

*Health Consideration in Architectural Design: An Interrelation Between
Architecture and Neuroscience*

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Abstract

Neuroarchitecture is a new frontier in architecture that lies between the interrelation of neuroscience and architecture. This research aims to understand and accumulate factual knowledge on the impact of architectural design in human perception and judgment while monitoring brain activity using electroencephalogram (EEG) recordings. To achieve this, we have conducted an experiment separated into two parts: an observation part and a judgment part - both consisting of 3 sessions of pictures of indoor built environment categorized by color, proportions, and texture. To present the pictures and achieve the collection of information from the judgment, we have used a digitalized semantic differential method using a bipolar rating scale, whereas to monitor human brain activity, we have used NeuroSky Mindwave mobile device. Subjects have been exposed to a visual stimulation while the selection of the pictures has taken into consideration cultural background, a range of colors from monochromatic to colorful and from bright to pastel, rooms of classical golden section proportions, and contemporary approaches, as well as various textures. Results showed a judgment and observation impact varying from environments with bright and pastel colors, rough and soft texture, as well as classical proportions and traditional Japanese rooms. This study provides an opportunity to improve the approach to architectural design, placing a primary focus on the user's well-being.

Keywords: Neuroarchitecture, Evidence-Based Design, Well-Being

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Introduction

The past decade has seen a growth in the concern of occupants' health and comfort in indoor environments resulting in a widespread interest of research in new ways of architectural planning and design. Architecture, in addition to the meaning of art or the practice of designing and constructing buildings, as a word, it also defines the structure of something carefully designed, such as the chemical architecture of the human brain (New American Oxford Dictionary). Brain architecture is comprised of billions of neuron connections, so neuro-architecture has historically been used to define those connections across the brain. Simultaneously, "*neuro-architecture*" portrays a new frontier in architecture that lies between the interrelation of neuroscience and architecture. This discipline aims to combine human experience in architecture on one hand and brain research on the other in order to accumulate factual knowledge on the impact of architectural design in the human brain, respectively, in human behavior.

Several authors have expressed the meaning, potential, and the importance of this approach. Edelstein (Edelstein, 2013) describes Neuroarchitecture as the approach that informs design by measuring the built environment, with brain and body measurements as well as the sociological, behavioral, and economic outcome. Meanwhile, (Banaei, Hatami, Yazdanfar, & Gramann, 2017) define Neuroarchitecture as a field that uses neuroscientific tools to get a better understanding of the impact of architectural design on human perception and experience. Similarly, in his book 'Neuroarchitecture' Metzger defines the notion as a combination of aspects of neuroscientific research with features of the buildings designed to 'provide people with essential sensory stimulation.' Further, Metzger recognizes its fundamental potential, although he argues that it is still mostly presented as a collection of ideas rather than as a tenable theory (Metzger, 2018), while Edelstein highlights the challenges that the 'inherent complexity of the brain and mind brings to the researchers (Edelstein, 2008, p. 54). Previous researches have been focused on architectural form (Banaei, Hatami, Yazdanfar, & Gramann, 2017), Familiarity, Novelty, Comfort, Pleasantness, Arousal and Presence through VR (Virtual Reality) (Vecchiato et al., 2015), multisensory perceptual integration and embodiment – the role of tactile perception and hapticity (Papale, Chiesi, Rampinini, Pietrini, & Ricciardi, 2016), spatial cognition (Hartley, Lever, Burgess, & O'Keefe, 2014). Conducting such collaborative research would require a systematic investigation that would quantify observations to create an empirical database. An increasing number of studies on this matter (Albright, 2015; Gage, 2016; Pallasmaa et al., 2009; Arbib (2009) have noted that the importance of the joint efforts of architecture and neuroscience land towards empirical evidence, as an essential part of the research process. With the technological developments, the interest in the readings of brain electrical signals known as impulses has grown. Brain-Computer Interface (BCI) represents the connection between the computer and the human brain – which is the most recent development of Human-Computer Interface (HCI). BCI reads the electrical signals produced by the brain from different areas of the human head, translates these signals into actions, and commands that can control computer(s) (Ramadan, Refat, Elshahed, & Ali, 2015, p. 31). This way, the BCI system has opened a new window to the architects in their design process so that they can base their decision making on the evidence on brain recordings, which leads to a better understanding of how architecture affects the brain.

However, it is still not widely understood the relationship between observation and judgment in architecture. This paper presents an attempt to investigate the impact of different indoor environments on the human brain, by using neuroscientific tools for brain wave measurements on one side, and additional analysis for understanding the subjective declaration on the other.

Methodology

Participants

Nineteen volunteers have participated in this study (eight females; mean \pm SD 31.0 \pm 6.11). The group of participants has consisted of different cultural backgrounds (9 Japanese, 1 Korean, 1 Thai, 1 Taiwanese, 1 Kosovar, 1 Sri Lankan, 1 Moroccan, 1 Hungarian, 1 Iranian and 1 Spanish). Statistical analyses of the data were carried out using the IBM Statistical Package for the Social Sciences. The study was approved by the Ethics Committee of The University of Tokyo. Prior to the start of the experiment, participants were informed that the research was related to the investigation of aesthetic judgments during the measurement of brain waves, but the experimental goals were not mentioned.

Experimental design and procedure

The experimental set-up considered two aspects of analysis: psychological response (brain wave) and subjective declaration (questionnaire). To extract the data for the psychological response, we measured brain waves using the tool selected for this research – NeuroSky Mindwave. Based on the algorithms that this device offers – information on meditation and attention, we have tried to understand more deeply the interconnection between these two psychological states in relation to the visual stimuli of the environment, which in this case would be the means for testing subjects. Whereas, for the second part of the research, a semantic differential type of questionnaire was used. Prior to the set-up of the experiment, the initial stage of the process analyzed the tendency of the use of materials, colors, openings and proportions in an indoor environment. We analyzed and selected the interior design pictures from Books, Magazines and Open sources on Internet.

Color

Categorization for color divisions has taken into account the proportional distribution of colors in the physical aspect of the environment, color palette (bright, pastel), as well as combinatorial variation concerning the quantity and variety of colors (monochromatic, polychromatic).

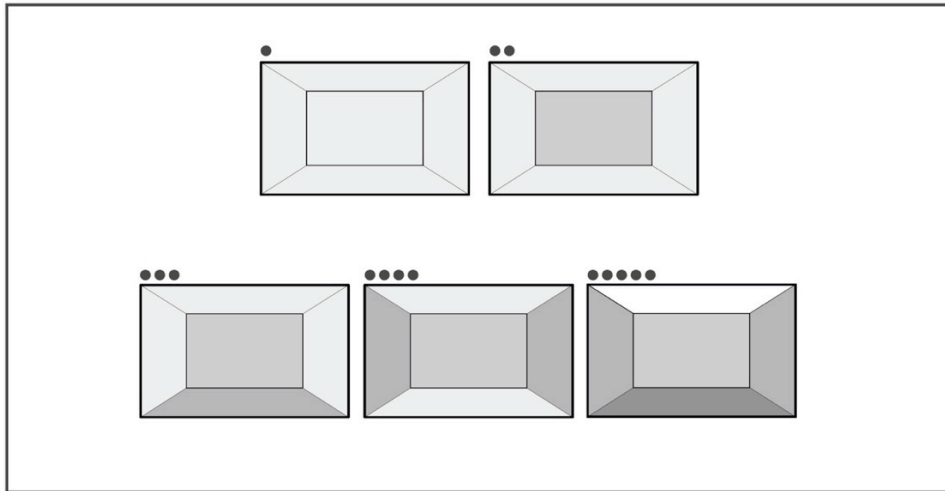


Figure 1. The number of colors in use and its distribution in the physical environment

Proportions

Historically, proportional characteristics have played an essential role in the design of architecture but also its perception. Therefore, in order to reach variations in terms of proportion, it has been proposed that within the framework of this group to include some of the typical historical proportional applications such as Golden Ratio, Georgian, Modular, Contemporary, and traditional Japanese. In coordination with these groups, it has been proposed to use some of the images of buildings designed by world-renowned architects such as Palladio and Le Corbusier. As a result, this group could be defined in two main categories: the height of the space and the ratio of openings in relation to the axes of the room.

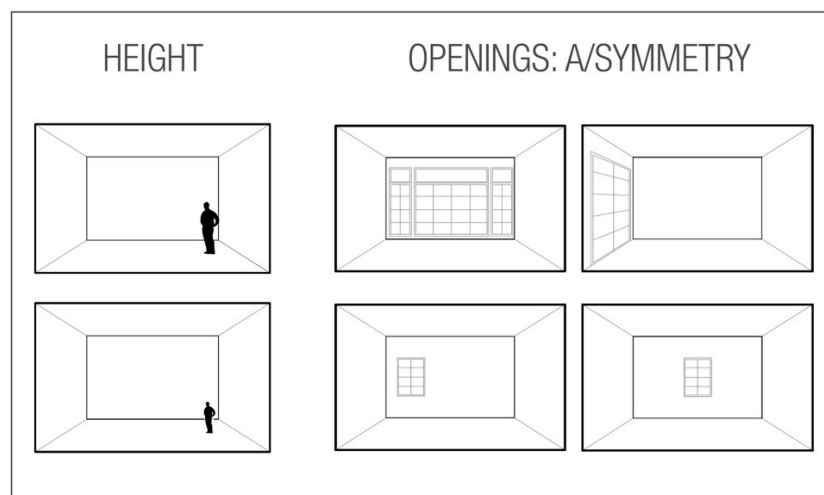


Figure 2. Analysis of the proportional characteristics of the environment

Texture

The interior texture stimuli were selected based on two sub-categories, including usability (common and uncommon), and the method of application / proportional balance of the texture (uniformly and in combination). Resultantly, the setting is was composed of the textures, including tiles, concrete, wood, stone, and metal, whereas Japanese interiors include cases of the use of tatami as well.



Figure 3. The choice of textures in interior design

Moreover, the properties of these materials, such as reflection, semi-reflection, and absorption, are also considered as subcategories of these divisions.

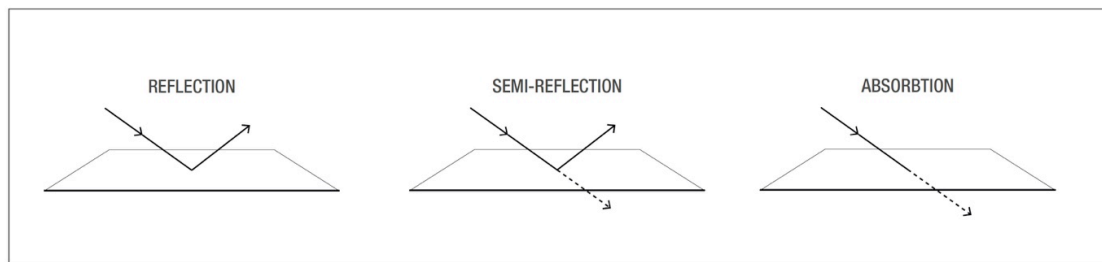


Figure 4. Properties of the materials

Part 1: Observation

The first part of the experiment started with the screening of 30 pictures (10 pictures represented each category) representing the before-mentioned categories, which began with Colors, to be followed by Proportion and Texture. Each picture lasted 3 seconds parted by a 1-second break through a fixation cross between each picture. Before every section, two displays (every 5 seconds) appeared: the name of the section: Section 1 / Colors and the second display with a guiding line to the participants: “Please take a look at these pictures” following with the third display with the fixation which remained in view for 1000ms before the pictures appeared. Participants have been asked to sit in front of the computer screen in the lab environment. The images were presented on a 25.6 inches monitor at a viewing distance of 90 cm.

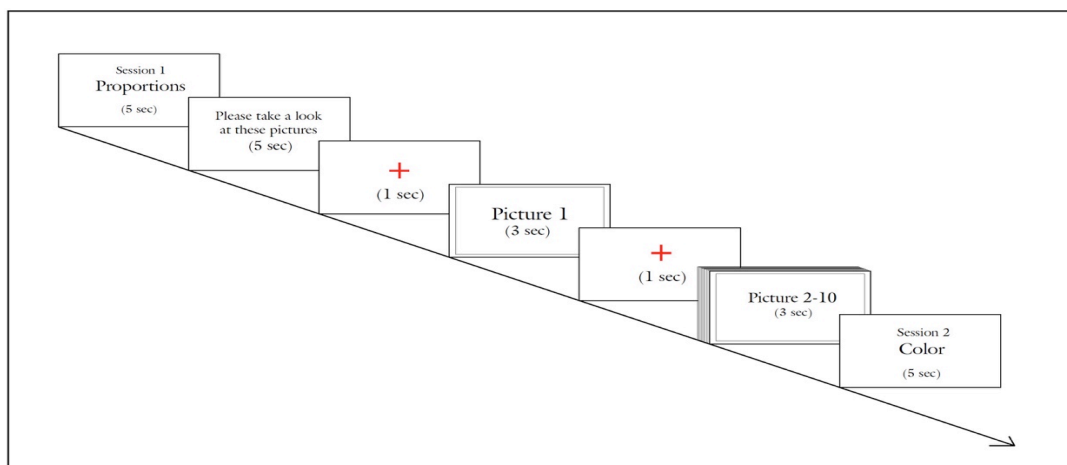


Figure 5. The sequence of events on trial

Part 2: Judgment

With the same set of pictures, this part of the experiment intends to slow the pace of the observation - different from the first part which is characterized with short timing observation - by asking the subjects to take as much time as they need to look at the pictures and follow by a judgment in scale from -5 to 5 (Fig. 6). For interactive purposes, subjects have been given a tablet (Huawei Media Pad T3-7) in which they had a semantic differential bipolar slider designed in MAX Cycling 74 interactive language programming software. Pictures have been presented in random order, although the selection of the pictures consistent with a gradual scale of difference.

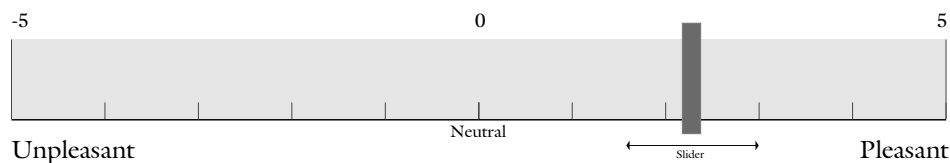
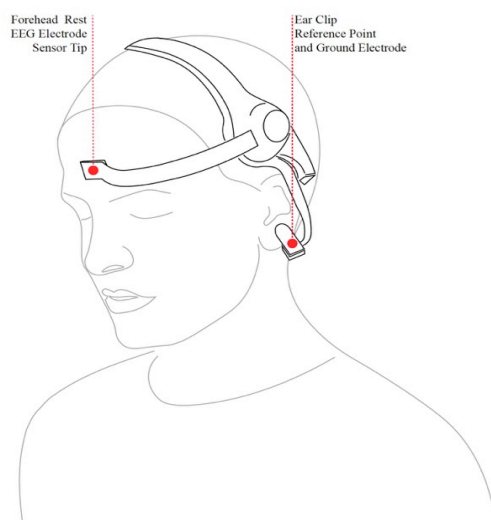


Figure 6. Illustration of the bipolar slider for judgment

EEG Recording

NeuroSky is designed to give you real-time feedback on brain activity. Its brain-computer interface (BCI) technology works by monitoring brain electrical impulses with a forehead sensor. The neural signals are input into the ThinkGear chip and interpreted with NeuroSky's patented algorithms. The values of Attention and Meditation for each second brain wave (gamma, beta, alpha, theta, delta) - converted to binary numbers, which later one was reorganized to an average value in a chart separated for each subject. Based on the NeuroSky indications, "Attention" values range from 0-100 (eSense meter), and its intensity represents the mental "focus" or "attention". Meanwhile, "Meditation" values have the same range 0-100, but they indicate the level of mental "calmness" or "relaxation." (Neurosky, 2012).



Neural Oscillation

Brainwave Type	Frequency range	Mental states and conditions
Delta	0.1Hz to 3Hz	Deep, dreamless sleep, non-REM sleep, unconscious
Theta	4Hz to 7Hz	Intuitive, creative, recall, fantasy, imaginary, dream
Alpha	8Hz to 12Hz	Relaxed, but not drowsy, tranquil, conscious
Low Beta	12Hz to 15Hz	Formerly SMR, relaxed yet focused, integrated
Midrange Beta	16Hz to 20Hz	Thinking, aware of self & surroundings
High Beta	21Hz to 30Hz	Alertness, agitation

Neurosky. (2012). MindWave Mobile: User Guide, p.12.

NeuroSky Device Brain Wave Measurements

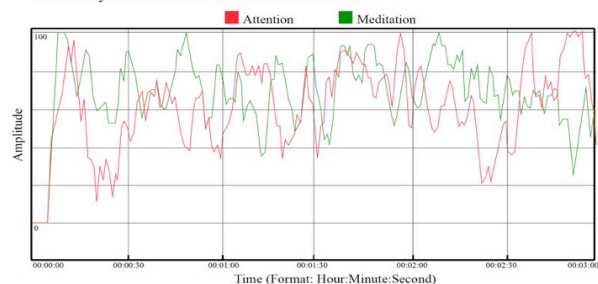


Figure 7. NeuroSky device details

Results

The participants' brainwaves and subjective declarations were measured using standard statistical techniques. First, for both attention and meditation, we calculated the mean values for 19 participants ($M=31.0$, $SD=6.11$) for the rooms where for the first round, each group represented one variable. Secondly, each of the rooms inside one group represents another set of variables. Our goal was to find out whether there are any statistically significant differences in the mean measurements between the three groups of stimuli (color, proportions, and texture) and whether there are significant differences between rooms individually. The one-way analysis of variance (ANOVA) was used to detect any significant changes that could influence EEG recordings between the average values of participants. Statistical analysis data was produced using EXCEL 2019 (Microsoft Inc.). A p-value of <0.05 was considered significant. Bonferroni tests were used for posthoc tests of multiple comparisons.

Part 1: Observation results

Statistical analysis

The results showed that there were statistically significant differences between groups as determined by one-way ANOVA ($F(2,126) = 7.904$, $p=0.0005$). Differences in between pictures within the groups have also shown a statistical significance. The differences in the values have been shown in the attention level, while, in general, values of meditation have shown no significant changes.

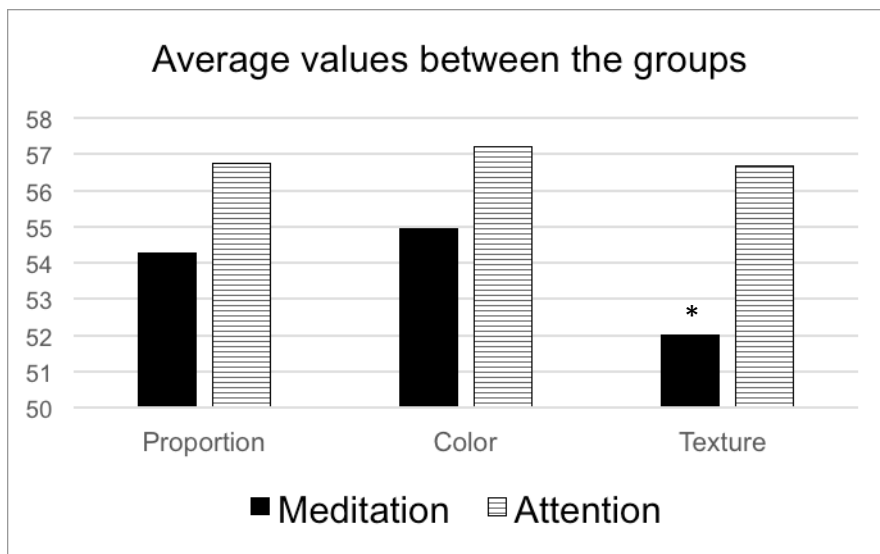


Figure 8. Average values between groups

From the analysis of brain waves, we can notice the average values increase or decrease depending on the combinations of indoor environments. In the table below, we present the mental effort visually for each category in particular:

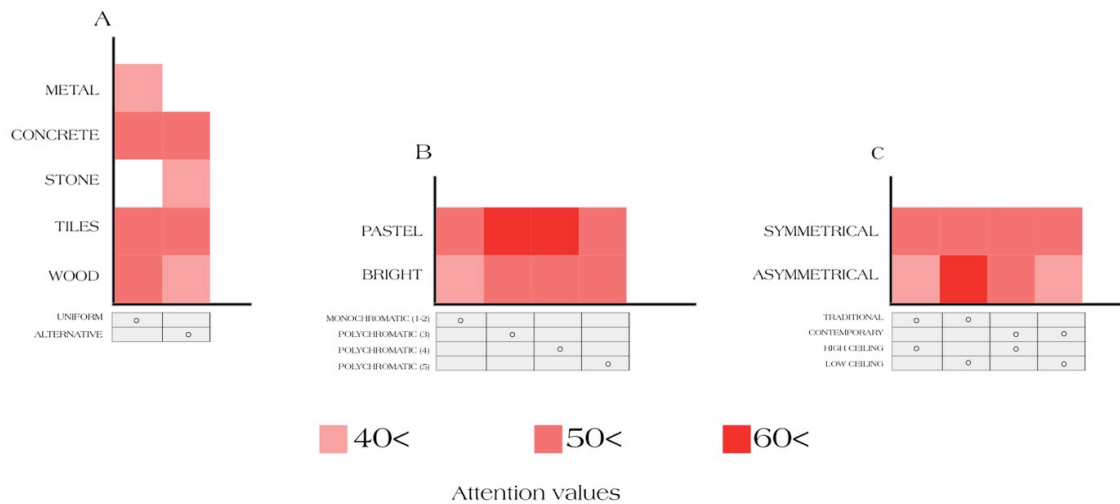


Figure 9. Levels of attention values in different categories

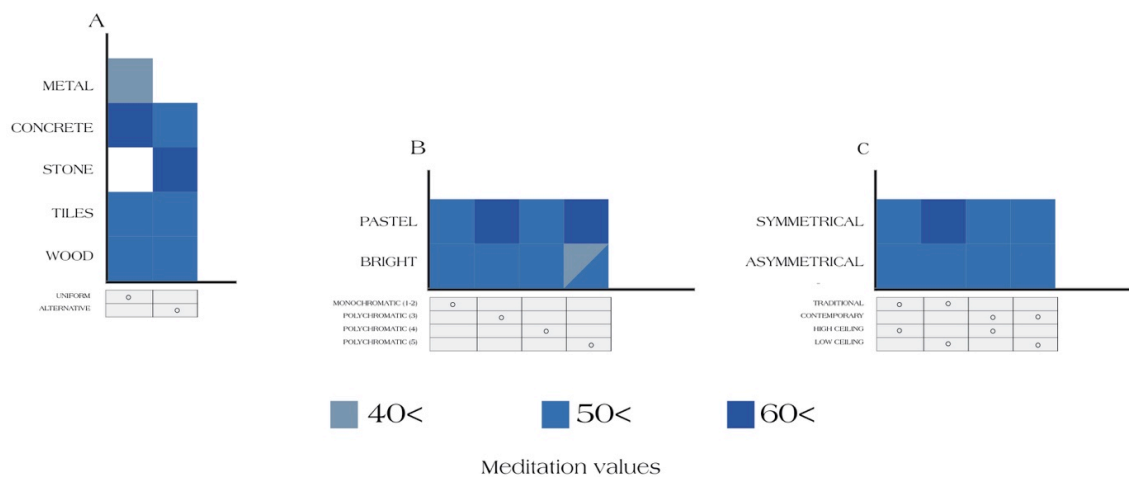


Figure 10. Levels of meditation values in different categories

Based on the NeuroSky indications of "Attention" and "Meditation" values which range from 0 - 100 (eSense meter), we have analyzed the tendencies for neutral (40-50) or elevated (60<) levels of attention and meditation in an attempt to understand the effect of those pictures in these values. Tendencies for higher focus have shown rooms with multiple colors, asymmetrical proportional axis as well as room categorized by a uniform distribution of materials. On the other hand, higher meditation levels have shown rooms with the symmetrical proportional axis, pastel colors. Meanwhile, variations in the distribution of the texture, particularly concrete and stone, have shown elevation in meditation. However, a significant reduction has been observed in the room made of metallic textures.

Part 2: Judgment results

Subjective declarations have shown a trend slightly different from that of the brain waves. In the semantic differential ratings between "pleasantness" and "unpleasantness" of the pictures, in the group of pictures with colors, two most pleasant environments resulted two traditional Japanese rooms, where one of them was characterized by a soft blue color which is an unusual example of a typical Japanese environment, and the other one represents a common Japanese environment.

Regarding unpleasantness in this category, the overall response to this question was surprisingly persistent within participants. The highest negative value goes to the three images which represent cases of a polychromatic interior (5+colors). Interestingly, unpleasantness has been related to the image which represents a case of a monochromatic interior (1 color) as well.

Further, regarding proportions, a pronounced sense of pleasantness is observed in the case of a contemporary room with asymmetrical features and dominated by wood paneling, while the second most pleasant room is the Georgian style room of high ceiling room and many openings. In terms of unpleasantness, unlike the previous category, in this category only one photo has marked negative values represented by it is a room characterized by polychromatic bright colors (yellow, red and green) as well as relative roughness of the material such as exposed concrete.

Lastly, Texture group photos are actually photos with higher values of pleasantness on average compared to the two aforementioned groupings. The most pleasant picture regarding texture based on the evaluation is indicated to be the wood-enclosed environment. Other distinctive components of this room are brightness and uniformity in the distribution of the materials.

Below (Fig. 11) represents detailed results between judgment and observation in each category, and the comparison between them.

Factors			Judgment <small>(subjective declaration)</small>		Obersvation <small>(Brainwave evaluation)</small>	
Classification			Pleasant	Unpleasant	Attention High	Meditation High
Color	Type	Bright		○		
		Pastel	○			
	composition	Monochromatic C	○			
		Monochromatic B&W		○		○
		Polychromatic		○		○
Proportions	ceiling	High	○		○	
		Low	○			
	Balance	Symmetrical	○		○	○
		Asymmetrical	○	○		
Distribution	Uniformly	○	○	○		
	Variations	○	○	○		
Texture	Material	Wood	○			
		Tiles	○			
		Concrete			○	
		Stone				○
		Metal		○		
		Golden Ration				○
		The Modulor		○		
		Japanese Traditional	○		○	
		Georgian	○		○	
		Green				○

Figure 11. Judgment vs. Observation results

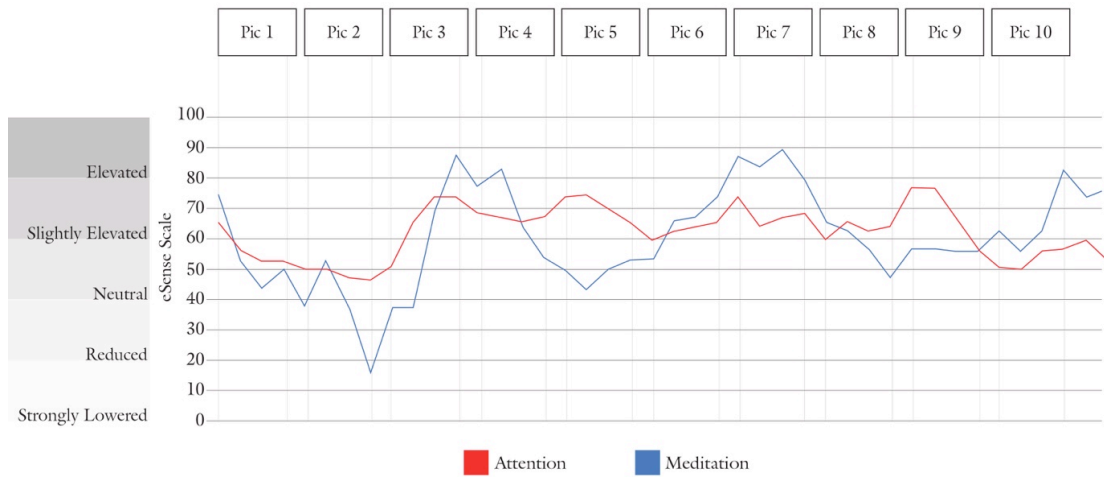


Figure 12. Details of brainwave evaluation using eSense meter scale

Differences in observation between architects and non-architects

Kirk et.al, (2009) on their brain study using fMRI have proved that brain correlates to aesthetic expertise. Their experiment on the judgment of architecture done by has tested two groups of people (architects and non-architects) exposed to an architectural stimuli and controlled stimuli (faces). The results show that the expertise impacts cognitive and perceptual system. Therefore, through this experiment, we extended our analysis towards the understanding whether professional background and a difference between architects and non-architects could be observed in the attention levels. As a result, a statistically significant difference between architects and non-architects has been observed in the average attention level of the proportion group ($t(4)=52.4$, $p=0.00000079$).

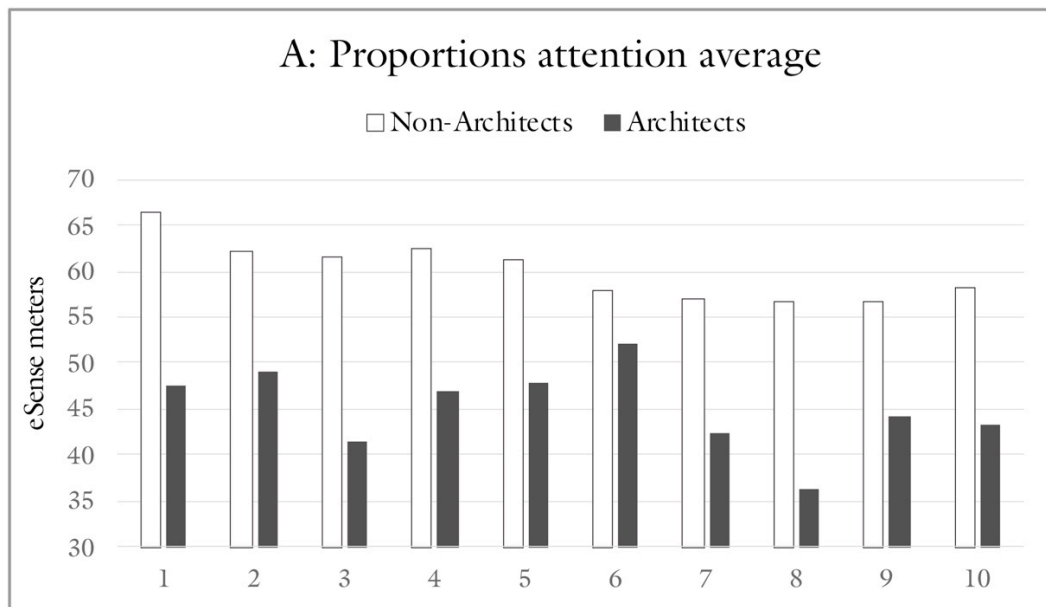


Figure 13. Difference in perception between architects and non-architects

Discussion and conclusion

The literature review shows a strong interrelation between the two disciplines and the methodologies applied for achieving results towards the understanding of occupants' judgment and perception in indoor environments. There was a significant difference in the brainwave's fluctuations between the three groups of stimuli as well as within each of the groups of stimuli, which support the assumption that brain dynamics differ between different architectural environments. The correlation between "pleasantness – unpleasantness" on the one hand and "attention – meditation" as brain dynamics on the other is evident, and the variability in the results has confirmed the complexity of intertwining these disciplines. However, given that our findings are based on a limited number of participants, the results of such analysis should consequently be treated with considerable caution.

The results obtained could be interpreted in two ways: on the one hand, the analysis revealed a correspondence between pleasantness and elevated levels of attention, which informs us about the tendency of cognitive "awakening" to the environments we tend to like. On the other hand, an overlap of the brain dynamic results has been observed in the cases where meditation as well has been related to the pleasantness. Consequently, this overlap could be accounted to the algorithmic ends, interpretations of which are beyond the scope of this study.

A remarkable result that has emerged from the data has been the high values of mental effort related to the uniformity of the distribution of textures in an indoor environment, primarily represented by traditional Japanese rooms. The observed correlation could be attributed as being a result of the relatively higher number of Japanese nationals as part of the experiment (9 out of 19).

As might have been expected, our findings highlighted a reduction in the meditative state towards the room consisting of metallic textures, which, due to its rarity of the use in every-day life environment, was chosen as one of the 'uncommon' rooms in the group. This would appear to indicate that a low level of meditation or 'calmness' could point with relation to the unfamiliarity with the environment. We cannot rule out that familiarity might have influenced the consistency of the high rate of pleasantness towards traditional Japanese environments due to the suggestion, as mentioned above, regarding the impact of the cultural background.

The correlation between professional background and perception of architecture is of interest mentioning especially because this research, in particular, emphasizes the importance of the shift in focus from the architects to the user, and how the design of the architecture affects them - regardless of the architects who design the houses based on their taste. This issue is consistent with several authors who have reinforced the idea and the importance of human-centered design (Pallasmaa, 2012), (Caroline Constant, 2015), (Hall, 1969), (Ashihara & Riggs, 1992), (Neutra, 1954), (De Botton, 2008). Moreover, this confirms previous findings in the literature (Kirk et al., 2009) of the relationship between the expertise and the brain dynamics. This correlation demonstrates just how important it is to have an empirical basis for measuring perceptions of architecture for the decision-making processes.

In fact, this evidence is compelling for the benefit of the collaborative approach between architecture and neuroscience especially since this collaborative approach has been increasingly recognized and pushed forwards by several authors who have focused their research on this opportunity (Albright, 2015; Eberhard, 2009; Edelstein & Macagno, 2011; Pallasmaa et al., 2009).

However, a number of potential limitations should be considered. First, the present study has investigated only through the algorithms provided by the device for measuring brain waves. As a result, the findings might not be transferrable to specific brainwaves in relation to particular stimuli. Secondly, given the relatively small sample size, further experimental investigations are needed to estimate the correlation between the perception of architectural environments in relation to the judgment.

Nevertheless, this study has gone some way towards enhancing our understanding of the relationship between architecture and neuroscience. Moreover, the present study could suggest several courses of action in order to extend further the empirical database, which would lead to aid for the decision-making process in the architectural design.

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