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EVALUATION OF EMOTIONS INDUCED BY BIOPHILIC LIGHTING PATTERNS USING EEG AND QUALITATIVE METHODS

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Abstract

This pilot study examines how lighting can support people's well-being in urban environments by designing lighting projections using biophilic principles and conducting a mixed-method assessment. Four biophilic projections were designed to induce positive feelings including relaxation as well as four non-biophilic patterns for comparison. All eight patterns were tested on five participants using electroencephalogram (EEG) quantitative methods as well as qualitative surveys using an adapted Discrete Emotions Questionnaire with ratings and open questions. The EEG results showed 75% of the biophilic patterns had a positive emotional response as compared to the control whereas, 50% of the non-biophilic patterns showed an expected negative emotional response compared to the control. Additionally, the qualitative questionnaire demonstrated that biophilic patterns had a 135% more positive result than the control and 417% more positive than non-biophilic patterns. The EEG analysis particularly provides a novel way to consider EEG testing in the context of lighting atmospheres and emotions to support well-being.

Keywords: Biophilic, EEG, Light, Well-being, Relax, Stress, Urban, Cities, Emotions

1 Introduction

Every year more people are living in urban environments with as much as 75% of Europeans living in developed areas in 2020 (The World Bank Group, n.d.). Urban living offers many benefits to people however, it also comes with health risks. Living in the city has been associated with increased mental health risks including stress, anxiety and mood disorders (Lederbogen, et al., 2011). Biophilic principles offer an approach for helping to relax people by incorporating natural, organic elements into designs and spaces. Biophilic principles or biophilia refers to the concept that people are innately connected with nature and through interacting with nature or analogues of nature, people may experience positive emotions including relaxation and delight (Kellert & Calabrese, 2015).

Typically, biophilic design is realised in ways such as incorporating actual nature as "plant/green walls" or increasing natural daylight. There is existing research showing that physical plants or physical exposure to nature has a positive effect on peoples' moods and stress reduction (William Browning, 2014). However, biophilic design also proposes that analogues of nature, such as images of nature, patterns from nature or references to nature should also have positive effects on peoples' mood and relaxing effects (Kellert & Calabrese, 2015).

Given the relationship between stress and urban living, the immediate solution that comes to mind is to add plants and green spaces to cities. However, the capacity to increase natural parks and landscapes to existing urban environments is very limited and access to land is highly competitive (European Environment Agency, 2020). Perhaps lighting design can offer support, considering green spaces and nature in a less literal but more immediately achievable way – through analogues of nature. Using lighting patterns inspired by the natural environment to light urban spaces because, as biophilic principles suggest, these analogues should generate positive mood effects. These could be applied with a focus on enhancing existing city environments and connecting people to nature for their well-being.

Well-being is a widely used term that encompasses many factors of a person's overall health and lifestyle. Ruggeri et al. developed an analysis tool to measure the well-being of people in different countries around the world. They developed 10 key dimensions that contribute to

overall well-being of people. These are: Competence, Emotional Stability, Engagement, Meaning, Optimism, Positive Emotions, Positive Relationships, Resilience, Self-Esteem and Vitality (Ruggeri, et al., 2020). The well-being dimension “Positive Emotions” is the most relevant well-being dimension for this research in the context of applying biophilic design principles in lighting given that biophilic studies already show that connections to nature positively impact emotions, moods and stress reduction (William Browning, 2014).

Previously, traditional research relied on self-report techniques to assess emotions of participants. Now, electroencephalography (EEG), which captures and analyses the electrical activity of the brain, is gaining recognition as a reliable method for evaluating emotional states of individuals (Costadopoulos, 2016).

In this context, this research uses EEG along with qualitative testing to understand if combining biophilic design principles and electric lighting could increase peoples’ connection to nature in the urban environment, generating positive emotions of relaxation to support well-being in the community.

2 Background

2.1 Biophilic Design

Stephen R. Kellert, presents biophilic design strategies and characterises three kinds of biophilic experiences: the direct experience of nature, the indirect experience of nature, and the experience of place and space. “The indirect experience of nature” refers to interaction with the representation of nature in different forms such as an image, sculpture, exposure to specific patterns, and processes with the characteristic of the natural world (Kellert & Calabrese, 2015). This category forms the basis of the biophilic lighting patterns that were developed and tested for this research.

Fartadi Scurtu investigated three parameters of biophilic lighting patterns using surveys. It was concluded that when the speed of change of the lighting pattern was slow then the responses of participants aligned with the positive adjectives: cosy, relaxed and pleasant/hospitable (Fartadi-Scurtu, 2018).

2.2 Lighting Atmospheres

Böhme explains that the character of an atmosphere is related to the mood being communicated to the subjects “the character of an atmosphere is the way in which it communicates a feeling to us as participating subjects” (Böhme, 2013, p. 2). However, one cannot define an atmosphere without first experiencing it, and in doing so will have an impression based on their own emotional state (Böhme, 2013). Light itself has a powerful impact on atmospheres and has the ability to transform the mood and tone of a space, influencing peoples’ emotions and experience (Böhme, 2013).

2.3 EEG

EEG stands for ‘electroencephalography’ which is a process where the changes in the electrical activity of the brain are recorded (EMOTIV, n.d.). The electrical activity can be distinguished into five main brain wave categories, separated by their differing frequency bands. These frequency bands are Delta (1-3 Hz), Theta (4-7 Hz), Alpha (8-13 Hz), Beta (13-30 Hz), and Gamma (31-50 Hz) (Jatupaidboon, et al., 2013). Measuring the electrical activity of the brain can provide quantitative data representing real time changes in the brain that can be related to emotional states. Costadopoulos explains in his research that “research into brain and heart processes indicate that (1) emotions are reflected in brain and heart activity and (2) it is possible to detect changes in both brain activity and heart rate in subjects for basic emotions.” (Costadopoulos, 2016).

Linking EEG measurements to discrete emotions is being researched extensively and there are varying approaches and factors such as ‘participants, model of emotion, stimulus, feature, temporal window etc’ (Jatupaidboon, et al., 2013). In particular ‘feature’ refers to the signal characteristics of the EEG that are used for the analysis. Jatupaidboon et al. identify that Power Spectral Density (PSD) is a widely used feature related to the frequency bands of the EEG and

has good proven performance across different research (Jatupaidboon, et al., 2013). For this research, the data captured is in the form of PSD and is then converted by an EEG software from PSD to the form of 'average band power'. The average band power is effectively a number that "summarises the contribution of the given frequency band to the overall power of the signal" (Vallat, 2018).

2.3.1 EEG Emotional Model

The valence arousal model can be used to analyse emotions from EEG data. In this model there are two dimensions where valence is a scale ranging from negative to positive and arousal represents calm to excited (Jatupaidboon, et al., 2013). Using the valence and arousal model it can be understood if an emotion is positive or negative and if that emotion is a more aroused emotion such as excited (positive valence, high arousal) or a less aroused emotion such as calm (positive valence, low arousal). Figure 1 Russell's Valence Arousal Emotional Model below (Galvão, et al., 2021) shows the Russell's 2D model of emotion classification using these valence and arousal parameters.

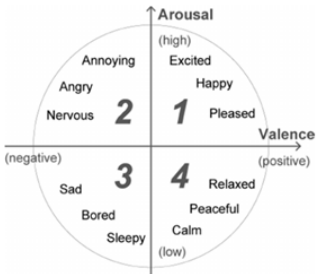


Figure 1 Russell's Valence Arousal Emotional Model (Galvão, et al., 2021)

The relationship between these valence and arousal parameters and EEG frequencies needs to be clarified to apply the model to the EEG results. Jutupaidboon et al. in "Emotion classification using minimal EEG channels" demonstrated that higher EEG frequencies have higher accuracies and in particular for 'valence'. They show that, for valence, gamma has the highest accuracy of 81.91%, closely followed by beta with 80.64% (Jatupaiboon, et al., 2013). For arousal, David Schubring and Harald T Schupp demonstrated that alpha waves are a reasonable representation. They establish that "high arousing pleasant and unpleasant stimuli compared with low-arousing control stimuli decrease alpha and beta-power across task contexts (free viewing and categorization task) during initial perceptual stimulus processing" (Schubring & Schupp, 2021).

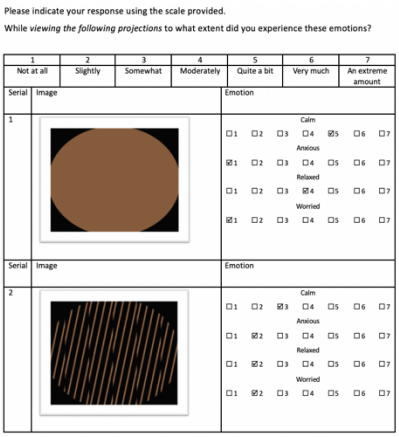
Additionally, this information aligns with the research by Dabas et al. who also identified that Gamma can be used to understand valence where a reduction in gamma PSD is related to an increase in valence and that alpha reduces as arousal increases (Dabas, et al., 2018). Lastly, Galvão et al. also established through literature that alpha, beta and gamma bands provided the most accurate results for emotional analysis. (Galvão, et al., 2021)

This research applied the valence arousal model using gamma waves to represent valence where a reduction in gamma represents an increase in valence (positive experience) and alpha waves to represent arousal where a reduction in alpha represents an increase in arousal.

2.4 Discrete Emotions Questionnaire (DEQ)

The Discrete Emotions Questionnaire (Harmon-Jones, et al., 2016) is a new tool proposed for the measurement of current emotional states. The questionnaire can be used as a short measurement to quantify emotions of fear, anger, sadness, disgust, happiness, anxiety, desire and relaxation. It is a fairly recent development that aims to provide a better measurement tool for emotions being experienced at a point in time (as opposed to being experienced over a period of time). The questionnaire measures subjectively experienced discrete emotions rather than broad dimensions of positive and negative affect such as with the well-known PANAS scale.

The whole DEQ covers a range of emotions and four emotions (calm, anxious, relaxed and worried) were selected for this specific research. These four emotions could be organised into two groups: anxious (anxious and worried) or relaxed (calm and relaxed). A rating scale of 1-7 was provided for each pattern and emotion where 1 represented 'not at all' and 7 represented 'an extreme amount'. An excerpt of the questionnaire is below at Figure 2. At the end of the questionnaire there were also three open questions: "What was your favourite pattern?", "Why?" and "Do you have any other comments?".


Please indicate your response using the scale provided.

While *viewing the following projections* to what extent did you experience these emotions?

1	2	3	4	5	6	7
Not at all	Slightly	Somewhat	Moderately	Quite a bit	Very much	An extreme amount

Serial	Image	Emotion
1		Calm ☐1 ☐2 ☐3 ☐4 ☑5 ☐6 ☐7 Anxious ☑1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 Relaxed ☐1 ☐2 ☐3 ☑4 ☐5 ☐6 ☐7 Worried ☑1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7
Serial	Image	Emotion
2		Calm ☐1 ☐2 ☑3 ☐4 ☐5 ☐6 ☐7 Anxious ☐1 ☑2 ☐3 ☐4 ☐5 ☐6 ☐7 Relaxed ☐1 ☑2 ☐3 ☐4 ☐5 ☐6 ☐7 Worried ☐1 ☑2 ☐3 ☐4 ☐5 ☐6 ☐7

Figure 2 – Adapted DEQ example

3 Experiment

The following two hypotheses were tested:

1) Biophilic light projections will generate more positive emotions including relaxation, than non-biophilic light projections.
2) Patterned light will be more positive and calming than standard non-patterned light.

The test was designed as a mixed method using EEG for quantitative data and an adapted Discrete Emotions Questionnaire (DEQ) for qualitative data with five participants. The Unicorn Black EEG headset with 8 channels was used for testing participants with the band power software package. The questionnaire included ratings for each of the patterns as well as open questions. A total of 5 people participated in the test and it was completed in the lighting laboratory at Aalborg University in Copenhagen, Denmark.

3.1 Experimental Setup

3.1.1 Equipment

The following equipment was used for the experiment: Aalborg University Lighting Laboratory, Projector Sanyo XPL 200, Unicorn Black Bluetooth EEG set (8 channels) & band power software package, Madmapper software, Laptop connected to EEG, Laptop controlling the projector, participant consent forms and an Adapted Discrete Emotions Questionnaire.

3.1.2 Testing Parameters

The following parameters were considered when designing the format of the test:

1) Room layout – the layout of the room for the test was designed to ensure as little stimuli as possible other than the lighting projection. The projector was placed above and behind participants to ensure they are covered by the projection although not distracted or impacted by glare from the projector itself. A chair was provided as the test was approximately 12 minutes and it was important that the participants would be comfortable.
2) Control – a control was included in the test to provide a base comparison for the results. A plain warm spotlight was used to represent a typical spotlight. The colour was selected to match the colour of all the biophilic patterns ensuing that colour was constant for the testing. Additionally, the control was shown first as a baseline then in-between each pattern

or colour exposure. This provided a new 'baseline' or 'control' measurement for each stimulus.

3) Exposure time – The time that each participant was exposed to the pattern needed to be constant and long enough for the participants to adapt to the new stimulus. It was determined that the plain control spotlight be exposed for 30 second and each pattern would be shown for 60 seconds.
4) Randomisation – the order that the patterns were shown to each participant was randomised to ensure a fair comparison.
5) Patterns – Four biophilic patterns were designed using local ecology (Waves, Gum Leaves, Daffodil and Pines) and for comparison there were four non-biophilic patterns (Bricks, Lines, Circles and Roofs). Creating the four biophilic patterns involved collecting cuttings from local wild plants and creating videos in the lighting laboratory. The cuttings were used to create natural shadow effects that were then video recorded moving slowly resulting in a 'gum leaves', 'pines' and a daffodil pattern. Whereas the waves pattern was created by recording natural reflections from the sun on some moving water. The four non-biophilic patterns were standard Madmapper video patterns chosen to reflect the urban cityscapes such as "roofs" of buildings, "lines" of sky scrapers, "bricks" of buildings and "circles" representing paths around the city.

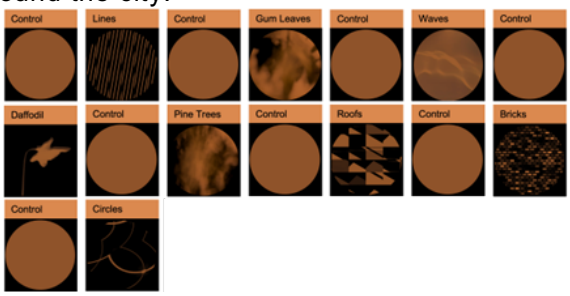


Figure 3 – Example pattern order for Participant 2

3.1.3 Procedure

1) The experiment started with the participants entering the room, where they signed a letter of consent, then they were positioned in the middle of the light lab. The light installed in the lab was turned on with a CCT of 2800 kelvin. From here the experiment was explained to the subject.
2) Next, the EEG headgear was installed on the participant's head and the signal was tested. As the equipment was wireless, the signal was monitored from a laptop computer in the same room.
3) The light for the room was then turned off and the warm projected spotlight was turned on once the signal was stable.
4) In the next step of the test, a sequence of the patterns was shown to the participants, and recordings of the brain signal started at the same time. The experiment ran for 12 minutes, where the patterns had an exposure time of 60 seconds, and a control warm spot light was shown at the beginning and in between each pattern for 30 seconds.
5) At the end of the sequence the EEG recording software was stopped and the EEG equipment was removed. Once the EEG test was completed, the participants were filled out the adapted the Discreet Emotional Questionnaire (DEQ) and open questions.

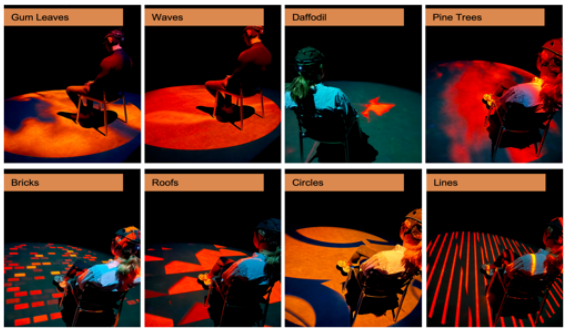


Figure 4 – Experiment set-up

4 Results

4.1 EEG Analysis and Results

The results from the EEG were saved as an excel file per participant. The unicorn EEG software automatically provides the data as 'bandpower' for analysis of the different brain wave frequencies. The software collected 25 samples per second, resulting in 18000 rows of data per participant for analysis for this test (12 minutes). The number of columns of data was 70 columns representing the brainwave data from the 8 channels connected to each participant's head. Alpha and Gamma brainwave column data was extracted from the excel files for analysis. These columns of Alpha and Gamma signals were automatically averaged by the software from the eight channels (the eight connections to the head). The column data was then averaged into per second values for each stimuli and corresponding control. Next, the stimuli value was divided by each corresponding control resulting in a per second value/control for each stimuli (pattern). At this point the values were then converted into a percentage and then percentage change from the control for ease of comparison. Each participant's data was considered individually and then finally, the data was weighted for each participant and averaged to create one overall graph. This ensured all participant's values were comparable to one another.

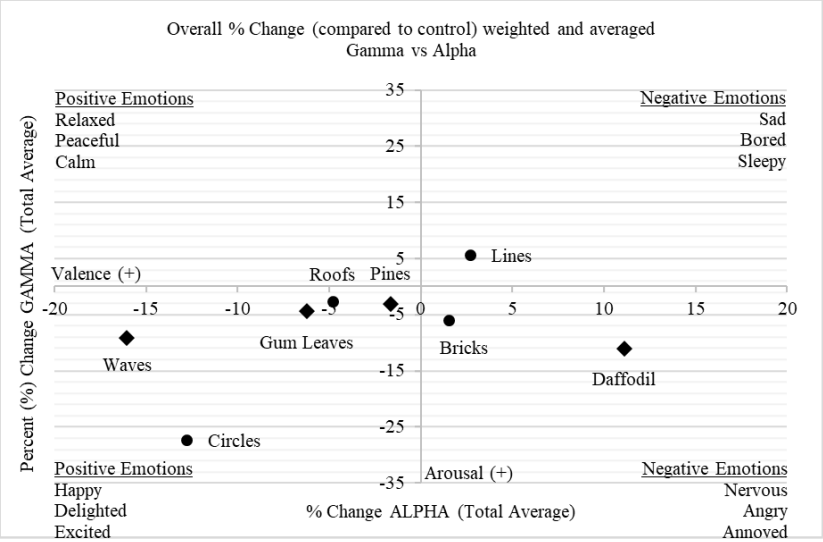


Figure 5 – Overall EEG results for all participants and patterns

Figure 5 shows the biophilic patterns (Waves, Gum Leaves, Pines and Daffodil) as diamonds and the non-biophilic patterns (Circles, Roofs, Bricks and Lines) as dots. The control is represented at (0,0). Overall, the EEG results in Figure 5 show that 75% of the biophilic patterns had a positive valence response as compared to the control with neutral to slightly positive arousal. 50% of the non-biophilic patterns showed an expected negative valence state representing a negative emotional response as compared to the control. The circles pattern is an outlier with a positive valence response and significant arousal compared to the other patterns.

4.2 DEQ Results

Participants' responses were considered in such a way that anxious (anxious and worried) represented 'negative' and relaxed (calm and relaxed) was understood as a 'positive' response. Overall this gave a total positive response and total negative response to each projection including a rating for the control projection (plain warm light). For ease of comparison to the EEG data, the survey data was transformed into percentage change from the control so that 0 on the Y axis in Figure 6 represents the control.

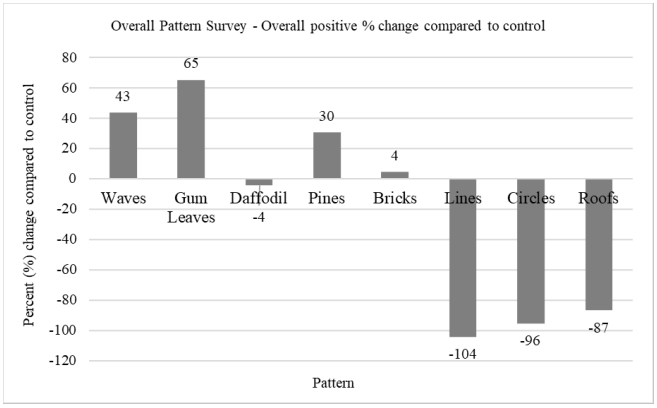


Figure 6 – Overall DEQ results for all participants and patterns

The qualitative survey demonstrated that the biophilic patterns had a 135% more positive result than the control and 417% more positive than non-biophilic patterns as shown in Figure 6. The Gum Leaves pattern was the most preferred pattern in the survey with a 65% more positive result than the control followed by the Waves pattern with a 43% more positive than the control.

4.3 Open Questions

Table 1 – What was your favourite pattern?

Pattern	Waves	Gum Leaves	Daffodil	Pines	Bricks	Lines	Roofs
Count	2	1	0	2	0	0	0

Table 2 – Why?

Pattern	Waves	Gum Leaves	Pines
Why	I liked the organic shapes and the repetitive calm movement	Gum leaves was relaxing	Both engaging and relaxing. It has a nice level of abstraction, which gives me the opportunity to look for patterns and images
	Very chill and calming effect		Highly calming, reminded me of being on the forest (lots of good childhood memories)

Table 3 – Do you have any other comments?

Participant 1	No
Participant 2	The bricks reminded me of Harry Potter
Participant 3	No
Participant 4	I think my memories and associations played a part in what I prefer and how I respond. The red colour was a bit stressful and reminded me of scary movies. The slanted lines that moved towards me was also a bit intimidating, and not very relaxing. I had a lot of memories (both good and bad) of the ocean with the waves pattern.
Participant 5	The longer I looked at patterns / the installation in general, the more relaxed and sleepier I felt
	Roofs were my least favourite pattern. No clear pattern visible, extreme contrast, reminded me of one of my nightmares
	Waves were my second favourite pattern. They were highly calming, positive associations to water and sunlight, slow motion, regular pattern.

4.4 Comparative results

The method for analysing EEG data using the arousal and valence model appears to provide some indications that align with survey results. The Waves pattern was the most positive biophilic pattern from the EEG and rated as the second most positive from the qualitative survey. Additionally, the Waves pattern was rated by 40% of participants as their favourite

pattern. Similarly, the Gum Leaves pattern was the second most positive biophilic pattern from the EEG results and rated the most positive pattern in the qualitative survey. Further considering that the questionnaire specifically asked about being 'relaxed' then comparing the arousal results it's clear the Gum Leaves were more relaxing than the Waves although the Waves were more 'positive' according to the valence. There were also further indications relating the quantitative and qualitative data particularly in regard to specific questions (as opposed to ratings) such as 'most favourite pattern' and 'least relaxing'. This was more apparent when comparing individual EEG results to individual survey responses. Ratings of patterns that were not the most favourite, most relaxing or least relaxing were more difficult to relate between the EEG and survey data but still had some indications.

One outlier is the circles pattern that is one of the most positive patterns in the EEG but one of the most negative patterns in the survey. This was likely due to the fact that the circles had a much higher arousal response than other positive valence patterns and was therefore, closer to 'exciting' rather than relaxing. As the DEQ compared anxious and relaxed rather than joy or excitement it is reasonable that the survey responses were negative even though the EEG shows a positive valence response.

5 Discussion

Two hypotheses were tested:

1) Biophilic light projections will generate more positive emotions including relaxation, than non-biophilic light projections.
2) Patterned light will be more positive and calming than standard non-patterned light.

The testing and analysis indicated in relation to hypothesis (1) that biophilic light projections probably generate more positive emotions than non-biophilic light projections. The survey data indicated they are also more relaxing however, the EEG data showed they are not necessarily more relaxing as the dynamic movement typically caused a certain small increase arousal (although less than some non-biophilic patterns). The EEG results showed 75% of the biophilic patterns had a positive emotional response as compared to the control whereas, 50% of the non-biophilic patterns showed an expected negative emotional response compared to the control. Additionally, the qualitative questionnaire demonstrated that biophilic patterns had a 135% more positive result than the control and 417% more positive than non-biophilic patterns.

For hypothesis (2), patterned light is not clearly more positive or relaxing than non-patterned light. It is highly dependent on the pattern. All the results were compared to the control and no patterns were more relaxing with seven out of 8 patterns showing an increase in arousal. It should be considered that the control was a plain warm sunset colour that is expected to be a calming state in itself. Additionally, the survey responses are mixed. In particular participant 2's survey responses show a reduction in 'relaxed' toward anxious for all patterns except waves. This almost aligns with participant two's corresponding EEG data that had an increase in arousal for all patterns except gum leaves. Another example is participant four where half of their responses were aroused and positive and the other 'half' were negative and less aroused.

Overall for this hypothesis it appears very subjective and dependent on the pattern. It shows that it should not be assumed that a pattern will have a more positive effect than a static plain warm light. Additionally, the movement in the patterns and the additional information from the pattern itself may cause arousal in people and therefore not be necessarily 'more' relaxing even if though it may generate positive feelings such as happy or excited.

Another important indication from the open questions was that personal memories had an impact on emotional responses to the lighting patterns. This is in line with the theories from Böhme that although the lighting can be the generator of an atmosphere or mood, it is a subjective experience dependent on the people experiencing the atmosphere and their own emotional state (Böhme, 2013).

6 Limitations and Future Works

This research was conducted in a laboratory with 5 participants and therefore the results are not statistically significant. It was a pilot study that provides a foundation for how to approach

further testing with more participants and potentially in an urban environment rather than a laboratory. Additionally, the non-biophilic patterns need further refinement with clarity on what makes a design or pattern not biophilic. This could lead to more distinctive results. Particularly the 'circles' pattern which had a generally positive EEG response but was classified as 'non-biophilic'. It could be discussed that circle shapes are biophilic and the pattern was incorrectly classified but that would require clearer parameters for defining 'non-biophilic'. Notably, the EEG is also still somewhat subjective due to personal memories and associations with certain patterns. This was seen in the open questions where people mentioned how their memories impacted their experience. Potentially a larger sample group would reduce the impact of personal memories on the results. Another important aspect was that the dynamic movement of the patterns almost always increased arousal compared to the static control. This impacted the analysis of the first hypothesis that the positive emotions would include 'relaxing'. Instead the results show that other positive emotions such as 'happy' and 'delight' were more consistent with the arousal and therefore the DEQ questionnaire should be adjusted in the future to also cover joy or delight. It could also be beneficial to consider using a questionnaire that doesn't have a rating scale but instead includes more distinct questions such as 'most favourite' and 'least favourite' as this appeared to be more consistent with EEG results and easier for participants to identify.

7 Conclusion

Using EEG for testing lighting atmospheres and emotions has been applied before but testing biophilic design principles in electric lighting employing a mixed method using EEG and the valence arousal model is a novel approach. This work investigated biophilic lighting projection atmospheres and the analysis offered a way to consider the EEG data in the context of emotions from lighting.

From the literature review, there were no other identified lighting tests that considered analysing the EEG data in this way, using the valence arousal model with alpha and gamma waves. Given the fact that indications show some interesting relationships between the survey rankings, open questions, and EEG data, this could be a new way for lighting EEG testing data to be considered. It could also be further investigated in relation to using both alpha and beta low waves as the arousal measurement. Furthermore, the data also provides a foundation for quantitative testing of biophilic principles in lighting design.

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9 Declaration of conflicts of interest

All authors declare that they have no conflicts of interest.

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