

Mind the perception and emotional response to design: emerging methodology

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ABSTRACT: Design involves constant decision-making. The decision process is influenced by sets of conditions or parameters; some controllable, such as the context, and some unpredictable and uncertain, such as stakeholders' preference. Design decisions related to user's perceptions and emotional response to sustainable features (daylight and green space) and aesthetic value (look and feel) are generally hard to evaluate and quantify. Typically, user response is solicited following construction, in post-occupancy evaluation studies. However, decisions with long-term impacts are often irreversible after implementation; therefore, decision-makers must seriously evaluate the design proposals(alternatives) before arriving at a decision. This paper presents an experiment conducted combining an immersive virtual environment and electroencephalogram (EEG) as a promising tool to evaluate design options during the early design stage of a project. More precisely, the objective is to (a) develop a data-driven approach for design evaluation and (b) understand the correlation between the end users' preference and emotional state. To our knowledge, this is the first time that the combination of virtual reality technology and brainwave response monitoring has been proposed to study the design validation method in architecture.

KEYWORDS: design decision, EEG, virtual reality

INTRODUCTION

What would it mean if data management were at the core of our discipline? Data gives insights into users' responses to environments. The more data, the richer the insights, promoting a better fit of environment to people. How can the design process be informed by data on human response to space and place? Stakeholder preference of one alternative over another plays an important role in design process, especially in dealing with multi-objective design problems in which designers juggle competing objectives. Current tools for design evaluation are surveys, scorecards, and verbal comments. The goal of this research project is to develop, test, and validate a data-driven approach for design decision-making. Such a framework would facilitate participation and action by multiple decision-makers and stakeholders, offering insights into the architectural design process. This paper presents an experiment combining an immersive virtual environment (VR) and electroencephalogram (EEG) as a promising tool to evaluate alternative options during the early design stage of a project. More precisely, the objective is to (a) develop a data-driven approach for design evaluation and (b) understand the correlation between end users' preference and emotional state. To our knowledge, this is the first time that the combination of immersive virtual reality technology and brainwave response monitoring has been proposed to study the design validation method in architecture.

1.0. METHDOLOGY: SAMPLE, EXPERIEMNT AND SETUP

1.1. Theoretic base

This research method is based on the event-related potential (ERP) neuroscience approach and cognition architecture (CA) theory. ERP studies brain activity in response to visual stimuli (Picton et al. 2000). More specifically, it compares the neural signal (brainwave) during different conditions to determine whether and how the brain responds to different stimuli. CA was proposed by Herbert Simon, a pioneer in artificial intelligence, in 1960. CA has since then

been explained, expanded, and further developed by researchers, mainly from the psychology and computer science domains. It has also been applied to research on design thinking. Leading researcher William Mitchell (1990) explained the basic trial-and-error structure of design process and stated that different types of computational devices may be used to generate proposals, test them, and apply control strategies. CA theory can be translated into a method of scoring and providing principles to demonstrate how specific physical/virtual environments can influence our mental state (Hollander and Foster 2016). Our hypothesis is that a design proposal based on the participants' preference could result in better evaluation scores and stimulate a more positive mental/emotional state. To this extent, the emotional state could be used as supplementary evidence to evaluate design proposals. In order to validate our hypothesis, we designed a case study in which participants experienced two alternative design solutions and we captured their responses to determine whether participants might experience a higher positive emotional state, such as interest and engagement, and less negative emotion (stress) as a result of being immersed in their preferred environment (the environment was constructed in VR). It is useful to illustrate the methodology framework in a diagram (refer to figure 1). The goal was to discover whether mental state corresponds with ERP and CA theory.

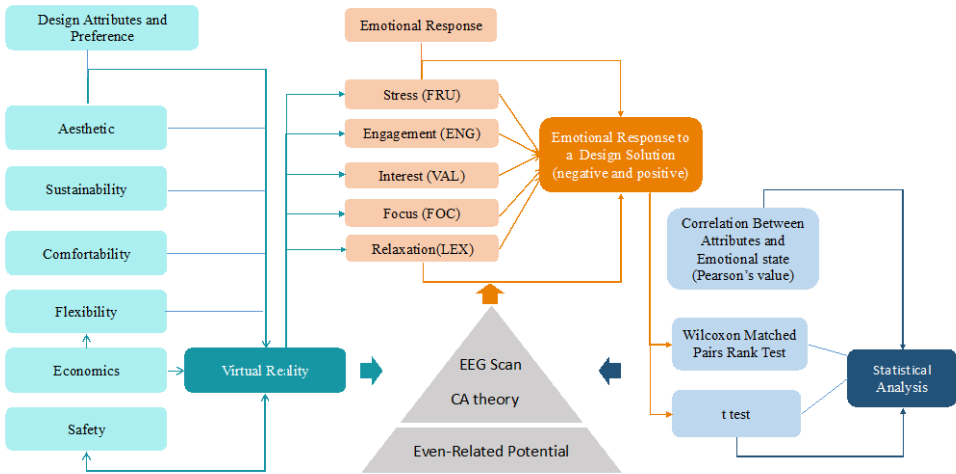


Figure 1. Research methodology

1.2. Case design and tools

This research combines a neuroscientific technology (EEG) with an emerging design technology (VR) to compare emotional stage levels (interpreted from the EEG raw signal) of participants in a well-controlled, three-dimensional virtual environment. A virtual reality set (Samsung Odyssey) and EEG equipment (Emotiv EPOC Insight) were used to collect design evaluation data from six males and two females (aged 18–60). All test participants at University of Maryland were either architecture school faculty members, architects, or architecture students. The design task was to create a layout best-suited to the preference and needs of an architecture department. The test layout occupied a single floor of an L-shaped building on a university campus. The space included lecture rooms, conference rooms, offices for professors and staff, computer labs, and other spaces (e.g., restrooms, stairs, and elevators). The design alternatives were proposed independently by two architectural designers. Test participants acted as clients who would be end-users of the building. Before the experiment began, the clients and designers agreed that six attributes (flexibility, economics, comfort, safety, sustainability, and aesthetics) were important to consider when designing the floor plan layout, although no specific interpretations for the various attributes were given at that point. Although we only chose six attributes, we acknowledge that other attributes would be considered in real practice, such as the initial cost, long-term profit, and ease of maintenance

and repair. The above attributes were used to test the hypothesis, and the same framework can be applied to other design attributes.

Two design options were proposed: OPT A and OPT B. OPT A was designed without knowledge of the primary weighting factors (comfortability, flexibility, and safety) whereas OPT B was designed with all the information. We built two virtual models reflecting the two design options (refer to figure 2) and asked test participants to experience the two design options in an immersive virtual environment (VR). We then used an EEG device to record their brainwaves and emotional response to those two different environments. Afterwards, each participant completed the survey, scoring the quality of design—on a scale of 1 to 7—on comfortability, safety, flexibility, aesthetic value, sustainability, and potential cost. Finally, they provided a preference score for both design options.

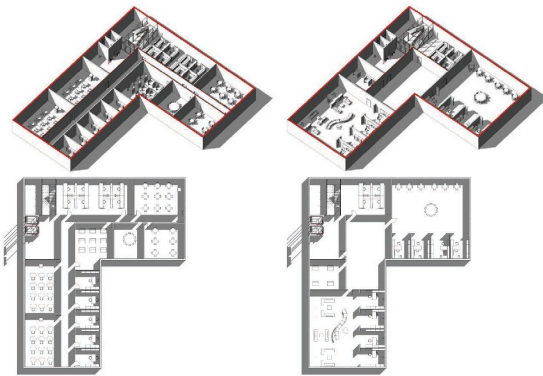


Figure 2. Two design options (Autodesk Revit model)

1.3. Virtual reality (VR) model setup and EEG measurement

In general, there are three types of VR technologies: (1) direct VR into 3D modeling software, (2) VR with a game engine, and (3) a 360-degree panorama picture (Burdea 1994). In this research project, direct VR integration technology was applied due to the speed and quality of the work. Firstly, a 3D model was created with Autodesk Revit based on the initial design. Then, a plug-in tool called ENSCAPE was used to translate 3D Revit to a virtual environment. This is the only program that can be directly integrated into multiple 3D modeling software, which creates high requirements for the hardware (computer); however, it allows for instantaneous design changes in a virtual environment. Two models were set up and transferred to VR (see figure 3). In this research, the Emotiv INSIGHT EEG headset was chosen based on its relatively low cost and the accompanying software, which can aggregate raw data. The headset was fitted on the underside of the VR headset. We immersed them into two different design options, with each design option taking approximately 15-20 minutes to experience. The device consisted of five sensors positioned on the wearer's scalp according to the international 10–20 system: the antero-front (AF3, AF4), parietal (Pz) and temporal sites (T7, T8). Brainwaves were measured through those five channels in terms of amplitude (10–100 microvolts) and frequency (1-80Hz) at 128 samples per second per channel (Aspinall et al. 2015, Emotiv website). The four main brainwaves/bands measured and recorded were beta, alpha, theta, and gamma. After the raw EEG data was collected from each participant, the signals were analyzed with the software Emotiv Pro (developed by Emotiv) and categorized into one of five emotional states: engagement, focus, interest, stress, or relaxation.

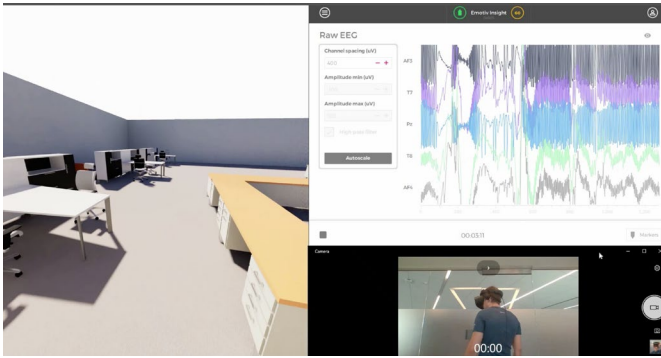


Figure 3. VR and EEG testing

After immersion in the two VRs, an eight-item questionnaire measuring the six design attributes of the building was given to each participant. Each attribute was rated on a seven-point Likert scale. The six attributes represented the criteria defined in the case design stage: aesthetics, safety, flexibility, comfortability, sustainability, and economics (potential cost). At the end, test subjects were also asked to provide a preference score ranking one design option over the other.

2.0 DATA ANALYSES AND FINDINGS

2.1. Questionnaires and EEG results

Altogether, six participants provided 56 scores for six attributes plus an overall preference score for each of the two design options. Design option B (OPT B) received a higher score than design option A (OPT A) in all six design attributes. In OPT B, comfortability, aesthetics, and flexibility were rated as the top three attributes, aligning with the fact that OPT B was created based on knowledge of the clients' preferences. The much higher overall preference score of OPT B validates the point that giving more consideration to the clients' preferences could result in a much higher satisfaction rate. One interesting finding was the fact that aesthetics was rated as one of the top three attributes by participants who favored the preferable option (OPT B) while aesthetics was not identified as an important design attribute by any of the three groups (architects, engineers, and members of the public) through the survey. This might be explained by the innate nature of human beings as visual thinkers who do not consciously or proactively acknowledge the important role of aesthetic value in our decision-making, particularly in design context. Scientists agree that humans possess five basic senses: smell, hearing, touch, taste, and vision. However, the human brain expressly prioritizes just one sense: vision (Hollander and Foster 2016). Furthermore, Kandel (2012) stated that about half of the sensory information reaching the brain is visual. The reason why none of the groups listed aesthetics as their primary design attribute needs to be understood and potentially represents the next research focus.

Next, we examined whether higher evaluation scores were correlated with a positive emotional state of the participants. Each participant had an approximate 20-minute recording, which generated more than 1,400 data points. Overall, OPT A stimulated more engagement, interest, and attention while OPT B generated greater relaxation and stress, with stress levels in the moderate range, which could indicate higher productivity (Emotiv). Unlike the scores from the questionnaires, which indicate a clear preference for OPT B from all participants, EEG data indicated that participants had varied responses—including negative, positive, and neutral—toward the two design options. In order to further understand the varied responses, we examined the data from individual participants and conducted a statistical analysis to determine whether there were significant differences in participants' emotional responses to the two design options. The five emotional states were used as a proxy measurement of participants' preference for design options. The following section explains the findings.

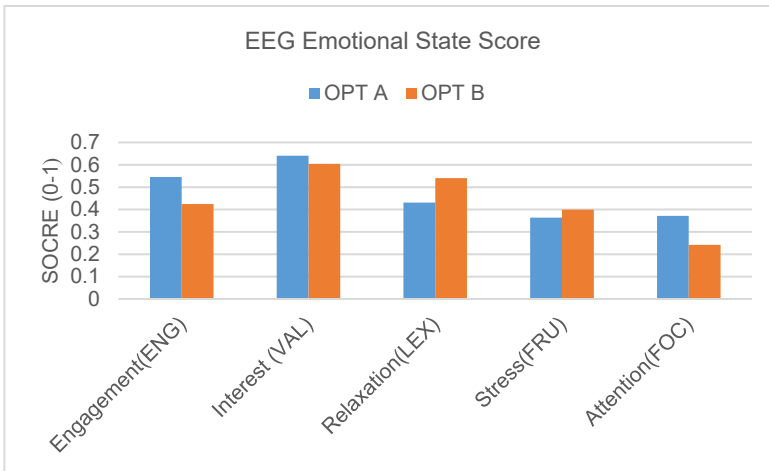


Figure 5. Emotional state score from the EEG recording

2.2. Statistical analyses

The EEG data did not directly lead to the overall evaluation of design options, and the emotional state could not be directly translated as negative or positive toward the design solutions. Therefore, instead of looking at the representation of the individuals' emotional state, the authors examined whether there was a significant difference in how participants responded to the different design options. A null analysis was appropriate for verifying the hypothesis. The Wilcoxon signed-rank test is commonly used to test for a difference in a paired observation, and a sign test is often used to test the null hypothesis.

The analysis considers one null hypothesis:

H_{01} : There is no significant difference between the participants' negative and positive emotional responses to OPT A and OPT B.

The alternative hypothesis is:

H_{a1} : There is a significant difference between the participants' negative and positive emotional responses to OPT A and OPT B.

Descriptive results: Wilcoxon signed- rank test:

Results from the Wilcoxon signed-rank test for OPT A, compared to OPT B, are illustrated in table 1. The equation used to obtain the statistic W was:

$$W = \sum_{i=0}^{n'} R_i^{(+)},$$

where n' is the actual sample size, R_i is the rank, and W is the Wilcoxon test score.

For null hypothesis H_{01} , among the five different emotional responses to the two design options, three response types were higher for OPT A while the other two were lower for OPT A (figure 11). The Wilcoxon test score (W), 64, was higher than the critical value used for a two-tier test of 52. Based on these results, we *could not reject* null hypothesis H_{01} . Instead, we should reject the alternative hypothesis, H_{a1} . In conclusion, **there is no emotional state difference** between the participants' positive and negative responses to the two design options (refer to table 1).

The rejection of the null hypothesis suggests that the overall positive or negative emotional state does not directly affect or correlate with how participants answered the design evaluation. Depending on the importance of design attributes, the preferred design solution might stimulate a negative emotion, and the less preferred design might stimulate a more positive emotion, such as interest and engagement. Participants clearly preferred OPT B overall, which

received higher scores; however, their emotional responses did not show clear negative or positive direction.

Table 1. Wilcoxon matched pairs signed-rank tests for responses to OPT A and OPT B

	OPT A	OPT B	Difference	Positive	[Diff]	Rank	Signed Rank	$\alpha = 0.05$
Response 1	0.718	0.227	0.49	1	0.49	12	12	
Response 2	0.703	0.699	0.00	1	0.00	1	1	
Response 3	0.497	0.648	-0.15	-1	0.15	9	-9	
Response 4	0.355	0.370	-0.01	-1	0.01	3	-3	
Response 5	0.325	0.054	0.27	1	0.27	11	11	
Response 6	0.533	0.471	0.06	1	0.06	5	5	
Response 7	0.564	0.631	-0.07	-1	0.07	6	-6	
Response 8	0.406	0.667	-0.26	-1	0.26	10	-10	
Response 9	0.372	0.467	-0.10	-1	0.10	8	-8	
Response 10	0.354	0.262	0.09	1	0.09	7	7	
Response 11	0.517	0.5	0.02	1	0.02	4	4	
Response 12	0.578	0.573	0.01	1	0.01	2	2	
Response 13	0.410	0.439	-0.03	-1	0.03	5	-5	
Response 14	0.377	0.377	0.00	-1	0.00	1	-1	
Response 15	0.542	0.298	0.24	1	0.24	10	10	
Response 16	0.413	0.498	-0.09	-1	0.09	7	-7	
Response 17	0.715	0.512	0.20	1	0.20	10	10	
Response 18	0.409	0.407	0.00	1	0.00	2	2	
Response 19	0.348	0.382	-0.03	-1	0.03	6	-6	
Response 20	0.264	0.353	-0.09	-1	0.09	8	-8	
							64	Positive sum
							-63	Negative sum
							64	Test statistic (W)

CONCLUSION

The research project has developed, tested, and validated a data-driven approach for design validation. Such a framework would facilitate participation and action by multiple decision-makers and stakeholders as well as lend insights into any design process marked by the characteristics of an architectural design process. Based on the available data from this experimental study, we cannot conclude that a positive emotional state (brain activity) can be correlated with a higher scoring design evaluation. Likewise, a negative emotional state does not automatically result in negative design evaluations. Additional experiments and data are needed for further studies. However, our research has demonstrated proof of the concept of a data-driven approach that uses emotional response as a method of design evaluation. This model has great potential to open new avenues for inquiry of how technology-based tools can be leveraged to influence mainstream design choices that incorporate clients' and end users' preferences. Furthermore, the use of an EEG device allows us to enter the research arena of

how brainwaves respond to different design solutions. Nonetheless, there are several limitations of this research that could be improved in the future :

- Interpretation of the brainwave is mainly conducted through a predetermined algorithm created and managed by the company that made the device. The mechanism of translating brainwaves into emotional scores is unknown. Future research should consider applying a more transparent approach by using third-party software.
- The small sample size did not enable us to run a multivariate statistical analysis. For future research, larger samples and datasets are needed for a full in-depth analysis.
- More design options could be built and tested in order to understand the correlation between design attributes and emotional response.

Despite the limitations, this experimental research project has shed light on how a design evaluation could be combined with neuroscience methods illuminating human response to proposed environments. The findings from this study enable us to identify a set of research questions for the next step. Since a theoretical framework explaining the attitude and behavior toward an architecture design evaluation does not exist yet, this study employs an inductive approach and attempts to move toward such a theory. Such experimental results suggest that the ERP approach and CA theory could be applied to the design field, opening the possibility of data-driven design decision-making.

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