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A VR-based workflow to assess perception of daylit views-out with a focus on dynamism and immersion

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Abstract. Amongst the elements often overlooked in existing studies, dynamic movement and temporal changes in the content of views-out have been suggested to have a high potential to improve its perceived quality and occupant satisfaction. Moreover, in past and ongoing view-out research, most view quality indicators and representation methodologies primarily rely on static time-independent views and fail to acknowledge the importance of including dynamic features in the viewing content. To address this research gap, the present study introduces a novel VR representation workflow to accurately capture dynamic views in experimental settings. This study is the first to examine VR's effectiveness in maintaining immersion and dynamism when studying daylit views-out, using original data based on human subjects. The results provide insights into VR's suitability for representing office window views and assess a new workflow employing a dual fisheye lens and scale model to depict views in physically-based IVE.

1. Introduction

Views are dynamic. They provide a constantly evolving visual content to what is seen from the interior space through changes in sensory stimuli [1]. This moving visual content informs us about the passage of time, weather changes, or objects moving closer or further away from the observer, and is therefore critical for our holistic understanding of the environment and our appraisal of view-out. Consequently, in conducting research on view-out perception, dynamic elements of a view need to be accurately preserved by the chosen representation medium to ensure the validity of comparisons and predictions made from experimental responses to real-world environments [2, 3]. In recent years, virtual reality (VR) has emerged as a prominent tool in the study of daylight and view-out perception, offering control over environmental factors and consistency in experimental conditions [4, 5, 6]. However, current VR representation methods for view-out studies mostly rely on capturing static points-in-time impressions with no presence of movement or changes in the surrounding context, and there is a lack of specialized instruments to accurately capture dynamism and temporality in view-out studies [7]. This paper aims to address this gap by introducing a new VR representation framework designed to accurately capture dynamic views within experimental settings. The proposed methodology combines a scale model of an office room with a dual fisheye lens camera setup to generate view-out scenes based on real environments, which are then projected onto the VR headsets.

Although scale models had previously been used in view-out studies [8], the novelty of our methodology lies in its combination with camera recording and the use of VR as a display medium.

2. Methodology

We conducted two comparative studies in a pilot experiment to assess the adequacy of using VR in view-out studies. These studies account for potential physical symptoms related to VR use and test the effectiveness of using a scale model in capturing view scenes for creating an immersive virtual environment (IVE). In this experiment, we asked participants to observe window views under two different conditions, one from a real office and the other projected in VR, with the latter video-recorded from the same office space right at the beginning of each participant's session using the proposed scene collection method. The objective was to compare the participants' responses between the real and virtual environments so as to evaluate the perceptual accuracy of using VR for view-out studies. We also presented the same participants with two variations of a selection of view scenes that we pre-recorded with and without the use of a scale model. The goal was to determine whether framing the views might enhance perceived presence and realism in representing view-out in an IVE.

2.1. Equipment

We used a Canon RF 5.2 m F2.8L Dual Fisheye lens and a Canon EOS R5 camera to collect view scenes. The dual fisheye lens features a 60 mm interpupillary distance, closely mimicking human vision with natural parallax. The lens captures a 190-degree field-of-view horizontally, vertically, and diagonally, which allows taking perfectly aligned 180-degree stereoscopic videos. We converted collected videos into equirectangular projections to create stereoscopic 180-degree videos, using Canon EOS VR Utility software and Adobe Premiere Pro software with the EOS VR plug-in. We then projected the generated scenes in the Pico Neo Pro 3 Eye (Neo3 Pro) standalone VR headset with a 3664 * 1920 LCD screen display and up to 90Hz refresh rate, resulting in an angular resolution of 19.6 pixels per degree on average and 1832 * 1920 pixels per eye. The headset display offers a 98-degree horizontal and 90-degree vertical visible field-of-view with a luminance level of 60 to 100 nits.

2.2. Participants

All subjects included in the study met the eligibility criteria of having a normal or corrected-to-normal vision, age between 18 and 30, and English language proficiency of C1 level or higher. We implemented age and eyesight restrictions to ensure a homogeneous sample and to avoid potential age-related or vision-related differences. In total, 34 subjects participated in this study (21 male, 12 female, and one non-binary). Out of 34 participants, 29 were under the age of 25, and the mean age was 22.3 years with a standard deviation of 2.6 years ($\mu = 22.3$, $\sigma = 2.6$). This study was approved by the EPFL Human Research Ethics Committee (084-2022) and complied with the CH Federal law on data protection ("Loi fédérale sur la protection des données" – RS 235.1).

2.3. Experimental design

The experiment employed a within-subject design and took 30 minutes for each participant. The experiment was held at a scheduled time between 09:00 and 13:30 between January 16th and 26th, 2023. Outdoor sky and indoor lighting conditions were monitored to ensure the lighting level inside the test room remained consistent and to account for potential weather changes.

The pilot study consisted of three phases - introduction, phase 1, and phase 2 (see Figure 1). During the introduction, participants were instructed to read an information sheet and sign a consent form upon arrival. Participants then completed an online demographics survey while the researcher prepared to collect the VR scene for the experiment comparing view-out perception in a real and virtual environments. In preparation, the researcher first measured participants' seating height to adjust the tripod setup and then captured a 30-seconds video of the window view from the test desk position. During the time it took for the video to be exported into a virtual scene, phase 1 began with an experiment testing the effectiveness of using a scale model in generating view-out scenes in VR. In phase 1, participants viewed two virtual scenes for three minutes each - one minute without interruption followed by two minutes answering seven questionnaire items. To allow for a fully immersive experience, a researcher verbally asked questionnaires while participants were still viewing the scenes in VR or a real environment. Throughout the experiment, participants evaluated their perceptual impressions of the presented view scenes, realism and sense of presence inside the virtual environment, and reported their physical symptoms after wearing a VR headset on an 11-point scale with verbal anchors at the ends (0 - *not at all*, 10 - *very much*) [9]. After phase 1, there was a short break for the researcher to import the captured virtual scene into the VR headset. Phase 2 then began, which consisted of participants viewing two scenes (one in VR and the other in a real environment) for six minutes each – one minute without interruption and five minutes answering fourteen questionnaire items. For both phases, the order of the scenes was randomly assigned for each participant.

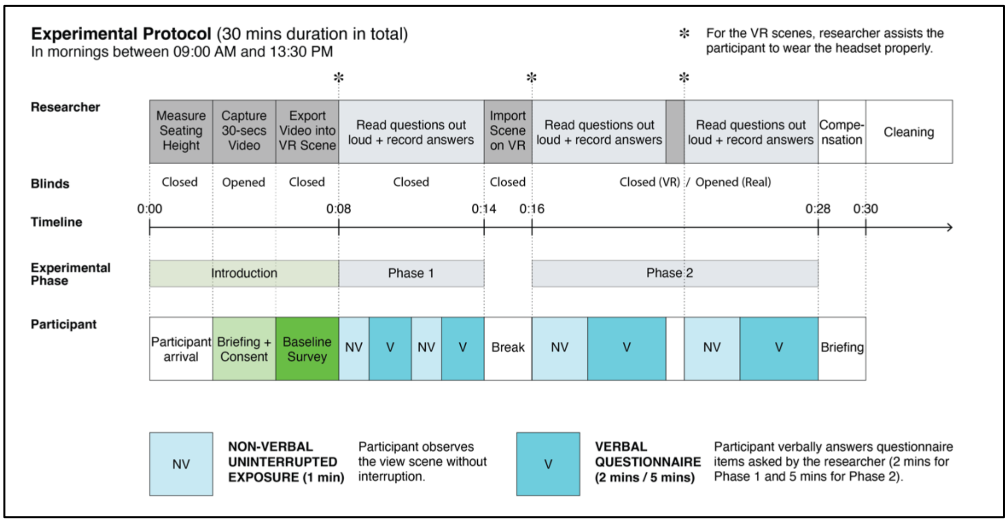

Figure 1. Illustration of the experimental protocol for the pilot study.

2.4. Design of the scale model

We used a 1:10 scale model of an office room as a framing device for capturing physically-based view scenes. The scale model, based on a real medium-sized office, measures 0.70 m in width, 0.20 m in length, and 0.30 m in height. The length of the scale model corresponds to the minimum focusing distance needed for the Canon EOS R5 camera to focus on both near and far objects. The scale model has a horizontal aperture with a 0.40 aspect ratio and 48% window-to-wall ratio, designed based on previous literature on building occupants' preferences for the size and shape of window views [10].

2.5. Workflow of the generation of the virtual view

To capture virtual views as close to the real window conditions in the test room, we generated a new 30-seconds VR scene for each participant at the start of the experiment using the Canon EOS R5 camera and the dual fisheye lens. The same camera setup was also used for generating two virtual scenes prior to the experiment to test the effectiveness of using a scale model for capturing views. We conducted recordings on an overcast day to avoid abrupt changes in the sky condition and monitored the sky illuminance using an LMT lux meter. The scenes were recorded as 1-minute videos on a recognizable central passageway at the EPFL main campus – one with the fully assembled scale model placed on a tripod and the other without. We then converted the collected footage into stereoscopic 180-degree scenes and imported them into the VR headset for visualization. Figure 2 illustrates the procedure for generating virtual view scene from video recording to VR projection.

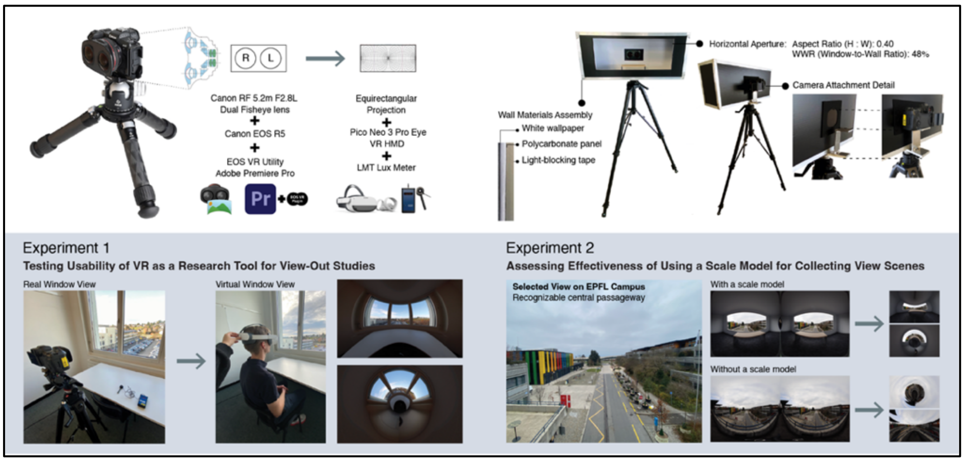

Figure 2. VR scene generation workflow for testing perceptual accuracy of VR and effectiveness of using a scale model for collecting view scenes.

3. Results

In this study, we analyzed participants' responses to verbally administered questionnaires to determine the suitability of using VR for conducting view-out research, discussed in sections 3.1 and 3.2, and to evaluate the effectiveness of using a scale model in generating virtual view scenes, discussed in section 3.3.

3.1. Perceptual Impressions

To address the first objective of the study, namely the adequacy of using VR for view-out research, we tested by evaluating whether there is a significant difference in perceptual impressions of views-out between real and virtual environments. The study found that the perceptual impression ratings from the two environments were almost identical, with a negligible effect size ($d < 0.2$) and no statistical difference ($p > 0.1$) for all questionnaire items. In Figure 3, we created scatter plots of each participant's answers in the virtual and the real environment to visualize the overall agreement between responses. In these graphs, most answers lie on the three diagonal lines, indicating zero and ± 1 difference between the paired responses. The results show that the use of VR in representing views-out provides high perceptual accuracy close to that of the real window view.

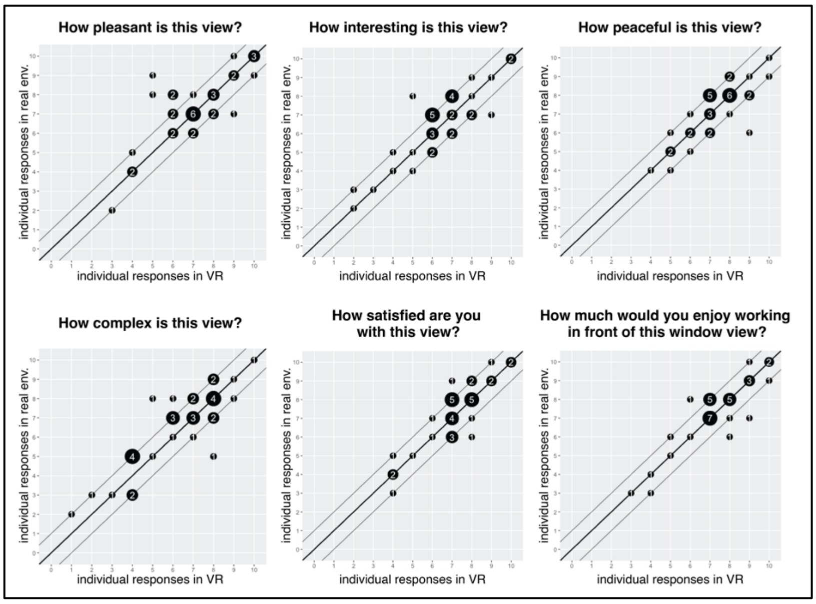

Figure 3. Distribution of each participant's perceptual impressions in the virtual (x axis) and the real (y axis) environment - the size and label of the circles in each graph represent the number of individual responses with identical values. The thicker diagonal line in the center of each graph represents when the paired responses have a zero difference while thinner diagonal lines mark the difference of ±1 between the two environments.

In addition, the participants' sense of presence in VR was gauged using two questions - (1) "How much do you feel like 'being there' in the virtual space?" and (2) "How realistic is this scene in representing a view out?" Participants gave positive responses for both questions, with most of their ratings being higher than 5. It is interesting to note that participants rated the realism of the scene slightly higher ($\mu = 8.06$, $Mo = 9$) than their sense of being there (μ = 7.74, Mo = 8).

3.2. Physical symptoms

To further investigate potential limitations of VR and more specifically whether using a VR headset could lead to negative physical symptoms, participants were asked to answer questions regarding their physical symptoms before and after viewing the first and last VR scenes. The results indicate that most participants did not report a significant difference in their physical symptoms ($u_z < 0.21$), and some even reported feeling less physical symptoms after the last VR scene. The study found no statistically significant differences ($p > 0.05$, $d < 0.2$) except for one question which showed that participants felt a greater sense of freshness in their heads after being exposed to VR scenes ($p = 0.03$, $d = -0.21$). The analysis suggests that the use of VR headset to visualize virtual views-out does not have adverse physiological effects on participants.

3.3. Effectiveness of using a scale model for collecting view scenes

The second objective in this study was to test the advantages of using a scale model in virtual view scene generation by assessing participants' perceived realism in VR. As shown in Table 1, results showed a statistically significant difference ($p < 8.4e-06$) with a large effect size ($d > 0.94$) in perceived realism between scenes created with and without a scale model, with higher scores for the scene with a scale model. Overall, the use of a scale model was found to significantly enhance participants' perceived realism for virtual view-out scenes.

Table 1. Results from a Wilcoxon Matched-Pairs Signed-Ranks test comparing participants' perceived realism for viewing virtual scene with vs. without a scale model (significance level α of 0.05)

-	u_z	p	Cohen's d
How much does it feel like you are looking out through a window?	5.5	2.449e-07	2.824
How realistic is this scene in representing a view-out?	1.03	8.39e-06	0.940

4. Discussion and conclusions

This pilot study explored the suitability of using VR for view-out research and assessed the effectiveness of integrating a scale model in the generation of virtual view scenes. When comparing participants' perceptual impressions of views-out in real vs. virtual environments, we found a remarkable similarity between the two environments with nearly identical participant responses. This high degree of perceptual accuracy for virtual views indicates that VR can provide an immersive and accurate representation of real environments in view-out studies, thereby confirming its potential suitability for view-out research, provided other conditions are respected (e.g., luminance dynamics, tone-mapping in the case of renderings, etc., which were not within the scope of this pilot study). Participants also reported a strong sense of presence and realism within the VR environment, further supporting its potential as an effective research tool. Additionally, the use of a VR headset did not induce negative physical symptoms, demonstrating that VR can be safely employed in view-out research without causing adverse physiological effects on study participants. With respect to immersion aspects, the results revealed that incorporating a scale model in generating virtual view scenes significantly enhanced participants' perceived realism, emphasizing the importance of improving the quality of virtual view-out scenes. Overall, these findings hold significant implications for future view-out research, as they underscore the potential of VR as a reliable, practical, and immersive method for studying view-out perception.

However, this study focused on a specific age range (18 to 30 years) with normal or corrected-to-normal vision, which may limit the generalizability of the findings to other age groups or those with visual impairments. Additionally, the experiment's total duration of 30 minutes per participant does not fully represent the long-term effects of using VR headsets and the potential for experiencing negative physical symptoms. Moreover, the fixed dimensions of the scale model and overcast sky condition cannot account for other office environments or window configurations as well as the full range of daylighting conditions and their impact on view-out perception. Therefore, future work is necessary to expand the environmental contexts and experimental conditions in order to further validate and generalize the findings from this pilot study.

In conclusion, this study addresses the existing gap in view-out research by introducing an innovative VR representation framework that accurately captures dynamic views in experimental settings. The use of dual fisheye lens camera setup generates physically-based virtual scenes that closely resemble real window views, while the incorporation of a scale model in scene generation significantly enhances the perceived realism of the virtual view-out scenes. These findings support the potential of the proposed VR representation framework as a valuable tool in future view-out research, enabling more accurate investigations into the dynamic and temporal aspects of view-out perception. To open up new possibilities for experimental design and pave the way for more immersive and realistic virtual environments in view-out research, we encourage further investigation to confirm the findings from this pilot study in a wider range of environmental settings.

Acknowledgement

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