

Neuroscience And Architecture: Brain Waves Within Different Architectural Spaces, An Experimental Study

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Abstract: This research used brain wave powers and ratios to measure the electroencephalography (EEG) responses of students exposed to different architectural spaces. EEG indicators were used to determine changes before and after stimulation. The objective of this study is to determine the effects of certain proportions of architectural spaces on people's mental and emotional states. Here, twenty-eight students sat inside two architectural spaces, and their design principles were derived from sacred geometry. Before and after measurements of brain waves were taken, and a survey of their emotional and cognitive effects was conducted. As a result, statistically significant differences ($p < 0.05$) in brain waves at the frontal lobe were observed after individuals sat inside each architectural space, especially in the beta and gamma waves. Moreover, differences in the theta and theta/alpha ratios were observed in the pentagonal space (PS). A qualitative assessment revealed that the emotional and cognitive behavior of the students varied from a sense of sleep and rest to a sense of deep thinking and increasing attention. The study concluded that changes in architectural spaces affect the brain and the outcome behavior of individuals.

Keywords: Architectural spaces, Brain waves, Built environment, Form impact, Neuroarchitecture.

1. Introduction

Neuroscience is a comprehensive science that studies the brain's capabilities, development over time, and related factors. However, architecture, in simple words, is the art and science of building design. Both of these disciplines are currently emerging as one field but originated in the early 21st century when their convergence was first suggested by John Eberhard and Rusty Gage in 2003, a pivotal year marked by the establishment of the Academy of Neuroscience for Architecture (ANFA).

"Neuroarchitecture" integrates neuroscience, environmental psychology, and architecture to examine the intricate relationship between the human brain and the built environment. The "neuroarchitecture" hypothesis can be used to articulate a testable idea about how specific design features within the built environment may influence humans psychologically or physiologically [1]. Fred Gage, a neuroscientist and one of the initiators of the ANFA academy, stated that architectural design changes our brain and behavior [2]. The design of the built environment can modulate positive aspects of psychological functioning, such as learning, social behavior, and emotional wellness [3].

The researcher [4] conducted an experimental study on Sultan Hassan Mosque to address the effect of sacred buildings on the brain after standing for 30 minutes inside the building; the results revealed increases in the alpha and theta parameters, which are suggestive of relaxation. The psychological impacts and changes in the alpha and theta/beta ratios were confirmed by observing the interior of the Imam Mosque building in Iran [5]. In India, researchers have examined the mean amplitude of brain waves under the effect of meditation outside and inside the "Maitreya-Buddha" Pyramid in the

“Pyramid Valley”, which is located in Kanakapura. The results revealed an increase in the means of the alpha, theta, and delta waves [6].

His research [7] mentioned that there are still areas, including interior and building design, that require further intensive research to guide future regulations toward a healthier modern built environment. Standard protocols must be created to quantify and determine the cognitive effect of how interior spaces are perceived [8]. This field posits that the design of spaces can significantly influence human behavior, cognition, and emotional states by modulating neural activity. This collaboration between neuroscientists and architects aids in the study of the psychological and physiological impacts of architectural designs on individuals.

The main purpose of this approach is to explore the influence of architectural spaces on the neural system to improve human well-being, relying on sensory perception and cognition processes to create spaces that promote positive psychological outcomes. Architecture engages multiple sensory networks, presumably the visual, auditory, somatosensory, olfactory, and vestibular systems, and triggers motor responses such as approach and avoidance [9].

Current knowledge of neuroarchitecture indicates that there is a significant connection between architectural design and different neural responses, but many gaps remain. Architects, through conscious knowledge, can design different building types with certain effects on their occupants to improve their spiritual, mental, and physical health, leading to a better quality of life. This concept builds on Christopher Alexander’s notion of a subtle quality crucial to the spirit of any living space, characterized by a sense of sacredness or timelessness. Sacred architecture, which is often found in religious places, tends to extend beyond the visible structure to increase spirituality and mental health through “sacred geometry” principles. Sacred geometry is a sacred art form due to its fundamental association with Creation’s principal laws [10]. It was highly regarded as the backbone of architecture in many ancient civilizations [11], as it was regarded as one of the vital instruments for unifying the mental and physical structures of mankind [12].

Therefore, timeless architecture is characterized on the basis of its alignment with core aspects of quality of life, soul, and spiritual vision rather than solely serving religious purposes. This spiritual dimension is a dynamic component of the psyche that operates independently of physical forms, and this spiritual flow energy, which imbues the building of divine essence, is facilitated by certain geometrical ratios and proportions.

Accordingly, the interaction of the neurosciences and architecture provides an opportunity to enhance the quality of the built environment. Any scientific research that clarifies the link between the characteristics of the built environment and our behavior and response will certainly help to make claims for better acceptable architectural spaces. Therefore, architectural design now needs to be considered in its biological and ecological context [13]. Scientific studies have also determined the characteristics of buildings and spatial environments associated with various comfort and health effects [14].

Neuroscientific data offer the means to advance and validate novel additional guidelines, which can now be continually updated on the basis of measurable evidence. In this context, objective measurement of the neural, psychological, and cognitive impact of the built environment becomes feasible and is indeed necessary [15]. The fields of biotechnology and related devices were developed to record and measure broadband data from the brain and body, e.g., brain waves through electroencephalography (EEG), eye movements through electrooculography (EOG), cardiovascular rhythms through electrocardiography (ECG), and muscular potentials through electromyography (EMG) [16].

2. Brain waves and Ratios

Brain waves represent the electrical activity of the brain, and their different types can be recognized by their amplitudes and frequencies. The frequency indicates the number of waves per second (Hz), whereas the amplitude represents the power of these waves measured by microvolt (Mv); analyses of brain waves and their functions are presented in Table 1 [17].

TABLE 1 BRAIN WAVES FREQUENCIES AND THEIR GENERAL CHARACTERISTICS [17]

Brain waves	Frequency (Hz)	General characteristics
Delta	1-4	Sleep, repair, complex problem solving, unawareness, deep-unconsciousness
Theta	4-8	Creativity, insight, deep states, unconsciousness, optimal meditative state, depression, anxiety, distractibility
Alpha	8-13	Alertness and peacefulness, readiness, meditation, deeply relaxed
SMR*	13-15	Mental alertness, physical relaxation
Beta	15-30	Thinking, focusing, sustained attention, tension, alertness, excitement, intensity, hyperalertness, anxiety
Gamma	30-100	Learning, cognitive processing, problem-solving tasks, mental sharpness, brain activity, organize the brain

*SMR: Sensorimotor rhythm

The pattern of EEG brain waves could be used as a bioelectrical marker for mental states and disorders, and increases and decreases in the power of brain waves are related to different mental and psychological conditions [18]. These waves are categorized into five main types: delta, theta, alpha, beta, and gamma.

Delta waves (0.5 to 4 Hz) are the slowest brain waves and are associated with deep sleep and restorative processes. They play a critical role in healing and regeneration. Increasing delta waves in the brain are associated with a state of empathy and deep meditation and relaxation [19].

Theta waves (4 to 8 Hz) are linked to light sleep, relaxation, and creativity and are often observed during meditation or daydreaming. ta waves can be recorded during sleep, resulting in low brain activity [18]. An evident increase may lead to difficulty in concentrating and producing feelings of depression.

Alpha waves (8 to 13 Hz) signify a relaxed, calm state, which is usually observed when individuals are awake but relaxed, such as during quiet reflection or light meditation. In addition, alpha waves are associated with peak performance and the release of serotonin, which controls mood, and low serotonin levels are linked to depression and other neurological disorders, such as anxiety and panic attacks [19]. The balance of the theta/alpha ratio is crucial for understanding the meaning of the messages we receive and influencing our emotional domains.

Beta waves (13 to 30 Hz) are associated with active thinking, focus, and problem solving, which are common during tasks requiring mental concentration and cognitive engagement. These waves are related to being more social, feeling excited, and being goal oriented. It is related to a high level of consciousness, brain activity, and motor behavior [18]. However, there are negative effects of increased beta waves, e.g., anxiety, stress, paranoia, muscle tension, increased blood pressure, and insomnia. Decreased beta and increased theta in frontotemporal regions are indicators of obsessive-compulsive disorder [20].

Gamma waves (13 to 30 Hz) are the fastest and are linked to high-level cognitive functioning, including problem-solving, precision, and consciousness. On the other hand, an increase in gamma waves occurs with sensory stimuli, meditation, and learning. There are negative effects of increased gamma waves, such as anxiety and headache. When gamma brain wave activity decreases, susceptibility to depression, stress, and unfocused or impulsive thinking may overtake the brain [19].

Thus, the relationships between brain wave patterns and mental/psychological states have been studied. It has been reported that delta waves correlate with unconscious states and deep physical relaxation, theta waves correlate with intuitive and creative states, alpha waves correlate with a relaxed peaceful mind, beta waves correlate with alertness and active thinking, and gamma waves correlate with peak mental performance and cognitive processing. Understanding these connections provides a foundation for exploring how different architectural spaces might influence mental health and cognitive function.

Therefore, the importance of the brain wave ratio further highlights the influence of these patterns. The theta/alpha ratio is an important indicator of peacefulness and meditation. A higher theta/alpha ratio indicates a state of deep relaxation and inner calm, which is usually achieved during meditation practices. This ratio reflects the ability of the brain to transition from a more alert state to a relaxed, introspective state, promoting mental peace and stress reduction.

Conversely, the theta/beta ratio serves as an indicator of attention and concentration. A lower theta/beta ratio is typically associated with high focus and attention, which are essential for tasks requiring sustained mental effort and cognitive control. A higher theta/beta ratio may indicate difficulties in maintaining concentration and attention, as observed in various attention-related disorders.

With respect to this concept, the current research aimed to examine the physiological and psychological effects of different architectural space designs on a group of students.

3. Research Design

This research combines both quantitative and qualitative measurements to explore the influence of two architectural spaces on humans' cognitive and emotional states. A quasiexperimental design was employed to investigate the effects of architectural spaces on brain wave patterns. The key consideration included the selection of two forms on the basis of two sacred geometry proportions, as will be clarified later. These forms were translated into physical installations suitable for individuals to sit inside. Brain wave measurements have focused on the prefrontal cortex, aligning with its role in executive functions and emotional regulation, thereby linking architectural stimuli to specific neural responses.

The qualitative measurements were gathered via a predesigned questionnaire to explore the students' ability to express their emotional experience after interaction with these spaces and to make comparisons between quantitative and qualitative measurements to obtain more reliable results.

3.1 Sample selection

After the research was accepted according to the ethical standards of scientific research of "Alexandria University" (Serial No. 0305960 and 19/1/2023), we started outreach through university mailing lists and oral meetings with students. This step provides a brief overview of the experimental study and the basis of eligibility criteria, as well as providing information for the interested students. The nature and procedures of the experiment were clarified, as were the methods of protecting the rights of human subjects. Twenty-eight students (19 females and 9 males), aged 18--20 years, volunteered to

participate in the experiment. Furthermore, the eligible participants provided informed written consent, as they were provided with complete detailed information about the study's aim, scope, potential risks, and benefits. Moreover, once consent was obtained, the participants were scheduled for their sessions in experimental spaces that were provided with clear instructions according to location and the duration of each task.

3.2 Research Methodology

The study employed pre- and postmeasurements of brain wave power via the “ProComp5 Infiniti” device and “EEG BioGraph Infiniti” software. The participants were exposed sequentially to the two spaces. The students were asked to sit on a chair with their eyes closed for 10 minutes before sitting inside the two spaces; then, they were asked to sit inside each space for 10 minutes with their eyes closed. Brain wave recordings were gathered after each step for 2 minutes to capture immediate neural response comparisons before and after architectural form stimuli.

3.3 Architectural Design

The first researcher designed two architectural spaces. The design of these spaces is based on several sacred geometry principles, as it is derived from two of the most important shapes in the sacred geometry (hexagon and pentagon) to apply their ratios and proportions in the designed spaces, as shown in **Fig.1** and **2**. The square root of three ($\sqrt{3}$) was used in the hexagonal space (HS), whereas the ratio Phi (ϕ) was used in the pentagonal space (PS), as shown in **Fig.3**.

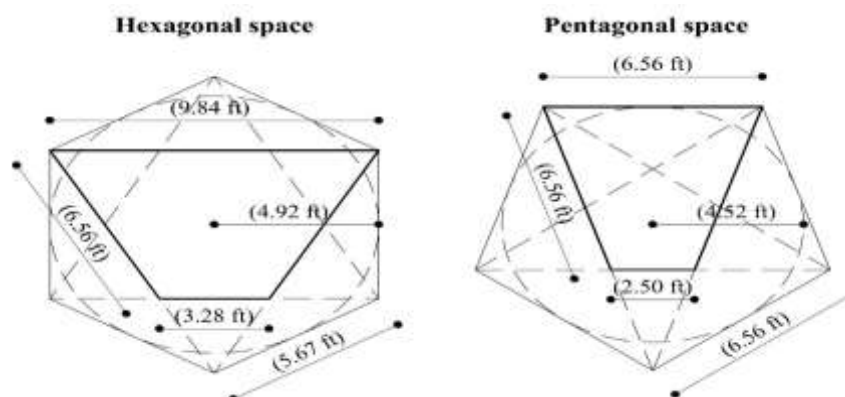


Fig.1 Dimensions of the designed spaces within the hexagon and the pentagon (Authors)

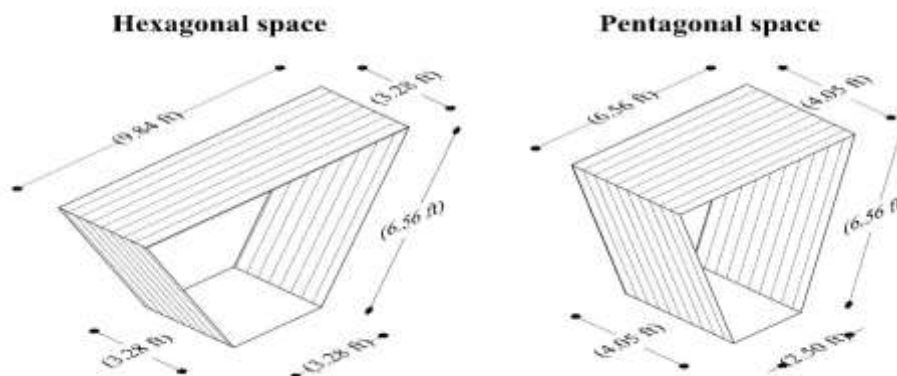


Fig.2 Dimensions of the designed spaces (Authors)

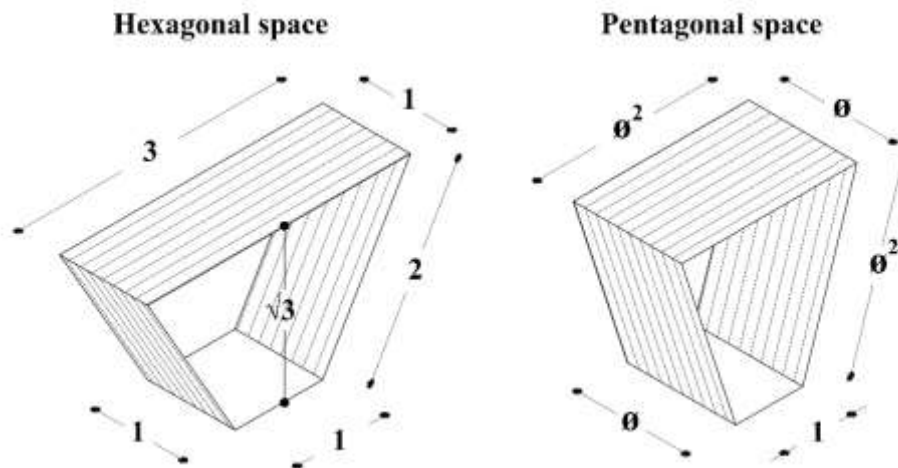


Fig.3 Proportions of the designed spaces (Authors)

The structure of these two architectural spaces was made from white polyvinyl chloride (PVC) pipes with a one-inch diameter, which were covered with white fabric to form these spaces, as shown in **Fig.4**. Each form was pulled from two opposite sides with two plastic ropes. These ropes were attached to four chairs to prevent the form from falling or deforming and to fix it properly against wind forces, as shown in **Fig.4**.



Fig.4 Fabrication and fixation of the two spaces (Authors)

These two forms were fabricated by the volunteer university students, with the contribution of two of the teaching staff members, under the supervision of the first author. These forms were assembled on the roof of one of the faculty buildings, as shown in **Fig.4**.

3.4 Brain waves Power and Ratio Analysis

Brain wave analysis focused on delta, theta, alpha, SMR, beta, and gamma waves, along with the Theta/Alpha, Theta/Beta, and SMR/Theta ratios. The electrodes were positioned at the Fp1 or Fp2 sites, as shown in **Fig.6**, to ensure consistent measurement conditions and minimize variability. Pre- and postassessments of brain waves were performed by using the “ProComp5 Infiniti” device and EEG “BioGraph Infiniti” software (**Fig.5**). Brain waves were measured before and after the participants sat in each architectural space.



Fig.5 ProComp5 Infiniti device (Authors)

The site of the assessment points was at (Fp1) or (Fp2) by a unipolar assessment technique through the insertion of an EEG electrode at the (Fp) site according to the students' dominant handedness, i.e., (Fp1) for right-handedness and (Fp2) for left-handedness, another electrode as a reference in one ear (A1/A2), and the other electrode as a ground in the other ear. Only three students were left-handed.

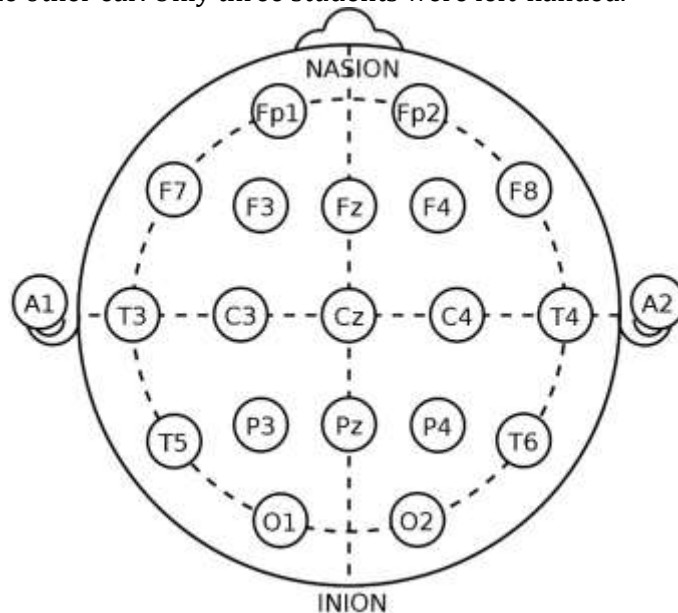


Fig. 6 10--20 system positions and Fp locations

(https://upload.wikimedia.org/wikipedia/commons/thumb/7/70/21_electrodes_of_International_10--20_system_for_EEG.svg/1024px--21_electrodes_of_International_10--20_system_for_EEG.svg.png)

The duration of each assessment was two minutes, and then, statistical analysis of the spectral EEG waves was performed via the “ProComp5 Infiniti” device database after the removal of artifacts. It provides the power of brain waves (delta, theta, alpha, SMR, beta, and gamma) and ratios (theta/alpha, theta/beta, and SMR/theta).

In this study, the frontal region (Fp) was assessed for brain wave changes. The prefrontal cortex (Fp1, Fz, and Fp2) is responsible for executive functioning, establishing goals, inhibiting information extraneous to the goal-directed planning process, planning and making decisions, and working memory. In addition to self-regulation, initiation, social-emotional behavior in the social context, recognition, and production of expression of language [21].

3.5 Post-Psychological Assessment Questionnaire

The participants completed a postpsychological assessment questionnaire comprising two open-ended questions regarding their cognitive and emotional experiences after each session inside the architectural spaces. This type of questionnaire was chosen for two reasons. The first is the wide range of brain cognitive and emotional states, which, if added to the questionnaire, affects the mental state of students, as they need to concentrate on choosing a suitable answer. The second reason is to let students express their psychological or physiological state freely according to their experience. As with open-ended items, students need to construct their own answers [22]. With respect to reliability, the results of an open-ended questionnaire are consistent with results from other survey modes [23]. Thus, this survey instrument was developed on the basis of existing validated questionnaires used in different fields of research. It was tailored to capture students’ responses to architectural spaces, ensuring relevance and reliability.

3.6 Application of the research

The participants underwent brain wave preassessment outside the spaces to establish baselines, which were followed by structured sessions in the HS and PS. The students were asked to sit in such space for ten minutes, after which their brain waves were measured for two minutes. This study also elucidates how architectural space impacts the neural activity of an individual in a controlled experimental setting.

3.7 Statistical Analysis

The data were analyzed via “IBM SPSS v20” [24], with certain artifacts collected via “BioGraph Infiniti” software to ensure the integrity and reliability of the data. Moreover, the design of this study is such that architectural design can be integrated with neuroscience methodologies. Furthermore, the dynamic interaction between the built environment and brain function is explored, from which novel insights into potential therapeutic and cognitive benefits of spatial design are achieved.

4. Results

Table 2 presents the changes in the brain wave power of the students after they sat in the HS and PS. In the HS group, the beta and gamma waves significantly decreased ($z = -2.1$, $p = 0.04$ and $z = -2.1$, $p = 0.03$), respectively, with nonsignificant changes in the rest of the brain waves and ratios.

Like those in the HS group, the power of the brain waves in the PS group significantly decreased in the beta and gamma waves ($z = -2.8$, $p = 0.01$ and $z = -2.6$, $p = 0.01$), respectively; moreover, the theta waves and theta/alpha ratio also significantly decreased ($z = -2.1$, $p = 0.03$ and $z = -2.1$, $p = 0.04$), respectively.

TABLE 2 THE STUDENTS’ BRAIN WAVE MEASUREMENTS IN BOTH ARCHITECTURAL SPACES

Brain wave	Before		Hexagonal space (HS)				Pentagonal space (PS)				Change between the HS and PS	
	Mea n	SD	Mea n	SD	Z ₁	p ₁	Mea n	SD	Z ₂	p ₂	Z ₃	p ₃
DELTA	343.8	144.6	373.0	22.0.3	-0.8	0.40	297.1	127.9	-2.0	0.05	-1.8	0.07
THETA	98.6	34.0	98.9	61.9	-1.3	0.21	85.9	34.3	-2.1	0.03*	-0.5	0.65
ALPHA	110.5	75.2	107.0	64.1	-0.1	0.90	106.5	68.9	-0.3	0.77	-0.6	0.59
SMR	22.0	12.0	21.5	14.4	-1.4	0.15	19.7	9.8	-1.8	0.07	-0.4	0.68
BETA	43.3	20.7	39.4	20.2	-2.1	0.04*	36.7	14.1	-2.8	0.01*	-0.6	0.54
GAMMA	10.4	7.4	8.8	6.5	-2.1	0.03*	7.7	4.3	-2.6	0.01*	-1.1	0.30
Theta/Alpha	1.2	0.6	1.1	0.6	-1.7	0.09	1.1	0.5	-2.1	0.04*	-0.6	0.53
Theta/Beta	2.6	1.1	2.7	1.2	-0.6	0.58	2.6	1.1	-0.1	0.96	-0.1	0.92
SMR/Theta	0.2	0.1	0.2	0.1	-0.5	0.66	0.2	0.1	-0.7	0.52	-0.4	0.70

- Wilcoxon signed ranks test * p value < 0.05
- p1 significance of the change between the basic position and the HS.
- p2 significance of the change between the basic position and the PS.
- p3 significance of the change between the HS and the PS.

Furthermore, Table 3 shows that at the HS, approximately 67.9% of the students experienced a reduction in both beta and gamma waves, and approximately 60.7% of them experienced a decrease in the power of delta waves. Moreover, 57.1% of them experienced a decrease in both Theta and SMR waves. Approximately 71.4% of the samples presented a decrease in the theta/alpha ratio, whereas 57.1% presented an increase in the theta/beta ratio.

Similarly, PS (Table 3) decreased in both the Beta and Gamma waves in approximately 67.9% and 71.4%, respectively. The power of the delta and theta waves decreased in approximately 64.3% of the students. Moreover, 60.7% of them experienced a decrease in SMR waves. Approximately 67.9% of the samples presented a decrease in the theta/alpha ratio, whereas 53.6% of the HS samples presented a decrease in the theta/beta ratio.

TABLE 3 FREQUENCY OF STUDENTS WITH RESPECT TO POWER CHANGES IN BRAIN WAVES IN BOTH SPACES

Brain waves*	Hexagonal space (HS)				Pentagonal space (PS)			
	Increase	%	Decrease	%	Increase	%	Decrease	%
Delta	11	39.3	17	60.7	10	35.7	18	64.3
Theta	11	39.3	16	57.1	9	32.1	18	64.3
Alpha	14	50.0	13	46.4	13	46.4	14	50.0
SMR	12	42.9	16	57.1	11	39.3	17	60.7
Beta	9	32.1	19	67.9	9	32.1	19	67.9
Gamma	9	32.1	19	67.9	8	28.6	20	71.4
Theta/Alpha	6	21.4	20	71.4	9	32.1	19	67.9
Theta/Beta	16	57.1	12	42.9	13	46.4	15	53.6
SMR/Theta	15	53.6	12	42.9	14	50.0	13	46.4

*Some students showed no change in their brain wave power

Table 4 shows the summary of the students' emotional and cognitive responses to the questionnaire. The HS significantly affected the students, as 42.8% of them felt sleepy and restful. Similarly, the PS affected the students significantly, but only 21.4% of them felt sleepy and restful. The same table shows a nonsignificant effect of PS on the students' emotional and cognitive responses, as 17.9% of them felt attention and deep thinking, and 17.9% of them felt upset and slightly stressed.

As a potential influence on a minor number of students' responses, it is worth mentioning that 4 students complained about hot weather; one of them felt fatigued in both spaces, another one felt sleepy and rested in HS, the third felt upset in PS, and the last one's response was no comment in either space. Moreover, only one student complained about a long waiting time before joining the experiment, and he felt sleepy in PS.

TABLE 4 COGNITIVE AND EMOTIONAL THOUGHTS AFTER SITTING IN BOTH SPACES

	Hexagonal space (HS)		Pentagonal space (PS)		p
	N	%	N	%	
Sleepy & rest	12	42.8	6	21.4	0.01*
Attention & deep thinking	1	3.6	5	17.9	
Fatigue	1	3.6	1	3.6	
Upset & stressed	0	0.0	5	17.9	
No comment	14	50.0	11	39.2	

- N=28

- P significant < 0.05

- Fisher's exact test

5. Discussion

Multiple reviews have discussed the effects of architectural spaces on the brain and psychological status; for example, [25] illustrated the connection between the shape and space proportions and human emotions, and [26] discussed the impact of architecture in the process of healing and well-being. A review was performed to identify the impact of designed spaces on users' attention and memory from a neuroarchitectural approach. The results revealed that many factors, including form and geometry, can affect human attention [8].

Researchers [27] tested digital models with different shapes and materials via the "CST Microwave Studio", which measures the resonance frequency of the forms, to investigate their influence on users' brainwaves. The study concluded that every model generates its own resonance frequency, which affects human brainwaves and consciousness differently. This research aimed to test the effects of sitting inside two physical spaces on the frontal brain waves of individuals.

Researchers [7] stated that the reviewed literature shows that brain activities are more disentangled and meditative in a natural environment than in a built environment and that the human brain has shown higher levels of stress. Thus, this research used two certain proportions obtained from sacred geometry shapes, which are claimed to have a beneficial effect on humans, to investigate their reliability.

The results in Table 2 show that both architectural spaces (HS and PS) significantly affected the students' brains by reducing their beta and gamma waves, which means a reduction in focus, tension, and overall brain activity. This could be a potential design method to reduce the higher levels of stress in the built environment. In addition, Table 2 shows a significant reduction in the students' theta waves and, accordingly, the theta/alpha ratio, as the theta/alpha ratio is an indicator of their cognitive ability [28]. This could be a privilege to design a meditative space that matches an individual's mental state in the natural environment, where [29] mentioned that mental fatigue causes widespread increases in theta/alpha.

The numbers in Table 3 show that both HS and PS reduced more than half of the students' brain waves, with the exception of the alpha waves; regarding the beta and gamma brain waves, the reduction occurred in more than 2/3 of them. Moreover, both HS and PS had unclear effects on alpha waves, as almost half of the students experienced an increase in alpha waves, and the rest experienced a decrease, while alpha waves remained the same for one student.

With respect to students' emotional and cognitive responses, the results displayed in Table 4 reflect the significant effects of sleeping and resting states in both spaces. Moreover, 50% and 39.2% of the students did not respond to the questionnaire after their experience with HS and PS, respectively. This could be an indicator of their relaxation and peacefulness, which is associated with the state of the alpha mind, as shown in Table 1.

All the results mentioned above indicate that the effects of both spaces tend to involve meditation, relaxation, and the alpha brain state. This complies with the meditational effects of the Sacred Geometry design principles, according to many past studies. From previous research, both neuroscience and architecture could help together determine what is suitable for humans in different architectural spaces.

Conclusion

This research highlights the potential of architectural design to modulate the brain wave activity and psychological states of humans, offering basic evidence that geometrical proportions, specifically those related to hexagons and pentagons, can significantly impact cognitive and emotional experiences.

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Ethics Declaration

The Ethics Committee of the Faculty of Medicine, Alexandria University, has accepted and approved the research protocol, and the IRB number (0305960) dated 19/1/2023, was granted accordingly.

Informed Consent

The eligible participants provided informed written consent, as they were provided with complete detailed information about the study's aim, scope, potential risks, and benefits. The authors confirm that written informed consent has been obtained from the involved participants.

Data Transparency

All authors declare that all data and materials, as well as software application, support their claims and comply with field standards.

Data Availability

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Financial Interests

The authors have no relevant financial or non-financial interests to disclose.

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by all authors. The first draft of the manuscript was written, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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