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Will Cities Survive?

The virtual environments lighting quality assessment using the virtual reality

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ABSTRACT: The computer simulation field opened up new application opportunities in architecture in the last decades. In particular, Virtual Reality (VR) and Immersive Virtual Environments (IVEs) enable to study the subjective experience in-vitro. This paper investigates the ability of VR coupled with immersive devices in providing users with a better spatial lighting understanding. The goal is to reason about the potentiality of VR and IVE on the lighting quality assessment studies involving final users. The research was carried out by analysing and comparing data of the spatial and lighting perception of users using conventional devices frequently used by researchers in the lighting field for running experiments: screens, video projectors, and VR. Three different virtual lighting conditions in a virtual environment were presented, and a survey was administered to twenty-six participants. Results show that immersive VR allows obtaining more significant correlations between lightning variables than the other devices. Besides, the statistical analyses highlight that VR navigation with immersive devices is associated with an overall better lightning perception of the virtual model than the other non-immersive devices tested in the experimentation. The findings also show that users prefer the immersive environment.
KEYWORDS: Virtual reality, Lighting assessment, Survey, indoor environment, ANOVA analyses.

1. INTRODUCTION

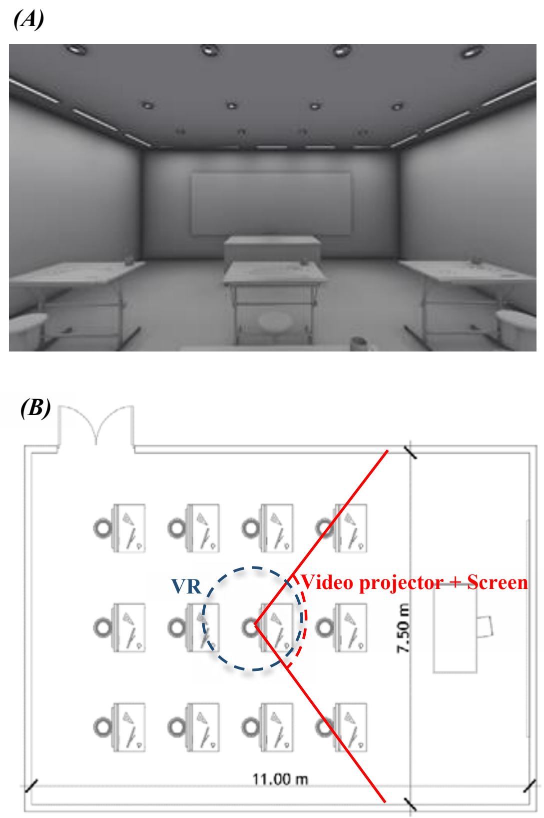
As a result of urbanization and industrialization, people spend more time indoors than ever before. It is estimated that, on average, people spend more than ninety percent of their time indoors (Luongo, 2016). Good lighting plays an important role in safeguarding health in indoor spaces by enabling users to perform their tasks comfortably and efficiently. Accordingly, there should be an appropriate level of light falling on the surfaces that users are working on. For instance, excessive contrast, intense glare, and light flickering in their fields of vision are inappropriate. To assess situations of visual discomfort, architects used two methods. The first one is a subjective lighting assessment: this method evaluates the quality of light in space using surveys (Daich, Zemmouri, Piga, Saadi, & Daiche, 2017; Yacine, Noureddine, Piga, & Morello, 2017; Day, Futrell, Cox, & Ruiz, 2019; Piga, B. E. A., Stancato, G, Rainisio, N, & Boffi, M. 2021). The second one is an objective assessment: this method evaluates the amount of light on the working plane and walls at the users' eyes level. The quantitative method is mainly based on a value obtained through physical measurements on-site using dedicated instruments (typically luminance-meter or luminance-meter) or virtually via computer simulations (e.g. via software such as Radiance, Ecotects, Dialux; Zhu & Rein, 2019). The early 1990s saw several failed efforts by various entities to bring Virtual Reality (VR) technology into widespread adoption in the lighting field, a concept ahead of its time (Lipnack & Stamps, 2008). Some years after, the maturation of key technologies such as lightweight, high-resolution displays and positional tracking improved the possibilities of such an approach. At the time of writing, multiple industries, including cinema, education, defense, design, architecture, and environmental planning, are actively exploring the potential uses and benefits of VR technologies (Portman, M. E & al., 2015; Luigi, Aniello, Gennaro, & Virginia, 2015). This paper investigates the seamless integration of VR technology in architecture and, more precisely, the lighting assessment process. The paper aims to expose the result of a comparative study between three devices frequently used by researchers for lighting assessment purposes: screen, video-projector, and VR (Mahdavi & Eissa, 2002; Newsham, Richardson, & Blanchet, 2005, Saadi,2019). A comparative study on three lighting scenarios of a (virtual) drawing classroom was performed by assessing the users' reactions via a survey administered to twenty-six participants.

2. METHOD AND APPROACH

2.1 Virtual experimental room

The experiment was conducted in a virtual space representing a university design classroom (Fig. 1). The classroom has a rectangular shape (7.50m x 11 m x 4.50m) and a total area of 82.50 M². Three different configurations of artificial lighting have been modeled: 1) overhead lighting, 2) peripheral lighting, 3) mixed lighting (overhead plus peripheral lighting) (Manav & Yener, 1999; Flynn, Hendrick, Spencer, & Martyniuk, 1979; Boyce, 2014).

Figure 1: *A) 3D rendering of the virtual classroom; B) Plan of the virtual room of the experiment showing furniture and subjects' eating location.*



2.2 Subjects

Twenty-seven students from the University of Biskra (Algeria), Department of Architecture, participated in the comparative study aimed at evaluating the perception of the three lighting environments. Thirteen subjects were female with ages ranging from 20 to 28 (M=24), and fourteen males ranging from 20 to 28 (M=23) years old. Thus, 23,5 represents the mean age of the design-classroom users (i.e. students). None of the participants had any visual correction.

2.3 Experimental procedure

A sample of twenty-seven participants was divided into three groups; each group comprised nine students, five female and four males, or reverse. The first group evaluated the three scenes in the following order: overhead lighting, peripheral lighting, and mixed lighting. The second group evaluated the three lightings scenes in a different order; peripheral lighting, overhead lighting and mixed lighting, using a video projector. The last group evaluated the same scenes in a third order, mixed lighting, , peripheral lighting and overhead lighting using a VR headset (Fig 02). Afterward, each group switched the other visualization settings (screen, projection, immersive VR) until all the twenty-seven participants were exposed to three lighting conditions of the design classroom using the three devices.

The virtual model of the university classroom was created with the LUMION software for enabling the personal and immersive exploration of the environment in VR from the same point of view. In particular, three 360° panoramic images representing three different lighting conditions were rendered for allowing the immersive visualization via a Samsung gear VR coupled with a smartphone (Samsung S8+). A Side-Sync application has been installed on both the smartphone and the computer to control the procedure in real-time. This application allowed to visualize in real-time on the PC what the user was looking at through the headset and switch between the three lighting configurations (Fig. 1). The questionnaire was administered to the participants to investigate the user perception about the three scenes; in VR, the questionnaire was incorporated directly in the 360° panoramas. To measure the subjects' perception of the virtual space, the questionnaire used a semantic differential method: 6 pairs of 19 bipolar items were (Flynn, Hendrick, Spencer, & Martyniuk, 1979; Tifler & Rea, 1992; Yacine, Noureddine, Piga, Morello, & Daich, 2017; Rea & Flynn's, 1979). The questionnaire was repeated for the three luminous configurations to all participants.

Figure 2: *A) Picture of the environment for the screen visualization; B) Screenshot of video projector visualization; C) VR Picture of the environment for the headset visualization.*

(A)

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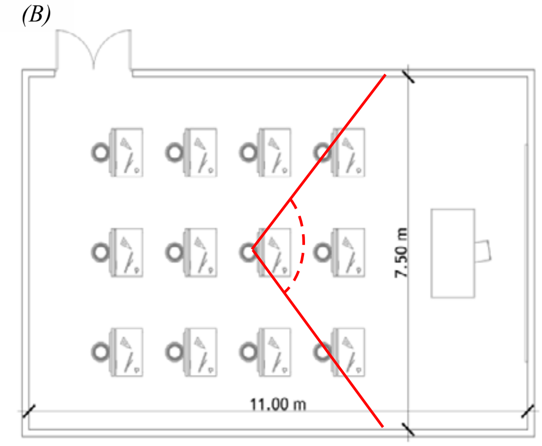
(B)



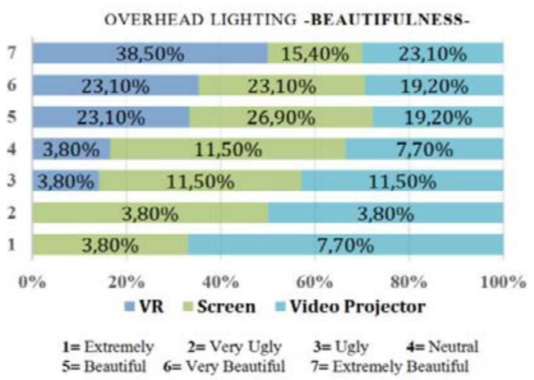
(B)

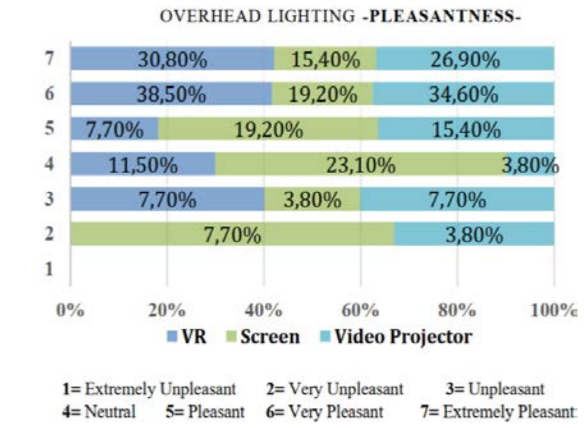
(C)

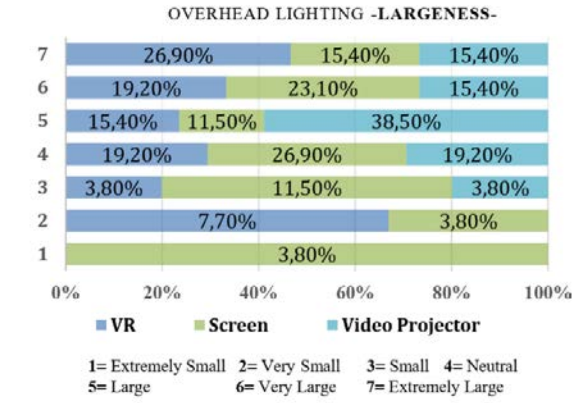
3. RESULTS

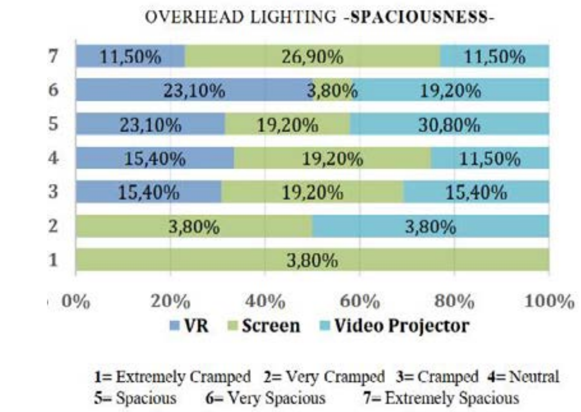
3.1 The overhead lighting condition

Figure 3: *Subjects evaluations of the peripheral lighting scene using the three devices for the variables, pleasantness, Beautifulness, Largeness, and Spaciousness.*







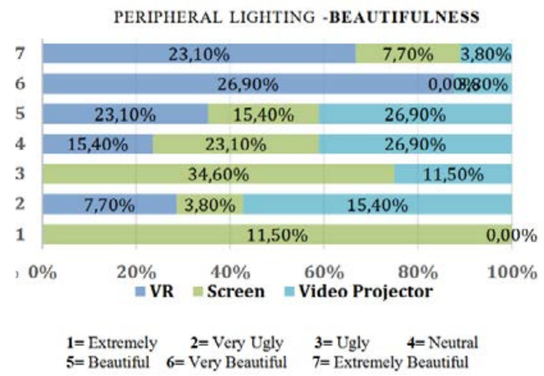


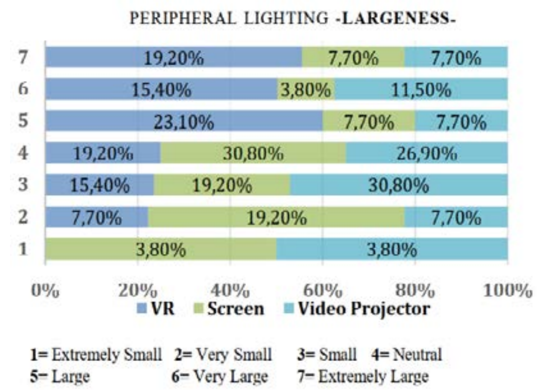
The comparison of the collected data for the overhead lighting scene using the three visualization devices is illustrated in Fig 3. Results show a similarity for the lighting assessment between video-projector and VR devices for Pleasantness, Largeness, and Beauty variables. Independently from the device used, around 60 % (cumulated three devices) of the subjects were more satisfied with the luminous quality of the overhead lighting scene than the other options with the three . Almost the opposite effect can be observed for the Spaciousness variable, where more than 55% of participants rated the classroom as more spacious using the screen for the visualization than video-projector and VR devices.

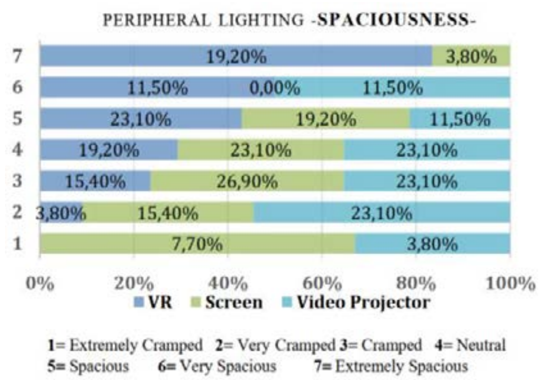
3.2 The peripheral lighting condition

The collected data for the peripheral lighting scene showed a wide divergence between the three visualization devices presented in the Fig 4. Despite this, about 62 % of the subjects were more satisfied with the VR than the two other devices. The classroom visualized via VR was perceived as more Pleasant, larger, more beautiful, and spacious. The results also show that the subjects were more satisfied with the screen than with the video projector. Then, results show a preference for the peripheral lighting scene, as positive reactions decreased from VR to the screen to the video projector.

Figure 4: *Subjects evaluations of the peripheral lighting scene using the three devices for the variables of Pleasantness, Beautifulness, Largeness and Spaciousness.*



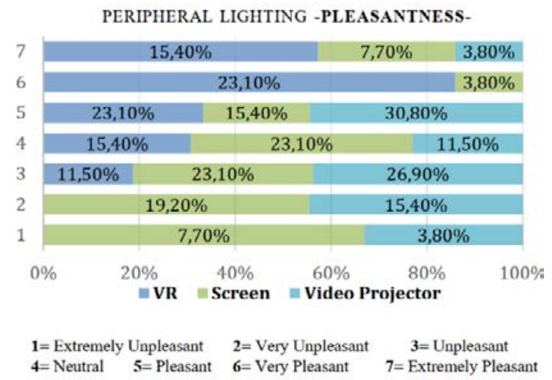


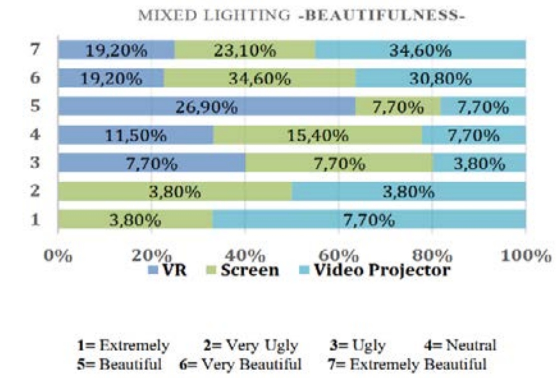


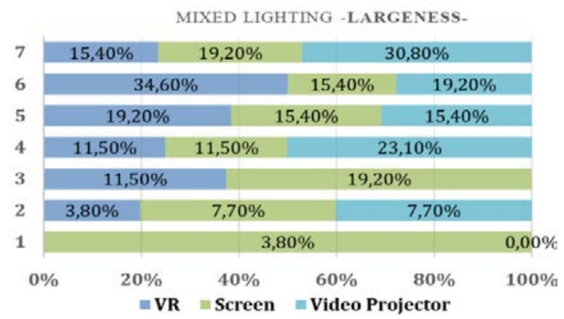
3.3 The mixed lighting configuration

The mixed lighting configuration scene using the three visualization devices, illustrated in Fig 5, showed similar outcomes to the lighting assessment using the video-projector and the screen for the four variables of Pleasantness, Largeness, and Beautiful, and Spaciousness. However, about 65% of the subjects were more satisfied with the VR than with the two other devices. Thus, the immersive VR solution for lighting visualization in an indoor space was judged with higher values for all the investigated variables (followed by the screen and video projector.

Figure 5: Subjects evaluations of the mixed lighting scene using the three devices for the variable's pleasantness, Beautifulness, Largeness, and







Spaciousness.

3.4 Data analyses ANOVA test

An ANOVA for mixed-design analysis was carried out to evaluate the effects of the devices used for the lighting scenes assessment. This analysis highlights significant differences between the three devices tested in the study (screen, video-projector, VR). To better understand the impact of the devices on the visual ratings by users, two 3×4 ANOVA were performed with Groups (Screen-Video Projector - Virtual Reality) 3-level between-subject factor and scenes evaluations as a 4-level within-subject factor (Pleasantness, Beautifulness, Spaciousness, Largerness). The Bonferroni correction was used to analyze post hoc effects. No significant difference between the groups (VR - screen) emerged ($F<1$). There was a main effect of global evaluations, $F(3, 116) = 9.961$, P-values < .001 since Spaciousness and Large showed higher ratings than all other evaluations. In addition, no significant difference emerged between the groups (video projector - Screen) ($F<1$). The main P-value < .001 showed higher ratings than all the other evaluations due to Spaciousness. A significant interaction between the groups (VR - video projector) factors emerged $F(3, 116) = 3.189$, P-values < .005, with the Spaciousness and Large showing higher ratings than all the other evaluations. The comparison of the three devices highlights that only two variables were significantly correlated for the screen (Large /Spaciousness). On the other hand, the four variables Large/Spaciousness and Pleasantness/Beautifulness of the VR and video-projector are significantly correlated per pair, with the VR P-values significantly lower than the video-projector for the Large/Spaciousness pair. A value of (M= 5.9) is obtained by comparing all tested devices using the VR tool for the lighting scenes assessment, meaning that the VR was more appreciated than the screen and video projector.

4. Conclusion

This research investigated the possibility of using VR for lighting assessment studies by comparing it with other devices (screen and video-projector) typically used by researchers in the lighting field for images visualization. The comparison of the subjective evaluations of the three lighting conditions (overhead lighting, peripheral lighting, mixed lighting condition) of a virtual design classroom using three different devices (screen, virtual reality, and the video-projector) shows that users perceive the lighting conditions in the same way with three devices. The ANOVA test analyses showed higher ratings with VR and video-projector than the screen. A higher number of significant correlations between variables, i.e. Large/Spaciousness and Pleasantness/Beautifulness, emerged with VR than the video-projector. Compared to the video-projector device, the results obtained with the VR present lower P-values than the video-projector. The significant correlation recorded between Large/Spaciousness with P-values <.003 and significant correlation between Pleasantness/Beautifulness with P-values < .001, is hypothetically explained by the significant sense of presence of the virtual environment in VR. This should be of course further investigated in future studies. In addition, the value of (M= 5.9) means that VR was more appreciated than other devices in the lightning assessment experiment. In conclusion, the findings presented are encouraging and sustain the multisensory study of lightning virtual environments with VR devices.

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