# Daylight patterns as a means to influence the spatial ambiance: a preliminary study.

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***Abstract.*** *This contribution focuses on perforated façades, investigating the effect of the façade and the resulting daylight pattern on the perceived spatial ambiance. The daylight conditions, as well as the geometry and regularity of the façade pattern are manipulated in an immersive virtual space, producing different conditions. A preliminary study was conducted, where subjective evaluations of the virtual space were recorded across six variations of façade pattern and sky type. The results indicate that the façade pattern characteristics have an impact on the perceived spatial ambiance, underlining the need to investigate further the perceptual aspect of the spatial and temporal diversity of light in space through experimental studies.*

***Keywords: perception, daylight pattern, daylight variability, virtual reality***

## Introduction

### *Perceptual effects of luminous conditions*

A notable difficulty in understanding the impact of luminous conditions on perceptual effects, such as user interest and emotion, is their dependence on the initial state of the observer (Vogels, 2008). Recent experimental studies in architecture aim to quantify the perceived *ambiance* in a space, describing it as an *affective evaluation of the environment*. The ambiance of a space is considered a more stable variable for the assessment of subjective experience, as it is deemed to be a more objective evaluation, which does not directly depend or influence the affective state of the observer (Vogels, 2008). Vogels suggested that the perceived spatial atmosphere can be represented by at least two factors, *cosiness* and *liveliness,* which the author notes as comparable to the dimensions of *affect* and *arousal* found in the literature. The notions of *ambiance* or *atmosphere,* which will be used interchangeably throughout this paper, have gained in popularity during the last decades.

There is little evidence in the literature regarding the effects of daylight on perceived ambiances of space. A study by Stokkermans et al. investigated the effect of artificial light and daylight on the atmosphere perception of a real and a virtual environment. The authors note that the addition of daylight had marginal impact on the perceived ambiance of an artificially lit space. However, the studied daylight was diffuse, and the authors suggest that the addition of direct light might have a more noticeable influence on the perceived ambiance, as it can lead to larger variations in luminance distribution (Stokkermans *et al.*, 2015).

Two indicators are widely accepted to impact the perceived lighting quality: the mean luminance and the variability of luminances, both applied in the field of view of an observer (Veitch & Newsham, 2000). The importance of contrast and luminance variability in the perceptual experience of space has been addressed in various studies (Kort & Smolders, 2010; Parpairi *et al.*, 2002; Rockcastle & Andersen, 2014; Veitch & Newsham, 2000). However, there are no widely accepted indicators regarding the positive perceptual qualities of daylight. A recent study by Rockcastle and Andersen proposes a contrast-based prediction model for visual interest in two-dimensional representations of space. This model was based on the subjective evaluation of renderings of different architectural spaces under various sun positions (Rockcastle & Andersen, 2015). This study underlines the significance of temporal and spatial diversity of brightness in a rendered scene and the need for further research on the dynamics of light and shadow. Similarly, Omidfar et al. investigated the relationship between preference judgements and façade patterns in renderings of an office space with different shading systems. The studied systems differ in the shape and regularity of their apertures, resulting in variations of perceived *order* and *complexity*, two factors identified as being crucial in the appraisal of daylight. Furthermore, the authors indicate a misalignment between the quantitative simulated evaluation of the studied configurations and the subjective judgments of the participants (Omidfar, Niermann & Groat, 2015). These findings highlight the importance of augmenting quantitative lighting analysis with qualitative measures and the need for further investigation of the impact of façade pattern characteristics on the subjective appraisal of daylight.

Although existing research has provided promising indications regarding the impact of luminance distribution and view on the occupant's appraisal of space, we have limited knowledge regarding more concrete relations between these factors and the perceptual qualities of the luminous environment, and even less so regarding the joint impact of daylight and view out. Drawing from the fields of experimental psychology and vision research, this study focuses on the effect of *irregularity* and the resulting perceived *complexity* of the façade pattern on the appraisal of a daylit space, through subjective evaluations. The aim of this evaluation is twofold, addressing the impact of the façade pattern both on the view through the façade and the spatial experience of the user. This experimental study is conducted in virtual reality, using a novel methodology to produce stereoscopic immersive scenes from physically-based renderings (Chamilothori, Wienold & Andersen, 2016).

### *The subject of context*

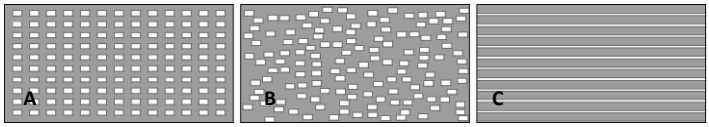
More broadly, the visual size and contrast characteristics of the particular task, along with the properties of the background lighting, are crucial for the evaluation of daylight as conducive or not to the task. The signal-to-noise ratio between the task and its background can provoke under-stimulation or over-stimulation (Boyce, 2003), which is a matter of attention dependent on the occupant's expectations; thus, a matter of *context*. An observational study by Wang and Boubekri suggested a potential link between daylighting patterns under sunny conditions and the overt activities of the room's occupants (Wang & Boubekri, 2009). A later study from the same research group investigated the declared seating preference in a room with various levels of sunlight penetration. The results indicate that access to view and sunlight were not welcome in the context of teamwork, but the latter was preferred in the context of isolated work and relaxation (Wang & Boubekri, 2010).

This study evaluates the importance of *context* in the perceived ambiance of a space, using the spatial context as a variable in the evaluation of the observer's perception. Our hypothesis is twofold, supporting a perceptual effect of changing the façade configuration, and a more positive evaluation of characteristics such as the irregularity of a façade and daylight pattern in a social, rather than a working context.

## Methodology

The space selected for this preliminary study was the DEMONA test room in the EPFL campus. The room was modelled in Rhinoceros[1] and then exported to Radiance[2]. The outside view, based on panoramic photographs, was mapped on the sky in Radiance. Each studied configuration was simulated as an immersive stereoscopic scene and projected in the virtual reality (VR) headset Oculus Rift DK2[3]. In this virtual scene, the user is able to look around and explore the space from a static viewpoint using normal head movements. The methodology for the generation of immersive scenes is described in a future publication (Chamilothori, Wienold & Andersen, 2016). The Oculus DK2 headset offers a resolution of 960 x1080 pixels per eye with a refresh rate up to 75Hz, with a 100° horizontal and 110° vertical field of view. Although the maximum measured luminance of the display is up to 340 cd/m$^2$, in this experiment the maximum luminance was 80 cd/m$^2$ due to software limitations.

Three different façade patterns were investigated, with shared attribute their opening ratio, the percentage of open to total surface. One of the patterns, acting as a control, is based on the existing shading system with blinds installed in the experimental room, providing a benchmark of a commonly used façade pattern (Table 1, *C*). The geometry and regularity of the other two facade patterns were manipulated accordingly, resulting to two patterns with the same number, size and shape of apertures and different distribution of these apertures (Table 1, *A* and *B*).




| | *A* | *B* | *C* |
|---|---|---|---|
| *Opening ratio* | ✓ | ✓ | ✓ |
| *Geometry of aperture* | ✓ | ✓ | X |
| *Pattern regularity* | ✓ | X | ✓ |

Table 1. Shared (✓) and unique (X) attributes between the studied patterns.

The façade configurations were modeled using materials with measured specularity and reflectance. The characteristics of the main materials (approximate RGB reflectance, roughness, specularity) are as follows: walls (0.92, 0.01, 0), floor (0.46, 0, 0), ceiling (0.92, 0, 0), façade (0.90, 0.016, 0), single pane glazing (visual transmittance 88%, RGB transmissivity 0.96). The models were exported in Radiance to realise a series of visualisations under clear and overcast sky using high-quality parameters (-ps

[1] https://www.rhino3d.com/
[2] http://www.radiance-online.org/
[3] http://www.oculus.com/

0 -pj 0 -ab 5 -ss 1 -st 0 -lw 0.00001 -ad 20000 -as 10000 -aa 0.05 -ar 512). The resulting variations span a matrix of different view and lighting conditions (Fig. 1).

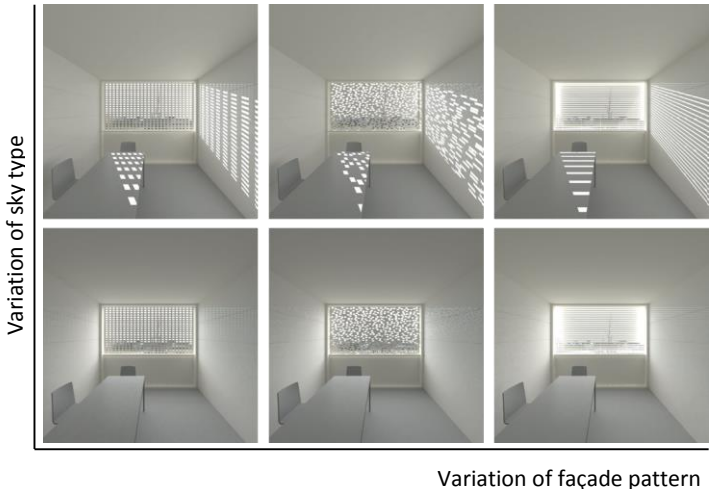



Figure 1. Variations of sky type (y axis) and façade pattern (x axis).

The experimental study was conducted with 30 participants (16 female, 14 male), using the VR headset. Each participant was shown three pattern configurations under the same sky type in randomized order of presentation. Due to time constraints, 21 participants saw the clear sky configurations. The participants were asked questions in random order, regarding their perceptual impression of the space -how pleasant, interesting, complex and exciting they found the space- and how satisfied they were with the amount of view in the space on a 5-point scale with verbal anchors at the end points ("Not at all" to "Very much"). The polarity of the scale was also randomized. The dependent variable *pleasantness* relates to the dimension of *affect*, whereas *interest* and *excitement* relate to the dimension of *arousal.* The dimension of *perceived complexity* is used to investigate the impact of spatial diversity of luminance in the scene. Along with these variables, the *satisfaction with the amount of view* provides an additional indicator of subjective judgement for the studied façade patterns. Of the 30 participants, 18 evaluated in the same 5-point scale their satisfaction with the luminous composition in the VR for two usage scenarios of the space: a discussion with friends (social context) and their everyday working activity (work context).

## Results

The results of the study show that the satisfaction with the amount of view was very similar between the two patterns with same geometry and slightly greater for the blinds (Fig. 2), which is to be expected due to the shape of the opening units. The evaluation of the irregular pattern was more positive in all other aspects, indicating that there is indeed a perceptual effect of changing the façade configuration. A one-sample Kolmogorov-Smirnov test showed the non-normality of our data for all studied variables and the need for non-parametric statistical tests (Siegel, 1956). Accordingly,

a Friedman test for all three patterns in each sky type revealed a statistically significant effect of pattern for three evaluative scales in clear sky: *pleasantness*, $\chi^2$=10.23, d.f.=2, p<.01, p'<.05, *complexity,* $\chi^2$=17.8, d.f.=2, p<.001, p'<.001 and *excitement,* $\chi^2$=17.84, d.f.=2, p<.001, p'<.001, where p' is the adjusted p-value with applied Holm-Bonferroni sequential correction for multiple analyses (Holm, 1979). The scale of *interest* failed to reveal a significant difference following the correction (*clear sky,* $\chi^2$=8.95, d.f.=2, p<.05, p'>.05 and *overcast sky,* $\chi^2$=6.91, d.f.=2, p<.05, p'>.05). The *satisfaction with the amount of view* showed no significant difference of pattern in either sky type.

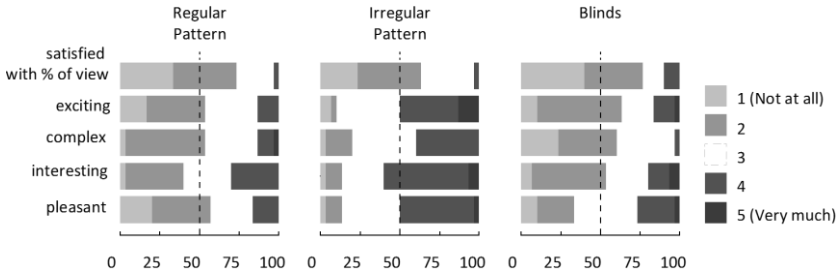



Figure 2. Responses (%) of 30 subjects for the three façade patterns.

Following these results, we investigated the effect of irregularity. A Wilcoxon Signed-ranks test comparing the regular and irregular pattern in both sky types revealed significant differences in perceived *pleasantness* (Z=22.5, p<.001, p'<.001), perceived *interest* (Z=31, p<.01, p'<.05), perceived *complexity* (Z=32, p<.01 ,p'<.05) and perceived *excitement* (Z=6, p<.001, p'<.001), where p' is the Holm-Bonferroni adjusted p-value.

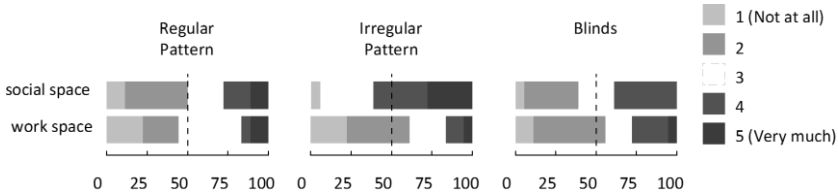



Figure 3. Responses (%) of 18 subjects for the two context scenarios.

Regarding the two context scenarios, the responses show that the irregular pattern produced particularly contrasting results (Fig. 3, *middle*). A Friedman test for the three patterns in each context scenario show a significant effect of pattern for the social space ($\chi^2$=11.82, d.f.=2, p<.01, p'<.01), in accordance with our research hypothesis.

## Discussion

Building upon a recently developed experimental procedure that uses an immersive virtual environment, this study investigates the perceptual effects of spatial distribution in luminance patterns. The results demonstrate the importance of façade –and daylight- characteristics, showing preference for irregularity. Moreover, the context of the studied space was shown to have a significant impact on the evaluation of daylight. Future work aims to represent and evaluate a wide range of daylight and view

conditions in virtual and real environments, seeking to link traditionally non-quantifiable aspects of daylight in space, such as its *ambiance,* with quantifiable metrics.

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