AN INTEGRATED APPROACH TO USER-CENTERED DESIGN: MOBILE BRAIN/HEART IMAGING IN VIRTUAL REALITY

ASMAA BARAKAT, HANY AYAD & ZEYAD EL-SAYAD
Department of Architecture, Faculty of Engineering, Alexandria University, Egypt

ABSTRACT
Poor communication between architects and end-users of the built environment has been implicated as the main barrier to improving design quality and end-user satisfaction. User-centered design (UCD) is an important approach to communication and reaching the end-user affective state. This study aims to develop a new integrated approach for achieving an enhanced user-centered design. UCD is a process of three stages: understanding end-user needs, creating design solutions, and evaluating designs. The new approach is concerned with the built environment's impact on the user's affective state in the early design stage. The mobile brain/heart imaging technology is used to record users' electroencephalogram (EEG) and heart rate variability (HRV) while they navigate the design proposal in non-immersive virtual reality (VR). In this context, the Farsi Lecture Hall in the Faculty of Engineering at Alexandria University was selected to be redesigned. The adopted methodology is based on understanding the needs of architecture students (end-users) through questionnaires and evidence-based design (EBD). Six design proposals were proposed and presented with still images. First, the students were asked to rate each proposal on a 5-point Likert scale. Then they were asked to select the best visualization technique, and the majority chose the 360-panorama. At last, the students sat in Farsi Hall for 3 minutes navigating the best proposal panorama on a full HD laptop screen wearing EEG headband that records EEG and HRV. The SAM test and 5-point Likert stress scale were recorded and compared to EEG and HRV results. The findings of this study show that there is a significant relationship between SAM ratings, EEG, and HRV. Furthermore, 360-panorama is an effective visualization tool for presenting design. Finally, involving mobile brain/heart imaging to induce the end-user affective state while navigating design proposals in VR could enhance design quality and end-user satisfaction.
Keywords: user-centered design (UCD), virtual reality, electroencephalogram (EEG), heart rate variability (HRV), stress, relaxation, emotions, valence, visualization, mobile brain/heart imaging.

1 INTRODUCTION

In recent years, architects and spatial designers have discovered a common interest in how spatial design and the built environment can influence end-user performance and satisfaction. This interest reflects the importance of considering end users' needs and desires in the early design stage, as well as the ongoing demand for new approaches to architecture design that include the end-user in the design process. For decades, understanding user needs and behavior has been regarded as a critical issue that must be considered in product design, giving rise to the term "user-centered design" (UCD) [1]. Many terms for UCD have emerged, including "user/client-oriented design", "people-centered design", "human-centered design", "universal design" and "person-centered design" which are defined as a cycle that starts from the beginning of any design process to its end [2], [3]. UCD is a process of three stages: understanding end-user needs, creating design solutions and evaluating designs [4].

However, UCD appears to have developed and established at a slower rate in the field of architectural design, particularly in large-scale public buildings such as organizations, schools, university buildings, and so on because of two factors. First, designers do not meet with end-users early in the design process. Second, architects (and other key players in the

WIT Transactions on The Built Environment, Vol 210, © 2022 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/ARC220171

spatial design process such as interior designers, engineers, and others) have traditionally been trained in functional and aesthetic conditions, concerning the various factors that comprise the building as a construction.

In this respect, no clear methodology or framework exists for implementing UCD in public buildings that serve a diverse range of end-users. For example, university buildings, which designed to accommodate and support several academic activities such as teaching, learning, and research. Staff and student productivity, health, and behavior are all affected by the effectiveness of the university spaces. So, university buildings have to provide appropriate facilities and spaces that meet the needs of their end-users (students and staff) [5], [6]. Similarly, lecture halls are an integral part of the physical learning environment in the university and can impact the entire learning process, as well as students' well-being, comfort, and productivity. The overall performance of a lecture hall is determined by specific parameters [7].

This study aims to develop a new integrated approach for achieving enhanced user-centered design in designing and retrofitting spaces in public buildings to meet the needs of end-users. The new integrated approach is concerned with the built environment's impact on the user's affective state in the early design stage. To accomplish this aim, we employed two affective state measures: self-report measures and physiologic measurements (mobile brain/heart imaging). Following that, we compared the two measures to determine the best method for evaluating design proposals and quantifying end-users affective states during the early design stage.

The first part of this paper (theoretical study) investigates the evidence-based design of the educational rooms in general. Particularly, this paper focuses on four design elements: colors, lighting, biophilic design, and furniture. Affective state measures, such as self-report and physiologic measurements, are also reviewed. The second part of this paper (empirical study) discusses the adopted methodology which is based on proposing six design proposals for the Farsi Lecture Hall and asking the students (end-users) to select the optimum proposal. At last, the students sat in Farsi Hall for 3 minutes navigating the best proposal panorama on a full HD laptop screen wearing a mobile brain/heart headband that records EEG and HRV and filled self-report questionnaire. The results of this study depict that there is a significant relationship between self-reporting, EEG, and HRV. Furthermore, 360-panorama is an effective visualization tool for presenting design. Finally, involving mobile brain/heart imaging to induce the end-user affective state while navigating design proposals in VR could enhance design quality and end-user satisfaction.

2 LITERATURE REVIEW

2.1 Evidence-based design (EBD)

A long-standing challenge in lecture hall design is how to influence the built environment to improve cognitive performance, affective state, relaxation, and stress reduction. As a result, the literature on stress and relaxation in the built environment was reviewed. A study was conducted to determine the effect of classroom wall colors on student attention. Purple wall color conditions were found to have the highest levels of attention, followed by blue, green, yellow, and red wall colors [8]. Similarly, according to another study, students preferred the colors yellow, dark blue, red, and light blue in that order [9]. Later, a study found that blue is the most popular color among students, followed by green, violet, orange, yellow, and red [10]. As a result, for our case study, we used light blue for the walls and dark blue and yellow for the furniture.

In terms of lighting, previous research has shown that using the standard lighting setting which is characterized by average horizontal illuminance measured at desk level is 300 lx, the CCT is 3000–4000 K, and the standard white light can improve concentration and alertness, and increasing productivity [11]. Furthermore, higher correlated color temperature LED lighting has a perceived positive impact on behaviors and emotional/mood responses, with bluer/higher kelvin temperatures improving alertness, focus, and arousal [12]. As a result, we chose LED lighting for our case study; the illuminance measured at the desk level is 300 lx, the CCT is 3000–4000 K, and the light is standard white.

According to the reviewed literature, students benefit from biophilic design in terms of cognitive function, emotional/mood responses, relaxation, and stress reduction [13], [14]. There are many patterns of biophilic design. We chose two major biophilic concepts for our research: nature in space patterns and natural analog patterns. Nature in space can be represented in visual connection with nature, plants, and dynamic and diffused lighting. Meanwhile, natural analog patterns can be represented in finishes, and objects with biomorphic and fractal forms [15].

Concerning furnishing, student responses gathered during the event "What makes a classroom great?" held as part of the transforming the instructional landscape (TIL) as a major classroom redesign at the University of Toronto, revealed that the FT20 chair was strongly preferred. The FT20 was popular because of its cushioning and attached desk [16]. As a result, we used the FT20 chair for our case study.

2.2 Affective state evaluation

The process of measuring a user's specific emotions is known as affective state evaluation. It has been extensively researched, and numerous techniques have been developed. There are various types of evaluation; however, for this study, we only used self-report measures and physiological measures (mobile brain/heart imaging).

2.2.1 Self-reporting measure

Self-reporting necessitates the user verbally or nonverbally reporting his or her feelings. The only way to measure the first component of emotion: a person's subjective feeling, is through self-reporting. This study will employ various self-reporting techniques, including the Patient Health Questionnaire-9 (PHQ-9), the 5-point Likert scale, and the Self-Assessment Manikin (SAM). First, the PHQ-9 is the depression module, in which scores of 5, 10, 15, and 20 indicated mild, moderate, moderately severe, and severe depression, respectively. Second, the 5-point Likert scale was chosen as the primary instrument in all stages of this study because it is the simplest and most practical way to measure the strength of satisfaction and stress [17]. Finally, we used the SAM which has two dimensions, valence (negative/positive emotions) and arousal or activation (low/high), and every emotion can be placed on these two-dimension of SAM. For example, "fear" would be an emotion with a high level of activation and negative valence, while "calm" would be a low-activation positive-valence emotion. Furthermore, high arousal and positive valence are associated with feelings of happiness, excitement, and alertness. Conversely, low arousal and positive valence translate as calm, relaxed, content, and serene [18].

2.2.2 Mobile brain/heart imaging (physiological measure)

The most commonly used physiological measures of affective state are autonomic nervous system indicators, such as heart rate variability (HRV), and electrodermal measures, such as electroencephalography (EEG). We chose a biometric sensor that can measure EEG and

HRV after considering several factors. First, we decided to use a simpler single-electrode EEG headband because it is easier to manage, smaller, participants are not afraid to use it, and it could be compatible with a VR headset if it is used [19]. Second, we plan to use a consumer EEG headset that will be widely used in the future, and searchers and architects are unconcerned about high costs. Third, we preferred an EEG headset that produces real-time affective states such as stress and relaxation, so that searchers and architects could use it without the need for a programming team or complicated analysis. Furthermore, the literature review supported our considerations by revealing that low-cost EEG headbands can be used to detect emotion in virtual reality [20], [21].

For our experiment, we chose the Flowtime Biosensing Headband which measures EEG and HRV. The output raw data from the Flowtime headband includes EEG absolute brainwave rhythm (dB) and power ratios (alpha α, beta β, delta δ, Theta θ, Gamma γ), heart rate variability (HRV), attention, relaxation, and stress levels. The higher the alpha and theta waves, the greater the relaxation level. While beta and gamma waves are associated with being active and thinking or when a person is highly focused during meditation. On other hand, delta wave refers to deep sleep. Furthermore, the higher the HRV, the greater the relaxation. We tested the Flowtime headband on a 30-year-old male participant who wore the Flowtime headband and watched IAPS emotional pictures of mirth, disgust, and fear, as well as different videos of natural scenes and slums without any sound. We discovered that EEG oscillations, HRV, stress, and relaxation levels varied depending on what was watched.

3 METHODS AND TOOLS

In order to achieve the previously mentioned aim, developing a new integrated approach for achieving enhanced user-centered design in designing and retrofitting spaces in public buildings to meet the needs of end-users, the following steps were adopted (Fig. 1):

1. Understanding the needs of end-users through questionnaires and evidence-based design.
2. Creating various design proposals.
3. Evaluation of the proposals to select the optimum proposal.
4. Using Mobile Brain/Heart Imaging and self-reporting measures to quantify the optimal proposal's end-user affective state.

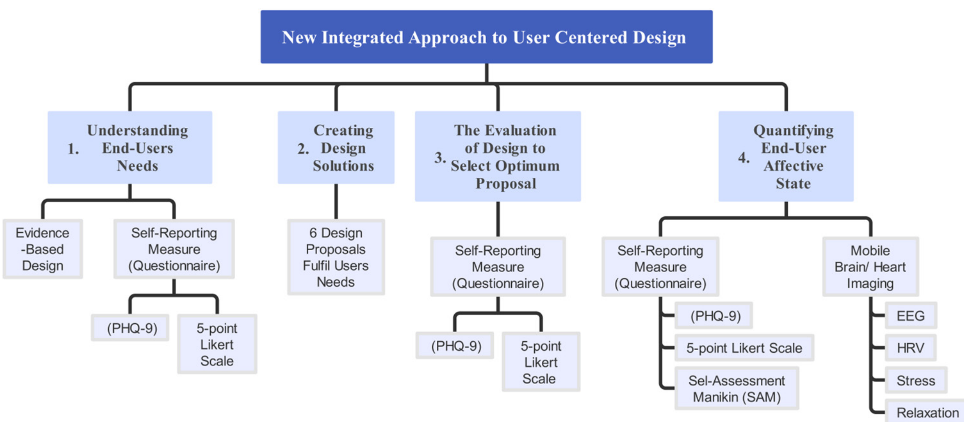
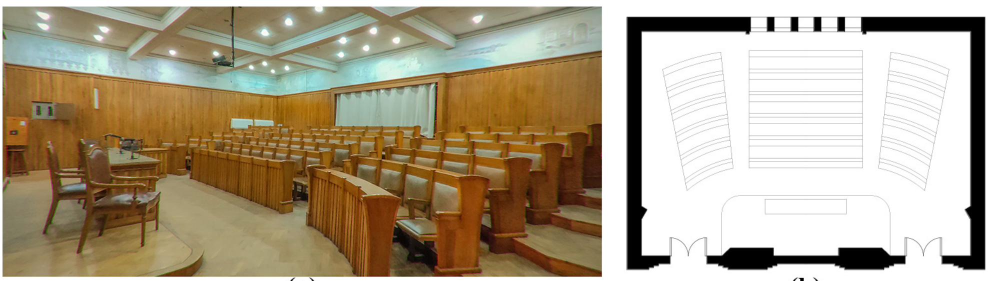


Figure 1: The integrated new approach to the UCD framework.

Our vision is to integrate biometric sensors into non-immersive virtual reality to measure EEG and HRV responses. Besides integrating self-reporting measures such as the SAM and a 5-point Likert scale to evaluate how users feel while interacting with the design proposal in non-immersive VR. Finally, statistical methods are used to quantify the sensor raw data captured throughout the experiment, as well as SAM and the 5-point Likert scale of stress results. The scope of this paper is limited to the affective states of stress, and relaxation in VR, and the biometric sensor data captured and analyzed are EEG and HRV only.

3.1 Study location: Farsi Lecture Hall

This study was conducted in the Farsi Lecture Hall at Alexandria University's Faculty of Engineering to be redesigned to meet the needs of students while adhering to UCD principles. The Farsi Hall is a large, traditional classroom that can accommodate 100–150 students. The Farsi Hall is distinguished by wood-clad walls, parquet floors, a white ceiling, and artistry drawings on the upper part of the walls. Tiered seating is provided, with fixed bench tables and movable leather chairs as illustrated in Fig. 2.



(a) **(b)**

Figure 2: (a) The real Farsi Hall perspective; and (b) Farsi Hall plan.

3.2 End users' needs (questionnaire)

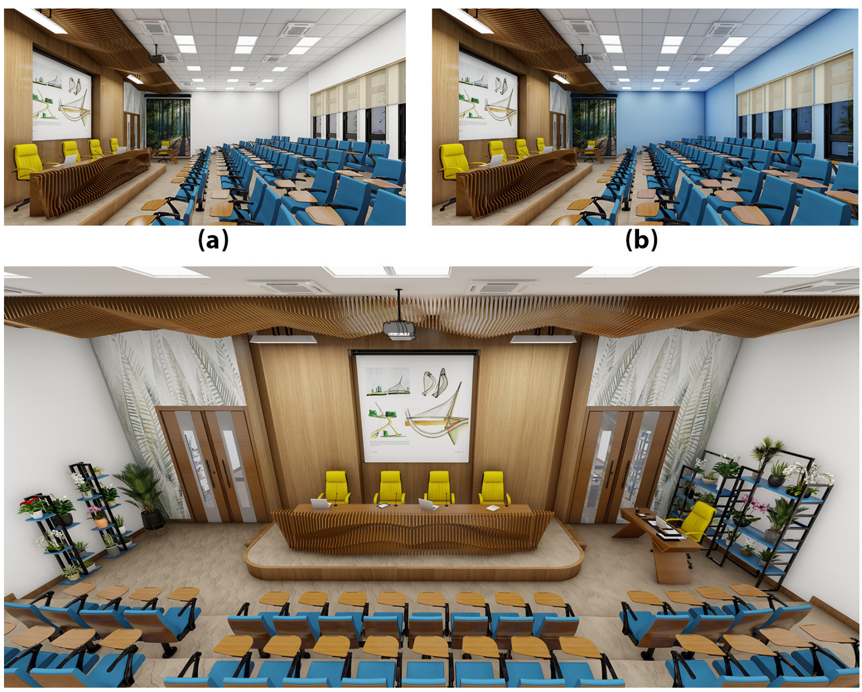
In this phase, we randomly distributed and collected 65 questionnaires. Among them, 60 (92.3%) questionnaires were valid. Participants included 12 male and 48 female architecture students, who were randomly chosen from the department of architecture in the Faculty of Engineering at Alexandria University. All students were aged between 21 and 25 years old. The students' educational backgrounds varied, with 11 being postgraduate students and 49 being undergraduates. The questionnaire was carried out in Farsi Hall. It began with demographic information and was followed by the PHQ-9. Five participants scored > 5 in PHQ-9, and they were all eliminated. The questionnaire then presented a 5-point Likert scale of satisfaction to determine the satisfaction level with the Farsi interior component such as color, textures, walls, ceiling, lighting, furnishing, and environmental aesthetics. Finally, the question of whether biophilic design should be integrated into Farsi Hall was raised.

3.3 Creating design proposals

Six design proposals were proposed based on end-users' needs questionnaire results and evidence-based design. All of the proposals follow the biophilic design. They all share the principle of nature in space, which is represented by plants outside on the window wall "The visual connection to nature" and motorized, perforated, and translucent roller blinds that print window plant shadows "Dynamic and diffused lighting" (Fig. 3(a)). Furthermore, they all adhere to biomorphic forms and patterns achieved by graphic abstract leaves covering the board wall, floor carpet with prairie grass print, front table made of 3D vertical tiles carved into the shape of a wave, and board wall wood cladding material. In terms of furniture, they all use the FT20 chairs with blue cushioning and a wood back (Fig. 3(b)).

(a) (b)

Figure 3: (a) Translucent window blinds and outside plants; and (b) Graphic leaves wall cover, prairie grass print on floor carpet with, 3D carved waves front table, and board wall wood cladding.



(a) (b)

(c)

Figure 4: (a) Proposal 1; (b) Proposal 2; and (c) Proposal 3.

Moreover, the LED lighting illuminance at the desk is 300 lx, the CCT is 3000–4000 K, and the standard white light is approved for all proposals. Whereas the walls of proposals 1, 3, 5, and 6 are white (RAL 9010), and the walls of proposals 2 and 4 are blue (RAL 5012). Indoor 19 plants were selected from the guidance set out by Wolverton in his publication "How to grow fresh air" [22] are used in proposals 3, 4, 5, and 6) while the mural photographs of woodland on the two-sided walls in the front part of the hall are applied in proposals 1, 2, and 6 as Figs 4 and 5. Finally, wood cladding of two-sided wall and ceiling is used in proposals 5 and 6 as indicated in Fig. 5.

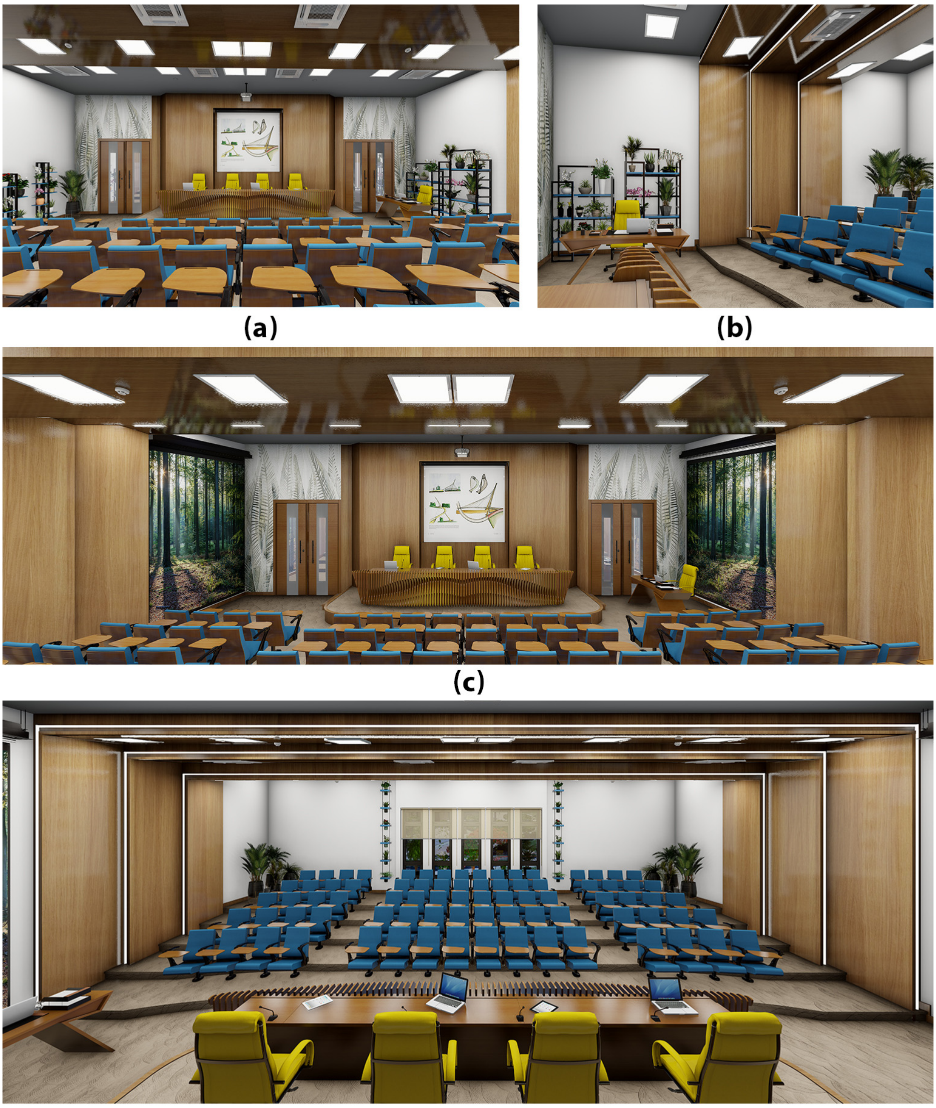


Figure 5: (a) Proposal 5 front elevation; (b) Proposal 5 side elevation; (c) Proposal 6 front elevation; and (d) Proposal 6 back elevation.

Proposal 1 is identical to proposal 2, except that the walls in the proposal 1 are white and the walls in proposal 2 are blue. Proposals 3 and 4 are the same, with the proposal 3 in white and proposal 4 in blue. Meanwhile, proposal 5 is identical to the proposal 6 in that both use wood cladding on two-sided walls and ceilings, with the exception that proposal 6 uses mural photographs of woodland and indoor plants in the back, whereas proposal 5 only employs indoor plants. All the previous design considerations are presented in Table 1 and Figs 3 and 4.

Table 1: Overview of proposals' design considerations.

Design considerations			**Elements**	**Proposals 1**	**2**	**3**	**4**	**5**	**6**
Wall colors			White walls (RAL 9010)	✓	×	✓	×	✓	✓
			Blue Walls (RAL 5012)	×	✓	×	✓	×	×
Furnishing			FT20 chairs blue cushioning and wood back	✓	✓	✓	✓	✓	✓
Artificial lighting			LED lighting illuminance measured at desk level is 300 lx, the CCT is 3000–4000 K, standard white light	✓	✓	✓	✓	✓	✓
Biophilic design considerations	**Nature in space**	**The visual connection to nature**	Plants outside on the window wall	✓	✓	✓	✓	✓	✓
			Indoor plants	×	×	✓	✓	✓	✓
		Dynamic lighting	Roller blinds are motorized, perforated, and translucent to print window plant shadows	✓	✓	✓	✓	✓	✓
	Natural analogs patterns	**Biomorphic forms and patterns**	Graphic abstract leaves cover the board wall	✓	✓	✓	✓	✓	✓
			Floor carpet with the print of prairie grass	✓	✓	✓	✓	✓	✓
			The front table is formed of 3D vertical tiles carved into the shape of a wave	✓	✓	✓	✓	✓	✓
			3D ceiling tiles are made up of horizontal planes carved into the shape of a wave	✓	✓	✓	✓	×	×
			Mural photograph of woodland on the two-sided walls in the front part of the hall	✓	✓	×	×	×	✓
		Materials connected to nature	Wood cladding of board wall	✓	✓	✓	✓	✓	✓
			Wood cladding of two-sided wall and ceiling	×	×	×	×	✓	✓

3.4 Proposals evaluation to select the optimum proposal

At this stage, all of the proposals' different still images were printed on one A0 sheet to facilitate comparison and hung in the foyer in front of Farsi Hall. We randomly distributed and collected 75 questionnaires. Eleven participants scored > 5 in PHQ-9, and they were all eliminated. 64 participants included 15 male and 49 female architecture students, who were randomly chosen from the Department of Architecture in the Faculty of Engineering as Fig. 6. All students were aged between 21 and 25 years old. The questionnaire began with gender and age questions, followed by a 5-point Likert scale of satisfaction to determine the level of satisfaction with each proposal. Then comes the question of which proposal is the most favorable. Finally, we inquire about the most preferred visualization technique (still image, 360-panorama, walkthrough video, and so on).

Figure 6: Proposals evaluation to select the optimum proposal.

3.5 Mobile brain/heart imaging and affective state

Based on the previous stage's results, proposal 6 was selected as the optimum proposal and presented as a 360-panorama on a full HD laptop wearing EEG Headband that records EEG and HRV. The laptop screen was chosen based on the findings of the study that discovered computer screen visualization (non-immersive VR) maintains a higher perceived quality than an immersive environment [23]. In the first, the PHQ-9 questionnaire was randomly distributed and collected from 42 students from the department of architecture in the Faculty of Engineering. Among them, six participants scored > 5 and they were eliminated. The 36 students who completed the experiment ranged in age from 21 to 25 years old. They spent 3 minutes in Farsi Hall navigating a 360-panorama of the best proposal 6 on a full HD laptop screen while wearing a Flowtime headband that recorded EEG and HRV Fig. 7. The SAM test and a 5-point Likert scale of stress level were recorded and compared to the results of the EEG and HRV.

Figure 7: Participants navigating proposal 6 panorama wearing EEG headband.

4 RESULTS

The data analysis results from the experiment stages are summarized below.

4.1 End-users' needs questionnaire

IBM SPSS Statistics v26 and MS Excel were used to generate descriptive statistics of the end-users' needs questionnaire. Total scores, distribution of percentages, and weighted mean were all analyzed. Weighted means were calculated for the Likert scales, ranging from very unsatisfied = 1 to very satisfied = 5, to determine the tendency of the composite scores. Based on the reviewed studies, the weighted mean results can be interpreted to show how satisfied (or dissatisfied) students are [17], [24]. The findings revealed that the majority of students, 42 of 60 (70%), are very satisfied with the artistic drawings on the upper part of the walls, with a weight mean score of 4.52. The wood texture of the walls and floor received the next highest weighted mean score of 3.47, indicating that the students are satisfied with it. The weighted mean score for artificial and natural lighting was 3.37, indicating neutral. Furnishing is also neutral, with a weighted mean of 3.1. On the Other hand, 60% of students were dissatisfied with environmental aesthetics, and 28.3% chose neutral with a weighted mean of 2.25 to represent dissatisfaction as shown in Table 2. Finally, when the students inquired about applying biophilia principles to the redesign process, 36 of 60 (60%) students strongly agree, 16 (26.7%) agree, 2 (3.3%) chose neutral, and 6 (10%) disagree. The weighted mean of applying biophilia principles is 4.3, indicating a strong agreement.

Table 2: The end users' needs questionnaire result.

Farsi components	Artistic drawings	Wood texture (walls/floors)	Lighting	Furnishing	Aesthetics
Weighted mean	4.52	3.47	3.37	3.1	2.25
Result interpretation	Very satisfied	Satisfied	Neutral	Neutral	Unsatisfied

4.2 The optimum proposal questionnaire

The optimum proposal questionnaire data were also analyzed using IBM SPSS Statistics v26 and MS Excel. Weighted means were calculated for the Likert scales, ranging from very unsatisfied = 1 to very satisfied = 5, to determine the tendency of the composite scores. According to the findings, the weighted mean of the proposals 5, 6, and 3 indicates that the students are satisfied. Furthermore, the weighted mean of the proposals 1, 2, and 4 indicates neutral as shown in Table 3.

Table 3: Proposals evaluation results.

Proposals	Proposal 1	Proposal 2	Proposal 3	Proposal 4	Proposal 5	Proposal 6
Weighted mean	3.34	2.77	3.89	2.95	4.06	4.06
Interpretation	Neutral	Neutral	Satisfied	Neutral	Satisfied	Satisfied

According to the results of the best proposal question, the proposal 6 is preferred by the majority of students 25 of 64 (39.1%). Proposal 3 was the second most popular proposal, with 17 of 64 students (26.5%) choosing it. Whereas proposal 5 was chosen by 13 students (20.3%). On the other hand, proposal 1 was chosen by five students (7.8%), proposal 2 by one student (1.6%), and proposal 4 by three students (4.7%). As a result, proposal 6 is regarded as the best proposal for the end-users. Proposal 6 is characterized by using mural photographs of woodland, indoor plants in the back, and wood cladding of two-sided wall and ceiling as illustrated in Fig. 8. Finally, 43 out of 64 students (67%) chose 360-panorama as the best visualization technique.

Figure 8: Proposal 6 which is selected as the optimum proposal.

4.3 The results of mobile brain/heart imaging stage

According to SAM results for the proposal 6 design, 15 of 36 students (41.7%) chose the highest level of valence (very positive emotions), while 18 of 36 students (50%) chose the second positive degree of valence (positive emotions), and three students (8.3%) selected neutral, while there is no one selected negative emotions. In terms of arousal, two students (5.6%) chose the highest level of arousal (very high arousal), eight students (22.2%) chose the second-highest level of arousal (high arousal), six students (16.7%) chose neutral, 10 students (27.8%) chose low arousal, and 10 students (27.8%) chose very low arousal. On a 5-point Likert scale of stress level, 50% of students chose “no stress”, 27.8% chose “low stress”, and 22.2% chose “neutral”. The raw data from the Flowtime headband is then analyzed, and their weighted means are calculated and compared to the weighted means of SAM and 5-point Likert scale stress level results.

5 DISCUSSION

The findings revealed that when participants in the SAM test have high arousal and positive valence (meaning high excitement and low relaxation), HRV, relaxation, alpha α-power ratio, and beta β-power ratio are all low, but they are all higher when participants have low arousal and positive valence (meaning high calm relaxation) as shown in Fig. 9. These results are associated with literature. But there is no relationship between these results and theta θ, gamma γ power ratios. Besides, there is a clear link between weighted means of 5-point Likert scale stress and headband calculations of HRV, stress, and relaxation. According to the literature, HRV is high when a person is in a relaxed state; HRV is high in participants who said they have no stress and decreases in participants who said they have low and moderate stress, respectively. Moreover, weighted means of 5-point Likert scale stress and weighted means of calculated headband stress have a directly proportional relationship. while weighted means of 5-point Likert scale stress and weighted means of calculated headband relaxation have an inverse proportion relationship as illustrated in Fig. 10. On the other hand, there is no relationship between 5-point Likert scale stress and the analysis of alpha α, beta β, delta δ, theta θ, and gamma γ raw data. As a result, the Flowtime headband is effective in stress interpretation by relying on its app equations of HRV, relaxation, and stress.

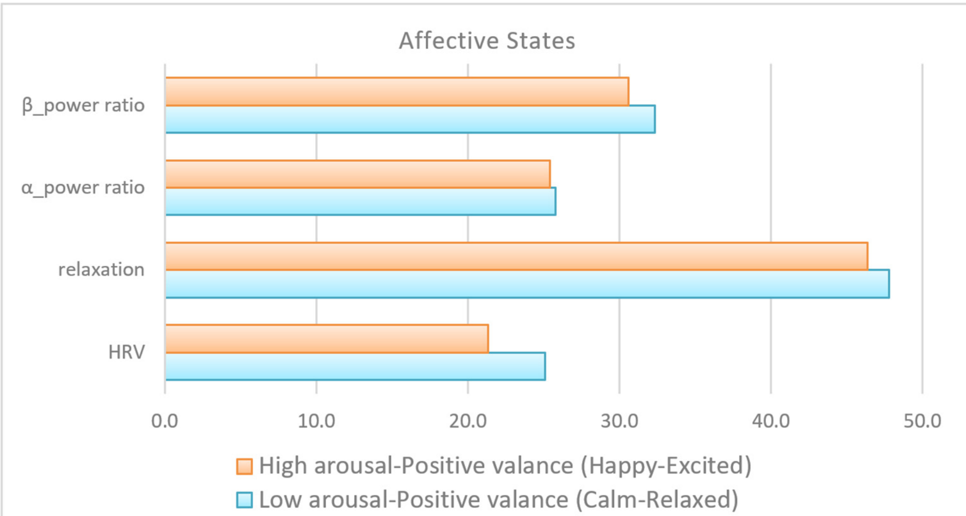


Figure 9: The SAM results and the output of the EEG headband.

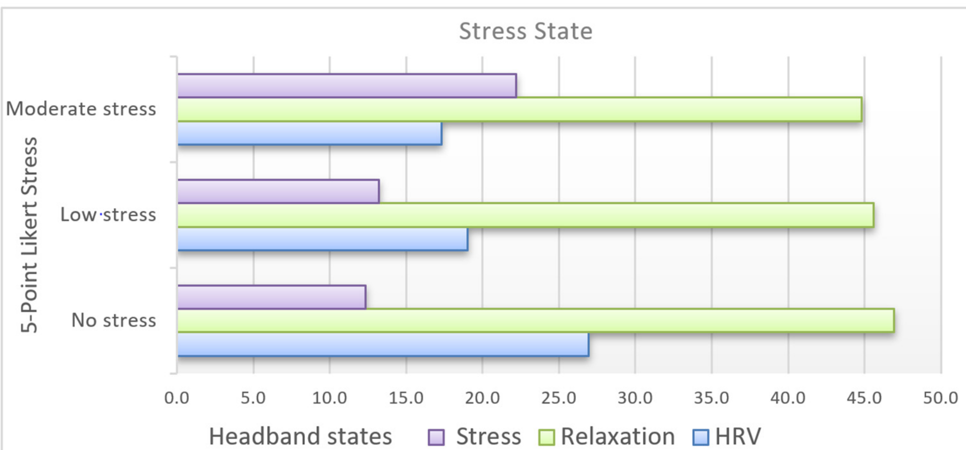


Figure 10: 5-point Likert stress results and the output of EEG headband.

While the methods used in this study are novel for the user-centered design approach, some limitations should be considered. One of the most important considerations in designing this study was the participant's affective mood state; they should not have a high level of depression in order for the results of EEG and HRV to be unaffected by depression; thus, PHQ-9 is required to decide whether to use mobile brain/heart imaging or not. Another issue is participants' willingness to wear the EEG headband without fear of being electrically shocked, as some students claimed; thus, the type of headband is critical to be simple and familiar in shape. This study aimed to use a consumer EEG headset that generates real-time affective states such as stress and relaxation so that searchers and architects could use it without the need for a programming team or complicated raw-data analysis of brainwaves. Future research should test other EEG headbands with more affective states, such as happiness, sadness, and so on, as well as simpler data analysis methods.

6 CONCLUSION

To summarize, the findings of this study show that a user-centered design approach is effective in built-environment design and leads to end-user satisfaction with the built environment. Furthermore, self-reporting measures such as questionnaires and a 5-point Likert scale can be used to determine end-user needs and evaluate design proposals. A 360-panorama displayed on a full HD laptop computer screen (non-immersive VR) is also the most appealing visualization technique for study participants. While end-users navigate non-immersive virtual reality, it affects their EEG and HRV and generates different affective states depending on the design. HRV, relaxation, and stress output of mobile brain/heart imaging while navigating 360-panorama have a direct relationship with a 5-point Likert scale of stress. Likewise, when participants in the SAM test have high arousal and positive valence (meaning high excitement and low relaxation), HRV, relaxation, alpha-power ratio, and beta-power ratio are all low, but they are all higher when participants have low arousal and positive valence (meaning high calm relaxation). Finally, using mobile brain/heart imaging to induce an end-user affective state while navigating design proposals in nonimmersive VR could improve design quality and end-user satisfaction.

ACKNOWLEDGEMENTS

All participants are students in the Department of Architecture at Alexandria University's Faculty of Engineering. The authors did all of the 3D modeling, VR creation, and data recording. This manuscript is not sponsored or endorsed by Flowtime, Inc., Lumion, Inc., or Autodesk, Inc.

REFERENCES

[1] Valand, M.S., Between organization and architecture: End-user participation in design. *Int. J. Work Organ. Emot.*, **4**(1), pp. 42–60, 2011.

[2] Farinango, C.D., Benavides, J.S., Cerón, J.D. & López, D.M. & Álvarez, R.E., Human-centered design of a personal health record system for metabolic syndrome management based on the ISO 9241-210: 2010 standard. *J. Multidiscip. Healthc.*, **11**, p. 21, 2018.

[3] El Sayad, Z.M., Farghaly, T. & Hamada, S.M., Integrating human-centered design methods in early design stage: using interactive architecture as a tool. *J. Al-Azhar Univ. Eng. Sect.*, **12**(44), pp. 947–960, 2017.

[4] Dwivedi, S.K.D., Upadhyay, S. & Tripathi, A.K., A working framework for the user-centered design approach and a survey of available methods. *Int. J. Scientific Res. Publ.*, **2**(4), pp. 12–19, 2012.

[5] Abisuga, A.O., Wang, C.C. & Sunindijo, R.Y., A holistic framework with user-centered facilities performance attributes for evaluating higher education buildings. *Facilities*, 2019.

[6] Vafaeenasab, M.R., Morowatisharifabad, M.A., Ghaneian, M.T., Hajhosseini, M. & Ehrampoush, M.H., Assessment of sick building syndrome and its associating factors among nurses in the educational hospitals of Shahid Sadoughi University of Medical Sciences, Yazd, Iran. *Glob. J. Health Sci.*, **7**(2), p. 247, 2015.
[7] Simpeh, F., Comparative analysis of lecture theatre performance parameters' importance to students learning experience. *3rd Int. Conf. Infrastruct. Dev. Africa*, 2014.
[8] Duyan, F. & Ünver, R., A research on the effect of classroom wall colours on student's attention. *A| Z ITU J. Fac. Archit.*, **13**(2), pp. 73–78, 2016.
[9] Ahmadi, N. & Tabaeian, S.M., The role of color in improving the educational environment quality. Case Study: A number of girls' elementary schools in District 2 of Isfahan. *Int. J. Archit. Urban Dev.*, **7**(2), pp. 33–40, 2017.
[10] Costa, M., Frumento, S., Nese, M. & Predieri, I., Interior color and psychological functioning in a university residence hall. *Front. Psychol.*, p. 1580, 2018.
[11] Sleegers, P.J.C., Moolenaar, N.M., Galetzka, M., Pruyn, A., Sarroukh, B.E. & Van der Zande, B., Lighting affects students' concentration positively: Findings from three Dutch studies. *Light. Res. Technol.*, **45**(2), pp. 159–175, 2013.
[12] Morrow, B.L., The impact of fluorescent and LED lighting on student attitudes and behavior in the classroom, 2018.
[13] Dadvand, P. et al., Green spaces and cognitive development in primary schoolchildren. *Proc. Natl. Acad. Sci.*, **112**(26), pp. 7937–7942, 2015.
[14] Determan, J. et al., The impact of biophilic learning spaces on student success. *Build. Res. Inf. Knowledgebase*, 2019. https://www.brikbase.org/content/impact-biophilic-learning-spaces-student-success.
[15] Bowman, C., Putney High School GDST The Biophilic Classroom Study – May 2020 –Final Report, 2020. DOI: 10.13140/RG.2.2.11556.50562.
[16] University of Toronto, Transforming the instructional landscape. 2019.
[17] Alonazi, M., Beloff, N. & White, M., Exploring determinants of m-government services: A study from the citizens' perspective in Saudi Arabia. *2019 Federated Conference on Computer Science and Information Systems (FedCSIS)*, pp. 627–631, 2019.
[18] Munoz-de-Escalona, E. & Canas, J.J., Online measuring of available resources. 2017.
[19] Horvat, M., Dobrinić, M., Novosel, M. & Jerčić, P., Assessing emotional responses induced in virtual reality using a consumer EEG headset: A preliminary report. *2018 41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, pp. 1006–1010, 2018.
[20] Suhaimi, N.S., Mountstephens, J. & Teo, J., EEG-based emotion recognition: A state-of-the-art review of current trends and opportunities. *Comput. Intell. Neurosci.*, 2020.
[21] Lakhan, P. et al., Consumer grade brain sensing for emotion recognition. *IEEE Sens. J.*, **19**(21), pp. 9896–9907, 2019.
[22] Wolverton, B.C., *How To Grow Fresh Air: 50 Houseplants To Purify Your Home Or Office*, Orion Spring, 2020.
[23] Fonseca, D., Villagrasa, S., Garcia, O., Navarro, I., Puig, J. & Paniagua, F., Statistical approach of user's experience in the visualization of architectural images in different environments. 2010.
[24] Joshi, A., Kale, S., Chandel, S. & Pal, D.K., Likert scale: Explored and explained. *Br. J. Appl. Sci. Technol.*, **7**(4), p. 396, 2015.