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WOOD INTERIORS IN ARCHITECTURE: AN EYE-TRACKING STUDY

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ABSTRACT: In this architecture study, we examine the gaze patterns of participants (n=20) when presented with a selection of images featuring building materials (concrete, stone, brick, wood and painted wood) and interiors (church, lobby and work area with high, medium and low levels of wood use). We utilize eye-tracking to quantify the fixations, saccades, blinks, and pupil dilations within the participants gaze pattern. This gaze pattern is then compared to the participants perception of naturalness and pleasantness. We show that naturalness and pleasantness strongly positively correlate with each other, and that material choice plays a role in the participants perception of these values. Gaze patterns do not clearly correlate with naturalness nor pleasantness, although we report indications that pupil diameter, blink count and saccade amplitude should be investigated further in separate experiments.

KEYWORDS: Eye-tracking, Architecture, Wood, Materials, Cognition

1 INTRODUCTION

First discovered in the 1970's [1] by examining the views from hospital patients windows, a significant body of research has been developed to better quantify and understand the positive effects of nature on building users [2], [3]. More recently, the use of wood has become more prevalent in the Nordic building industry due to its cultural acceptance, low emissions, and increased availability. This has also spurred research interest into the health effects of wood use on the habitants of buildings [4]–[7] that seem to suggest that multiple positive effects are achievable through thoughtful use of building materials. At the same time, more research is needed to better understand and quantify the effects.

1.1 RESEARCH QUESTIONS

In this study, we examine the relationship between gaze patterns and participant perception of naturalness and pleasantness. We hypothesise that and strive to answer the following research questions:

RQ1: Is there a correlation between naturalness and pleasantness?
RQ2: Is there a correlation between wood use and perceived naturalness and pleasantness?
RQ3: Do different building materials have a different gaze response?
RQ4: Is there a correlation between a gaze response and the perception of naturalness and pleasantness?

2 THEORY

Quantifying the perception and impact of architecture has gained more research interest in the recent years [2]. Two central aspects of this development have been the validity and usability of different quantifying methods as well as connecting the research to an existing body of research in environmental well-being.

2.1 EYE-TRACKING

The use of eye-tracking (ET) is an effective method to determine the gaze pattern of a person, which mainly consists of rapid movements with intermittent stops. Fixations are instances where the gaze dwells on a specific area, such as a flower or an oncoming car. Fixations vary in length but are generally in the 80-300ms range and indicate where the participants cognitive system engages with the visual stimuli. The opposite, a saccade, is a rapid eye-movement between fixations where the participant is not consciously registering what the eyes are looking at [8]. In Video Oculography (VOG) – based eye-tracking [9], a video recording of the eyes, when calibrated, analysed and correlated with a synchronized video of the world view in front of the participant allows for a relatively easy analysis of gaze patterns at both individual level and in a group, even with idiosyncratic differences between the participants.

Several measurements are available from current ET devices. Reduced saccade amplitude can indicate during increased mental effort, inspection, or high-frequency visual information. Alternatively, saccadic velocity decreases with low vigilance. Pupil dilation increases with arousal and mental workload. Long fixation durations indicate low arousal and shorter fixations can indicate stress responses. For a more thorough discussion on measures, see Holmqvist et al., part III [8]. Additionally, more complex relations are being investigated, such as the correlation between participants preferences and their gaze patterns [10].

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2.2 NATURE, WOOD USE AND HEALTH

Previous ET research into architectural material use is inconclusive, and it is difficult to examine the validity and generality of using ET to examine materials in architecture. The general correlation between pupil dilation and emotional reactions has been observed when looking at architectural interiors [11] and also linked to preference to stay [12]. When comparing natural environments to urban settings, [13] and in interiors [14], fewer but longer fixations were observed. Contrastingly, fixation time was found to be independent of vegetation when looking at indoor workplace design and the amount of vegetation in front of the participant [14]. Also material choice might be a factor as average fixation duration has been shown to differ between stone and mixed material facades, as well as experts and non-experts [15].

Wood materials exhibit positive effects similar to nature [4], are preferred by participants [7] and generally considered natural materials [16]. Eye-tracking studies of wood interiors has so far received little interest in research, although there are indicators that wood exhibits a similar gaze pattern as nature [17] and affect staying durations [12].

3 METHOD

This experiment is a within-subjects laboratory experiment using gaze pattern and survey answers as data.

3.1 STIMULI

The experiment used 2 sets of stimuli. For the 5 most common architectural materials in the Nordics (concrete, stone, brick, untreated and painted wood), 5 images of each were selected to cover the innate variation in the use of the material in a building context. This also provided an extra control to examine variations within material groups and to compare this to results between groups. Additionally, two images were baseline photographs, one of plants (i.e., purely nature stimuli) and another of a graphical plate with multiple overlays of texts (i.e., high visual density stimuli). The total amount of images in the first set of stimuli was 27. An example of material stimuli is seen in Figure 1.

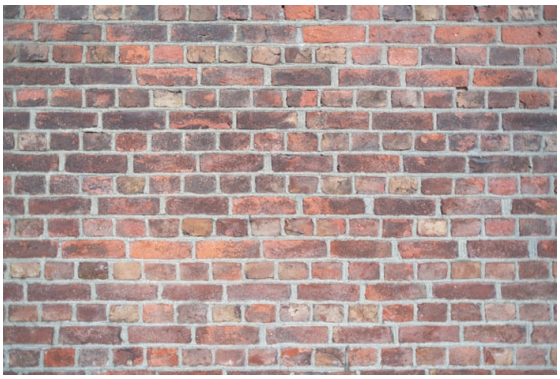

Figure 1: *Example image of a material stimuli, brick-3.*

Material images were taken with a Nikon D750 digital SLR with a 20mm f2,8 Nikon AF Nikkor lens. Both camera and lens were optically clean. The images were taken from a distance of 1.2 - 1.4 meters with suitable exposure settings to avoid clipped highlights or movement artefacts.

The second set of stimuli consists of 17 interior images showing 5 images each of 3 distinct spaces: church/sacral, lobby and an informal learning space in academia. Each group has 1 stimulus with high level of wood use, 2 with medium levels and 2 with low levels or no wood use at all. In addition, 2 baseline images were included, a nature image displaying a beautiful waterfall as well as a high visual density stimuli image of a city scape in Trondheim, Norway.

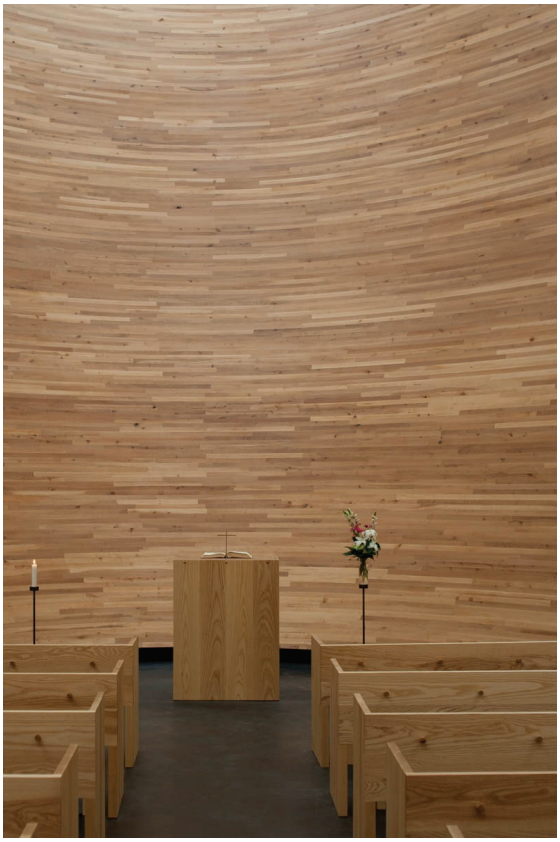

Figure 2: *Example image of a interior stimuli, church-2, exhibiting high level of wood use.*

The interior images were taken with either a Nikon D750 or D700 digital SLR with a 20mm f2,8 Nikon AF Nikkor or 17-35 f2,8 Nikon AF-S Nikkor lens. Both camera and lens were optically kept clean and suitable exposure settings were used to avoid clipped highlights or movement artefacts.

Each image was edited in Adobe Lightroom with a profile-based correction to chromatic aberration as well as

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distortion and vignetting. The images were manually corrected for residual distortion, vertical and horizontal parallel lines as well as image rotation. The exposure, contrast, texture, and clarity were adjusted to ensure an even lightness and tonality across images, as well as a natural look. Finally, the images were cropped to the same format, 3:2 landscape for the material images and 3:2 portrait for the interior images.

3.2 PARTICIPANTS

This study included 20 healthy participants of which 8 were female. The participants had either perfect eyesight or their eyesight was corrected with contact lenses. The average age of the participants was 23,5 years (SD=4,49). 3 participants had an educational background focused on buildings. Four of the participants were left-handed.

3.3 PRESENTATION

The participants were welcomed to the experiment space where they receive a short formal introduction to the study and give consent. Eligibility to the study is confirmed. The participants are fitted with a Pupil Labs Core [18] mobile binocular eye-tracking glasses recording 120 Hz video with 192x192 pixels of each eye. In addition, a 1280 x 720 world cam at 30 Hz is recorded. The participants view stimuli shown on a 27" Dell ultrasharp U2719DC screen with 1920 x 1200 pixels at 60 Hz. Each participant underwent a calibration and verification procedure to ensure accuracy of the recorded data (0.5 - 1.5 degrees from eye-tracker, corresponding to approx. 7-25mm accuracy on screen with 80 cm viewing distance). All images and survey are displayed using PsychoPy stimuli presentation software [19] linked with Pupil Capture through dynamic link. For each ET capture, Apriltag36_11 QR codes were present in the corners of the screen to allow surface tracking of the screen as seen in Figure 1.

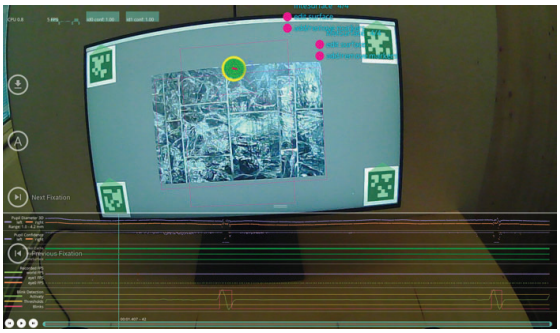

Figure 3: *Experiment setup from Pupil Player as seen by the participant world camera, showing Apriltag36_11 QR codes around stone-1 image. On screen is also pupil dilation, confidence, and blink data, while fixations are shown with a yellow circle around the gaze point when active.*

After setup, each participant is first presented with the 27 material images in randomized order. Each image is displayed for 10 seconds with a 2 second pause between images showing a re-focusing cross in the middle of the screen. The images were 1076 x 690 pixels, giving an on-screen size of 21 x 14 cm in landscape format. This approach leaves ample grey background area on screen to minimize luminosity changes from the stimuli, as this might affect pupil dilation. The stimuli size corresponds to approximately 10 x 15 degrees eye movement when viewed from 80 cm away.

In the second part, the participant reviews the re-randomized images one at a time and ranks them with 2 sliders, unnatural (0) – natural (10) and unpleasant (0) – pleasant (10), verified by an OK button.

In the third part, the participant similarly first views the interior images, followed by the fourth and final part where they assess the interiors with the same sliders. Before each part, the participant is given clear instructions on screen as to the next part of the experiment.

3.4 RESPONSE DATA ANALYSIS

Participants evaluation of the naturalness and pleasantness of each stimulus is recorded in PsychoPy as a value of 0-10. The sliders are by default valued as 5 (middle) and if the participant does not move the slider but clicks OK, this number is used in the analysis.

3.5 ET DATA EXTRACTION AND STRUCTURING

For each participant, 33 trials were captured, consisting of one video for each eye and one world view video per trial. Pupil Player was used to analyse each trial. The first analysis included fixation detection using 1,5-degree movement threshold and 100-500ms as duration, both on stimuli surface as well as during the entire trial. Secondly, gaze positions and pupil dilation were extracted. Finally, a blink detection analysis was performed to count the number and duration of blinks in each trial.

Exported data from Pupil Player and PsychoPy was structured into folders per participant and a custom Python script was developed to extract, structure, and output a joint CSV that included all trials for all participants. The data was structured by case, where each row represented a single stimulus, viewed by a single participant. For each case, the dataset included averages over the entire viewing duration of a given stimuli by the given participant. The structured data included average saccade amplitude and velocity, blink count and duration, average and total fixation duration, and count for both surfaces and in total, average pupil dilation for both eyes as well as participant responses and the order the stimulus was presented.

3.6 ET DATA ANALYSIS

SPSS (Version 29) was used for the statistical analysis. To explore the relationship between variables, partial correlation was used while controlling for the presentation order of the stimuli. To assess outliers and anomalies,

SPSS' Identify unusual cases-function was used and the identified data checked to ensure correct representation.

4 RESULTS

The data quality of the experiment was assessed to be good. All participants responded to the survey. During material and interior trials, 93% and 90% of fixations were within the presented stimuli boundaries, respectively. This indicates that the participants were actively engaging in the task.

4.1 CORRELATION BETWEEN NATURALNESS AND PLEASANTNESS

To explore the relationship between naturalness and pleasantness responses from the participants, two-tailed partial correlation was used while controlling for the presentation order of the stimuli. Statistical assumptions of normality and linearity were assessed.

When looking at material images (n=27), there is a strong, significant partial correlation between perceived naturalness and pleasantness when controlling for stimuli order, $r = .513$, $n = 540$, $p < .001$, where high levels of naturalness are associated with high levels for perceived pleasantness.

This partial correlation also held true when looking at interior images with an equally strong correlation, $r = .547$, $n = 340$, $p < .001$, indicating that naturalness and pleasantness are strongly positively related.

4.2 WOOD USE, NATURALNESS AND PLEASANTESS

A one-way ANOVA was conducted to examine the effect of material use on naturalness and pleasantness. During the first trial presenting only groups of materials, a statistically significant result was found for both naturalness, $F (6, 533) = 32.758$, $p < .001$, and pleasantness, $F (6, 533) = 15.574$, $p < .001$. A post-hoc Tukey test indicated distinct, homogenous subsets in the groupwise comparison for both naturalness and pleasantness as presented in Tables 1 and 2. However, when investigating the responses for each stimuli using a Tukey test, the results show that images within each group can be assessed very differently, although similarities exist within groups as well. To exemplify, concrete scored poorly in groupwise naturalness and pleasantness while the individual images of concrete also were among the bottom 6 in naturalness and bottom 7 in pleasantness, together with the graphic stimuli. Contrastingly, the wood-5 stimuli, showing OSB is ranked 10th in unnaturalness and 4th in unpleasantness, while wood-4, showing a worn, slightly damp, pressure treated wood cladding, was ranked second only to nature in pleasantness and 4th most natural stimuli.

Table 1: *Homogenous groups based on groupwise Tukey analysis on means of naturalness scores from 0 (unnatural) to 10 (natural).*

Material Group	N	1	2	3	4	5
Graphic	20	1.9				
Concrete	100		3.9			
Brick	100		5.0	5.0		
Wood Paint	100			5.5	5.5	
Wood	100			5.8	5.8	
Stone	100				6.4	
Nature	20					9.6

Table 2: *Homogenous groups based on groupwise Tukey analysis on means of pleasantness scores from 0 (unpleasant) to 10 (pleasant).*

Material Group	N	1	2	3	5
Graphic	20	3.2			
Concrete	100	4.1	4.1		
Wood	100		5.2	5.2	
Brick	100			5.4	
Wood Paint	100			5.6	
Stone	100			5.7	
Nature	20				9.6

An ANOVA looking at the wood-use in interiors revealed similar results. First, groupwise analysis between high, medium, and low wood use, as well as a nature image and an image of Trondheim city was conducted. Naturalness, $F (4, 335) = 15.691$, $p < .001$, and pleasantness, $F (4, 335) = 9.148$, $p < .001$, both showed significant differences between the groups. A post-hoc Tukey test showed that in both cases, the nature image was distinctly both more natural and more pleasant than the other images. In pleasantness, all other images showed the same grouping regardless of wood use, while in naturalness, both low and medium wood use scored lower than high wood use. An alternative grouping of the space functions (lobby, church, and work area) was conducted to compare results. This yielded similar results for both naturalness, $F (4, 335) = 22.323$, $p < .001$, and pleasantness, $F (4, 335) = 18.956$, $p < .001$, with work areas and lobbies scoring less than churches and the city, while nature again was the most natural and pleasant choice. Finally, the images were analysed individually using a Tukey test to see whether the defined groups were coherent as evaluated by the participants. In both naturalness and pleasantness, spatial functions and wood-use groupings showed variation within the groups.

4.3 GAZE RESPONSES

The participants gaze responses were examined using a one-way ANOVA, followed by a post-hoc Tukey test if the significance was nearing $p < .05$.

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4.3.1 Material trials

The ANOVA test showed no significant differences ($p < .05$) between gaze responses between the material groups, nor the individual stimulus, apart from the pupil dilation of eye 1 ($F\ 6, 553) = 2.232$, $p < .039$ for groupwise analysis, $F\ (26, 513) = 1.493$, $p < .057$ for individual stimulus analysis. When examining the Tukey post hoc test, the most significant difference was found to be between nature and concrete groups. Contrastingly, the dilation of eye 0 differed widely, $F\ (6, 553) = .659$, $p < .683$ for groupwise analysis, $F\ (26, 513) = .644$, $p < 0.914$ for individual stimulus analysis but this eye was considered more uncertain due to a single participant having a miscalculated 3d gaze parameter resulting in a very small pupil diameter.

4.3.2 Interior trials

Three ANOVA tests were conducted to examine gaze variables in interior images. The factors considered were the level of wood use (no significances $p < .05$), the spaces function (no significances $p < .05$) and individual images (no significances $p < .05$). However, a 2-tailed partial correlation test showed a weak negative correlation between blink count and naturalness, $r = -.153$, $n = 340$, $p = .005$, as well as a weak negative correlation between saccade amplitude and naturalness, $r = -.098$, $n = 340$, $p = .071$.

5 DISCUSSION

The aim of this study was to examine possible relationships between perceived naturalness, pleasantness, and gaze patterns in an explorative manner.

5.1 NATURALNESS, PLEASANTNESS AND WOOD

The participants show a strong positive correlation between perceived naturalness and pleasantness. The most consistently perceived stimulus, regardless of the stimulus set, are the 2 images of nature. When viewing material surfaces, a picture of chaotic graphic is clearly perceived as both unnatural and unpleasant, while an image of the city is more ambiguous as a baseline when compared to interiors.

A significant finding is the variation within material groups. While concrete surfaces were perceived as uniformly unnatural and unpleasant, wood surfaces varied to a larger degree. This internal variation should be expressly addressed in future experiments by selecting multiple stimuli within each material group. This affects both the validity and generality of the experiment as variation within groups can be better understood and the results be discussed in relation to practical everyday utilisation of building materials.

5.2 GAZE PATTERN, NATURALNESS AND PLEASANTNESS

The relationship between gaze patterns, naturalness and pleasantness is inconclusive. The study cannot confirm the relationship between saccade amplitude, blinks, pupil dilation and the survey responses, nor can we outright reject them. More advanced analysis might be needed to discover relationships between the variables. We have however identified some patterns that could help design better experiments in the future. Firstly, the viewing behaviour between purely material stimuli and interiors varies. Pupil dilation was found to be significant in viewing materials but not to the degree that it could differentiate multiple material groups. For interiors, blinks seem significant, as well as saccade amplitude. Secondly, variations within material groups needs to be accounted for. Thirdly, comparisons across studies will be essential to build systematic knowledge over time. Reporting threshold values, dispersion factors and specific analyses performed will speed development.

5.3 LIMITATIONS

Our approach has several limitations. Firstly, it was designed to explore potential gaze patterns rather than targeting a single measurement. The experimental setup for some of these measurements are contrary. To exhibit large saccade movements when searching, a bigger stimulus should be used. At the same time, pupil dilation will be affected as the size of the stimuli on screen increases to the grey background.

While a balance between trial length and the number of stimuli was necessary in this study, increasing the amount of images in fewer material categories would increase generality and validity of the results.

Finally, increasing the number of participants will provide a sounder base for statistical analysis that might uncover more nuanced results.

6 CONCLUSIONS

In this study, we performed a controlled within-subjects ($n=20$) laboratory experiment using gaze pattern and survey answers as data. We used 2 sets of stimuli, consisting of materials ($n = 27$) and interiors ($n = 17$). Our results show a strong positive correlation between naturalness and pleasantness when viewing images of both materials and interiors. We also demonstrated a that material groups score differently on naturalness and pleasantness, although variation within material groups exists.

We cannot confirm differences in gaze patterns between different building materials, nor a correlation between gaze response and naturalness or pleasantness. However, indications of pupil dilation, blink counts and saccade amplitudes being affected by materials were found.

7 ADDENDUM

7.1 AVAILABILITY OF MATERIALS

We support the replication and verification of experiments. The used images, data, PsychoPy files and Python scripts, as well detailed analysis files are available upon request.

7.2 CONFLICT OF INTEREST AND FUNDING

The authors declare no conflict of interest. This study was in its entirety funded by the Norwegian University of Science and Technology, NTNU.

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