotion is often confused with other terms such as "feeling" or "mood", as feelings are the result of an emotional experience. And because the person is aware of the experience, it is classified in the same category as hunger or pain. Thus, a feeling is: "The result of an emotion and may be influenced by memories, beliefs and other factors" [16].

1.2.1 Components of emotional experiences

While there is some disagreement concerning the sequence, there is a general agreement that emotional experiences consist of three components: a subjective experience, a physiological response, and a behavioral or expressive response [16].

Fig 5. Emotional experience components

1.2.1.1 The subjective experiences

Every emotion begins with a subjective experience, also known as a stimulus. While basic emotions are expressed by all people regardless of country or background, the event that causes them can be profoundly personalized [16]. Subjective experiences can range from as basic as seeing a color to as serious as losing a loved one. No matter how strong the experience is, it can elicit a wide range of emotions in a single person, and the emotions each person feels may differ [16].

1.2.1.2 The physiological responses

During experiencing an emotion, the sympathetic nervous system, a part of the autonomic nervous system, controls several physical reactions as it is responsible for regulating involuntary bodily responses. Many psychologists believe that physiological responses and emotions have helped humans evolve and survive throughout history [16].

Interestingly, research has found that autonomic physiological responses are strongest when a person's facial expressions most closely reflect the emotion they're experiencing. In other words, facial expressions play a significant role in physical response to emotion [16].

1.2.1.3 The behavioral responses

The behavioral response is the actual manifestation of emotion. The actual expression of the emotion is the behavioral response aspect of the emotional response. Depending on societal norms and personality, behavioral responses can include a smile, a laugh, or a sigh, among many other reactions [16].

Furthermore, emotion is much more than a mental state, as evidenced by the physiological and behavioral responses connected with it. Emotion influences both behavior and health. Furthermore, emotional intelligence is heavily reliant on the ability to comprehend the behavioral responses of others [16].

1.2.2 Emotions in the neurophysiological level

Emotion is primarily described at the neurophysiological level in terms of patterns of electrochemical activity in the nervous system, particularly in the cortex, hypothalamus, basal ganglia, limbic system, and facial and trigeminal nerves [18]. When an emotional state occurs, one or more of the following events occur.

- During emotions, electrophysical changes occur in the muscles of the face.
- Changes occur in brain electrical activity, the cardiovascular system, and the respiratory system.
- In times of intense rage or fear, the heart rate might rise to 140 to 160 beats per minute.

These variations in body processes during intense emotion imply that almost all neurophysiological systems and subsystems of the body are involved in emotion states to varying degrees. Such changes inevitably have an impact on a person's perceptions, attitudes, and actions. These physiological changes may also lead to medical and mental health issues [18].

Furthermore, the limbic system influences emotions, visceral emotional reactions, motivation, and mood [19]. Many scientists believe that the limbic system of the brain involves a relationship between two brain structures: the hippocampus and the amygdala [20]. Additionally, the hypothalamus regulates the internal environment of the body as well as certain elements of behavior. Neurons in the hypothalamus control emotions (such as fear, rage, and pleasure) [19].

According to Hall (1998), the amygdala appears to be the core of emotions, particularly fear and the physical sensations associated with feeling frightened. And it has attracted the most attention in terms of its function in fear and anxiety [20]. According to research, the amygdala is triggered when people are shown scary images. Furthermore, amygdala injury inhibits the fear response [18] [21].

Furthermore, PET scan investigations show that blood flow to the amygdala rises during difficult and stressful tasks such as trying to solve a puzzle with no proper answer [21].

1.2.3 Space-generated emotions

According to Augustin (2018), the most essential function of design is to affect feeling. Being in a space can lead to a feeling of calmness. scientists have investigated the emotional effects of experiencing design. Their findings support both space related or generated emotions and the effect of space over emotions [13].

Russell and Snodgrass created one of the most well-known and respected fundamental models of the emotional experience of space - Figure 6. Russell and Snodgrass (1987) identified the emotional characteristics of spaces and the states that can be induced through design. They employ two factors for this purpose: pleasurability and energy level. Therefore, spaces can be relatively more energizing and pleasant (e.g., exciting, exhilarating, pleasing, or interesting), pleasant but less energizing (e.g., calm, serene, or tranquil), less pleasant and less energizing (e.g., unstimulating, dreary, or boring), or less pleasant but more energizing (for example, intense, tense, or frenzied). A person in an energizing and pleasant environment is more likely to be in an energizing and positive mood than someone who is not [13]

Moreover Augustin (2018) asserts that, to increase the likelihood of positive emotions, spaces must share two qualities: Its energy level must be optimal for the activities that are likely to occur there, and it must send positive nonverbal messages to users [13].

1.3 Emotions detection technologies

There are two main approaches to study perception and its related emotions, the psychological approach and the physiological approach which is the most important to this research and is concerned with the functions of the nervous system.

Within the physiological approach there are many techniques that are used to investigate the brain activity and thus investigate related emotions. Those techniques can mainly be categorized into two groups ; (a) invasive techniques, which require surgery or implanting electrodes inside the skull, and (b) noninvasive techniques, which can be implemented superficially by either placing ultra-sensitive electrodes over the scalp or by scanning the brain using sensitive scanning machines [10].

Brain imaging refers to a collection of techniques that produce images indicating which regions of the brain are active [8] [22]. The most propounded technologies used today are the electroencephalography EEG, and functional magnetic resonance imaging fMRI. Nonetheless, there exist other noninvasive technologies that are being clinically and medicinally used but require the injection of radioactive substances into the blood stream such as positron emission tomography (PET), which is surely of rejected nature to architecture practice, such technologies will be reviewed briefly within the next section.

1.3.1 Computerized Axial Tomography (CAT) scan

The Computerized Axial Tomography Scan (CAT scan) combines thousands of separate X-ray images to create an image of the brain. [2].

1.3.2 Positron emission tomography (PET)

In 1976, Positron Emission Tomography (PET) scans were developed as a result of fundamental discoveries [2] [10] [8]. This method permits researchers to study the brain [10].

In PET, a person is injected with a low dose of non-harmful radioactive tracer, which enters the bloodstream and indicates blood flow volume. After a person receives an injection of radioactively labelled glucose, a scanner monitors the brain's glucose consumption [10].

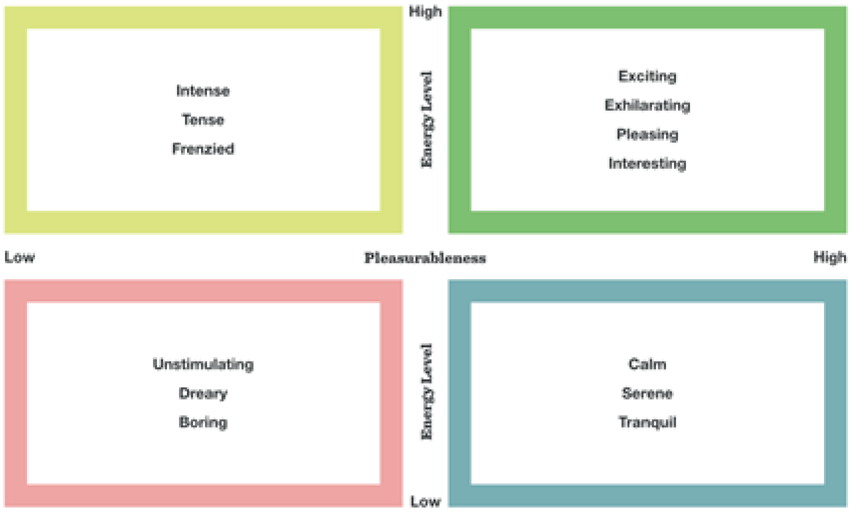


Fig 6. Model of the emotional experience of space by Russell and Snodgrass [11]

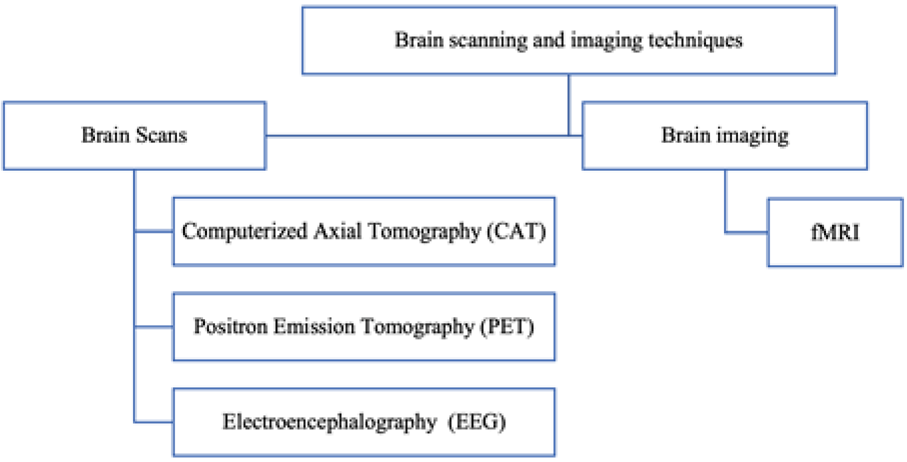


Fig 7. Brain study noninvasive techniques

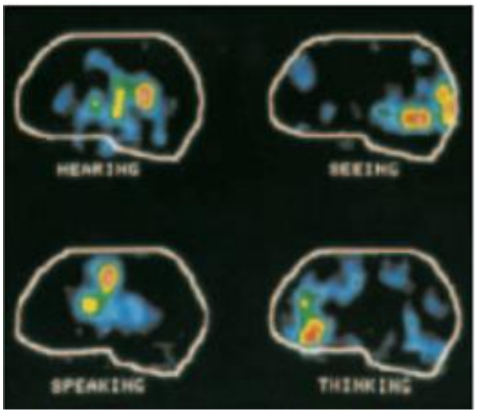


Fig 8. PET scan showing cross section of the cerebrum [10]

The basic principle behind the PET scan is that changes in the activity of the brain are accompanied by changes in blood flow [8] [2] and more active areas of the brain have higher energy demands [10]. Then monitoring the radioactivity of the injected tracer provides a measure of this blood flow [8] [2] . Then, as shown in

Fig **8**, different colors represent different activity levels in the brain [10].

1.3.3 Functional magnetic resonance imaging (fMRI)

Fundamental discoveries have led to the development of (Magnetic Resonance Imaging MRI) [10] as the MRI provides detailed and vivid image of the brain structures [10] [2] and individual bundles of nerves in other parts of the body [2].

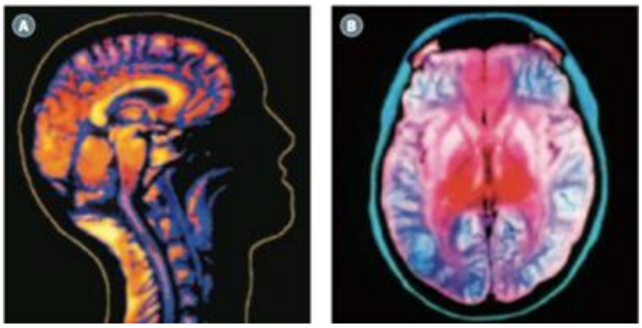


Fig 9. Detailed MRI (a) of a healthy brain (b) a brain with disease [10]

Researchers developed the subtraction technique, which measures brain activity under two conditions, to apply this method:

- An initial condition before the presentation of the stimulus of interest.
- Test conditions under which the target stimulus is presented.

Thus, subtracting the activity in the initial condition from that in the test condition reveals the brain activity associated with object manipulation [8].

In fMRI, a giant magnet encircles the patient's head, and alterations in the direction of the magnetic field cause hydrogen atoms in the brain to emit radio signals. These signals can then be detected, interpreted, and displayed as structural or functional images [10].

fMRI is based on the measurement of blood flow because hemoglobin, which carries oxygen in the blood, contains a ferrous molecule and magnetic properties; therefore, presenting a magnetic field to the brain that aligns the hemoglobin molecules forming tiny magnets. The fMRI indicates the presence of brain activity because oxygen-carrying hemoglobin molecules in regions of high brain activity lose some of their Oxygen. The fMRI apparatus determines the relative activity of various brain regions by detecting changes in the magnetic response of hemoglobin that occur when a subject perceives a stimulus or engages in a particular behavior [8].

Fig 10. fMRI setup and equipment [8]

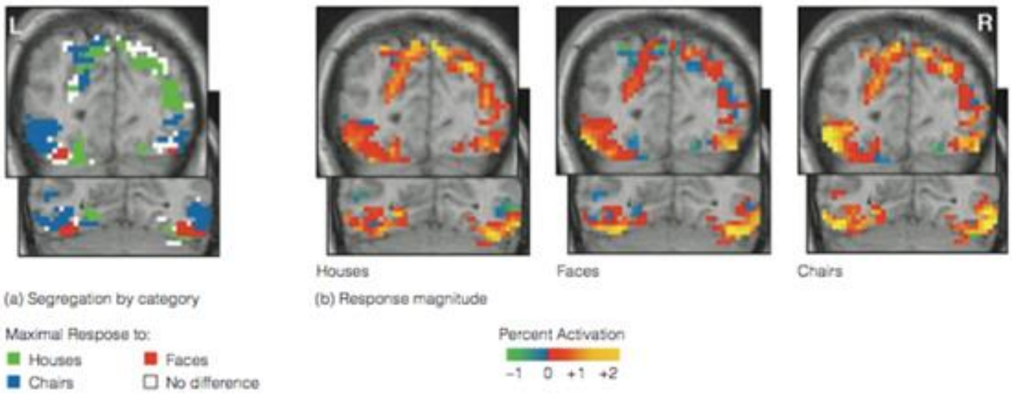


Fig 11. fMRI responses of the human brain to various types of stimuli [8]

1.3.4 Electroencephalograph (EEG)

EEG is the recording of electrical activity along the scalp produced by the firing of neurons within the brain [23]. It records the brain's spontaneous electrical activity over a short period of time, usually 20–40 minutes, as recorded from multiple electrodes placed on the scalp [24].

Fig 12. A person wearing electrodes for EEG [25]

Electroencephalogram (EEG) measurements of brain electrical activity provide a noninvasive method for directly measuring brain function and inferring regional brain activity [26] [24]. Moreover, it has many advantages as a direct measure of brain function that can be utilized in a vast array of biobehavioral science applications, ranging from the study of basic cognitive processes to emotional functions, dysfunctions, and development [26].

Fig 13. Portable recording device for EEG

The EEG signal is a voltage signal produced by synchronized neural activity, or the coordinated firing of millions of neurons in the brain. It can be measured non-invasively by placing an electrode on or near the scalp [27].

Lately, EEG developers have introduced low-cost commercial versions of more sophisticated clinical versions which are available to consumers as well as architects. Moreover, those rather inexpensive versions of EEG sets are fairly accurate and do not interfere with digital presentation media such as digital screens and virtual reality (VR) equipment [25].

The International Federation of Societies for Electroencephalography and Clinical Neurophysiology recommended the conventional electrode setting (also known as 10–20) for 21 electrodes (excluding the earlobe electrodes). Typically, the A1 and A2 earlobe electrodes, which are connected to the left and right earlobes, serve as reference electrodes [24].

1.3.4.1 Using EEG to detect emotions

Emotions influence perception, and human interactions. It also affects the physiological and psychological status of humans. Emotions can be expressed through both positive and negative representations, which can have an impact on both human health and performance [25].

According to Suhaimi (2020), the electrical clustering of neural cell electrical activity across the human cerebral cortex is regarded as a physiological sign. EEG is utilized to record these activities and is reliable for emotion recognition due to its relatively objective evaluation of emotional states. Moreover, Suhaimi asserts that EEG contains the most comprehensive features that can be utilized for basic emotion classifications. Recent advances in consumer-grade wearable electroencephalography (EEG) solutions can provide a low-cost, portable, and straightforward method for identifying emotions [25].

1.4 Evaluation of brain scanning and imaging techniques

Based on the previous revision of brain imaging and scanning technologies used to determine brain activity, such as Computerized Axial Tomography (CAT), Positron Emission Tomography (PET), Functional Magnetic Resonance Imaging (fMRI), and Electroencephalography (EEG), when comparing and assessing reviewed techniques particularly from an architectural perspective considering the following criteria: cost, safety, space required for operation (size), mobility, ease of operation, precision, comprehension of obtained data, interference with digital presentation media, support for local and distant collaboration, results are shown in Fig 15 suggesting a score of 1, .5, and zero for positive, relative, and negative characteristics of the reviewed technology.

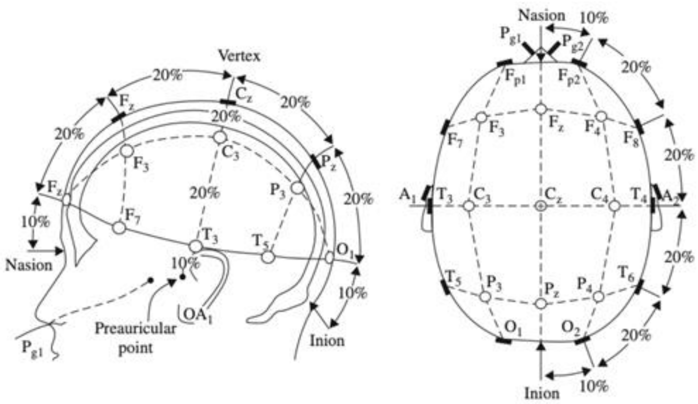
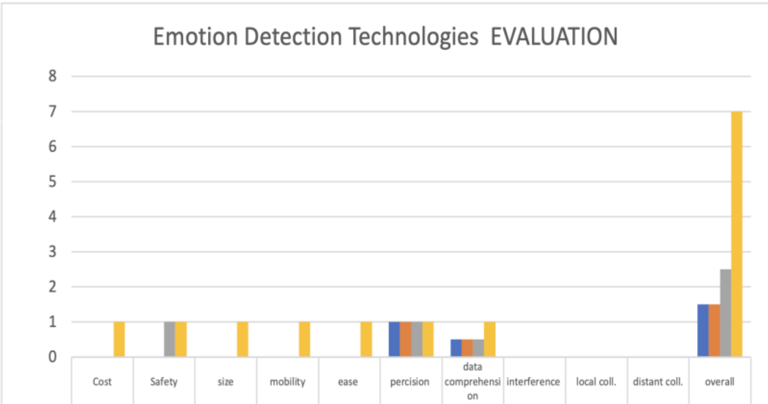


Fig 14. A diagrammatic representation of electrode placement [24]



	Cost	Safety	size	mobility	ease	percision	data comprehension	interference	local coll.	distant coll.	overall
CAT	0	0	0	0	0	1	0.5	0	0	0	1.5
PET	0	0	0	0	0	1	0.5	0	0	0	1.5
FMRI	0	1	0	0	0	1	0.5	0	0	0	2.5
EEG	1	1	1	1	1	1	1	0	0	0	7

Fig 15. Evaluation results for reviewed technologies

Based on the suggested criteria that is believed to suit the nature of architecture practice, As shown in Figure 15, EEG technology has the most potential and suitable characteristics and capabilities among other reviewed technologies to be implemented in architectural practice with the intention of detecting and evaluating emotional response towards spaces.

1.5 Futuristic technology outline

Based on an architectural practical point of view and on the suggested criteria, the need for a futuristic and innovative technology that can be implemented by architects to detect emotional response towards spaces either virtual or physical is of crucial and great importance. Such technology that is specifically developed to serve architects and designers can empower and facilitate decision making and urge architects to develop more emotionally pleasant designs rather than assessing their design solutions with an unprecended subjective, accurate, and unbiased manner.

A comprehensive system that is meant to be used in the detection of emotions of inhabitants or occupants should have the following characteristics; affordable, safe to operate, small in size to enable usage in small spaces and with groups, mobile and can be freely moved and not stationary while operating, can deliver results in an easy nature that can be understood by architects with no or little technical background, can deliver accurate data that can describe the kind and the intensity of the emotional state experienced, emits no magnetic field thus causes no interference with digital media and VR systems, and capable of connecting to networks either local or distant networks such as the world wide web to facilitate collaboration and remote data gathering.

Discussion

As presented by the reviewed literature, human perception is located and managed physiologically in the brain [8] [9], the perception of spaces can generate emotions [13]. Emotions can be detected using advanced technologies some are suitable for the architecture practice such as fMRI and EEG [25] and others are not such as PET [2] [10] [8].and CAT [2] [10] [8] technologies. Among the reviewed technologies EEG technology is the most suitable one for architecture usage [25].

EEG technology with being developed for clinical and medicinal usage inherit some disadvantages for architectural practice (i.e. lack of collaboration capability and interference with digital presentation media), if those disadvantages were surmounted, EEG can be considered – based on the suggested criteria – a technology that can empower and enrich architecture practice with enabling architects and decision makers to emotionally evaluate designed spaces subjectively and in an unbiased manner that is unprecedented.

Results

Among all reviewed technologies such as PET, CAT, fMRI, and EEG, the electroencephalograph EEG technology is the most promising one and can be used in detecting emotional response towards architectural spaces despite of its inherited incapability which if overcome, can deliver a powerful tool that can enrich the practice of architecture particularly in the domain of detecting and evaluating emotions generated because of space and architecture experiences.

Future research recommendations

Based on the results of this research, it is recommended to conduct an experiment that investigates the practicality of EEG technology in detecting space-related emotions. This can be achieved by examining space- related responses of participants using wearable EEG devices while being in spaces with different characters and attributes.

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