# Virtual interior environment: Influence of colour on the sense of immersion

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**ABSTRACT**

This article investigates the effects of colour on the sense of immersion in virtual interior environments. The perceptual significance of colour in interior design necessitates a critical evaluation of the three dimensions of colour - hue, saturation, and lightness (HSL) - in the context of their application in virtual environments (VEs). The study aims to investigate how the sense of immersion in virtual interior environments varies depending on hue, saturation, and lightness and to examine the extent to which colour dimensions influence the sense of immersion in VEs. In this study, the HSL colour space was employed to create varying degrees of colours, and an online survey was conducted to understand the individuals' sense of immersion in different virtual interior settings. The findings suggest that reducing the degree of lightness of colours in a virtual interior environment enhances the sense of immersion. In addition, the study reveals that whether a virtual interior environment highlights natural or artificial lighting, augmenting the degree of lightness of colours intensifies the sense of immersion in the perceived environment.

**KEYWORDS** colour perception, colour experience, virtual interior environment, sense of immersion

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## 1. Introduction

Virtual reality (VR) technology provides users with an immersive experience in virtual environments (VEs) through the stimulation of various senses in virtual spaces. VR has transformed into a potent technology that facilitates the assimilation of fictionality by stimulating human senses, enabling individuals to inhabit an artificial environment, and converting mental stimuli into tangible sensations (LaValle 2018; Kim et al. 2004). Alternatively, VR technology has also been identified as a tool that generates long-lasting emotions and memories that endure even after it has been turned off (Rizzi el al. 2012). The development of VR technology has advanced rapidly, particularly in the domain of computer graphics, and a diverse range of new VR equipment has been utilized to measure the degree of immersion in VEs (Feisst 2011; Cadet and Chainay 2020). Immersion is a concept that has been extensively studies in the domain of in video games to create a captivating VE that captures the player's attention. Design criteria to improve the VR in 3D video games are considered in terms of the degree of immersion, engagement, and presence (McMahan 2003). Our brains possess the ability to easily adapt to stories and disregard the surrounding world. Immersion, or the sensation of being transported, is metaphorically derived from submerging oneself in water. The feeling of being surrounded by water while swimming in the ocean or pool is also described as immersion. Compared to air, the sensation of being in the water is an entirely different reality. For instance, learning to swim is a psychologically immersive experience. An experiment that involves immersing oneself in a virtual environment is typically characterised by three elements: flow, cognitive absorption (CA), and presence (Jennett, et al. 2008). Flow is defined as a situation in which individuals are deeply engaged in an activity in such a way that nothing else matters. Flow represents an elevated level of engagement, while immersion eliminates the momentary lapse. Thus, immersion can be considered as a prerequisite for flow (Skarbez et al. 2017; Siple and Springer 1983). Csikszentmihalyi has identified eight factors that are critical for flow: a balance between challenge and skills, clear goals, clear feedback, a sense of uncertain time, a loss of self-consciousness, a sense of pleasure, and control in an autotelic activity (Roohi and Forouzandeh 2019). Nowadays, VR technology has become popular not only in the field of video games but also in various other areas. Immersion allows users to experience diverse VEs, enhancing their spatial perception and sense of presence using one-to-one modelling and 3D visualisation technologies (Murray 1997).

Numerous studies have explored the concept of immersion in various media, highlighting the importance of colour and light in virtual environments (Wästberg and Billger, 2006). Martini et al. (2004) state that the human visual system (HVS) exhibits variations in colour perception according to luminance, chromaticity, or whiteness image filters, aiming to identify the most effective HSL values within the HSV system in virtual environments. Colour perception is a fundamental distinction between human adaptation capability and colour reproduction. Billger et al. (2004) claim that when individuals view a production in a VR environment as an observer, they approach it "out of context" and behave differently than in a real-life situation "in context." Stimulating human colour perception is required to integrate to this experience in line with reality perception. Zeki and Martini's (1998) study on colour processing has showed that designing images as natural, unnatural and achromatic colour stimulate different regions of the human brain. As a result, three-stage cortical colour processing occurs in the human brain. The first stage comprises wavelength difference, consisting of the presence of wavelength and its intensity. The second stage is an atomic constant perception of colour, without any association with memory, judgment, or learning. The third stage is the colour of the object. All these factors influence colour perception in the human brain in both real-world and VR settings (Zeki and Martini 1998). In addition, Brown and MacLeod (1997) found that different nuances of colours elicit different senses, leading to variations in the sense of immersion in VEs. Although colour perception is considered one of the factors that influence the sense of immersion in a VE, few studies have focused on colour as the primary subject matter of investigating immersion in spatial contexts (Stahre et al., 2009).

This article seeks to investigate the influence of colour on the sense of immersion in virtual interior environments. The study aims to explore how the hue, saturation, and lightness of colours affect the sense of immersion and the extent to which colour dimensions influence the sense of immersion in such VEs. By doing so, this research can offer insight into how colour perception in virtual interior environments can influence the sense of immersion in a technical and practical manner in the field of interior architecture utilising emerging technologies.

## 2. The Study

### 2.1. *Participants*

The study involved a total of 228 participants, consisting of 165 females and 63 males, with 14 individuals under the age of 18, 62 between the ages of 18 and 24, 84 between the ages of 25 and 34, 38 between the ages of 35 and 44, 28 between the ages of 45 and 64, and two over the age of 65. Although 25% of participants reported backgrounds in architecture and interior architecture, the remaining participants represented diverse occupational groups to facilitate a more comprehensive analysis. All participants were of Turkish nationality.

### 2.2 *Visual Stimuli*

In this study, four different interior images were selected from the website of interior architect Kelly Wearstler (https://www.kellywearstler.com/) to evaluate the effects of colour on the sense of immersion virtual interior environments. The HSL colour space of Adobe Photoshop CS6 was utilised to adjust the degree of hue, saturation, and lightness of the selected images, with each image having four different modifications. To make the images appear warmer, the degree of hue in each image was decreased by 10%, while the degree of saturation was reduced by 35% to make the images appear duller. The degree of lightness was adjusted by a range of -35% to +35%, resulting in darker and lighter images (Figure 1). The first image was selected for its warm colour tones dominated by intense brown colours, which featured dotted dark elements with horizontal and vertical lines. The second image contained brown and warm tones and was chosen to examine the contrast of the white chair with the rest of the environment. The third image was chosen due to its visually intense reflection of natural lighting, which allowed for the exploration of the effect of sun on the interior environment. The fourth and final image was dominated by cold tones and combined with the reflectivity of artificial lighting to make a comparison with interiors in warm tones. All modifications were done in a controlled manner to ensure consistency and avoid any potential confounding variables.

### 2.2 *HSL Colour Model*

The HSL colour model, an acronym for hue, saturation, and lightness, is widely used tool in computer graphics applications. Although the HSL model is based on an RGB colour space, its aim is to describe more perceptual colour relationships. Thus, in this study, the HSL colour model was deemed appropriate for modifying image.

### 2.3 *Measures and Procedure*

In this study, an online survey was utilized to investigate the sense of immersion in virtual interior environments. The questionnaire comprised three sections: demographic features, colour vision assessment, and selection of the most immersive interior image. The first section requested demographic information such as age, gender, and nationality. The second section assessed participants' colour vision using Ishahara's colour deficiency test, with participants who passed the test being deemed to have normal colour vision. The third section aimed to determine the extent to which the participants felt immersed in the virtual interior environments presented to them, with participants being asked to select one of four sets of images with varying degrees of hue, saturation and lightness that best conveyed the sense of immersion from a total of four different interior images.

Given the COVID-19 pandemic and the resulting limitations on in-person research, the study necessitated the use of monitors and screens instead of VR glasses to display the interior images. To maximize the study's potential accuracy, certain prerequisites were established. For example, participants were instructed to set their monitor colour settings to RGB, turn off night shift or true tone settings if using a phone, and adjust screen brightness to between 80% and 90%. Additionally, participants were advised not to take the survey in bright daylight or in the dark. These measures were implemented to minimise potential variability in participants' responses due to differences in screen settings or lighting conditions.

## 3. Results and Discussion

After data collection through an online survey, statistical analysis was conducted using IBM SPSS Statistics 23. The data were analysed for frequency distribution, and the results are discussed in relation to each of the four images presented in Figure 1.

In the first set of images (see Figure 1a), a notable 31.1% of participants identified the image with a -35% degree of lightness (referring to #1) as providing the most immersive virtual interior environment in comparison to the other images. In contrast, 24.1% of participants found the image with a -10% decrease in hue (referring to #3) to be immersive, while 23.2% of participants found the image with a -35% decrease in saturation (referring to #4) to be immersive. The results demonstrate that 18.9% of participants found the image with a +35% increase in lightness (referring to #2) to be immersive.

In the second set of images (see Figure 1b), the image with a -35% degree of lightness (referring to #1) was identified as providing the most immersive virtual interior environment by 32.9% of participants, in comparison to the other images. However, 26.3% of participants found the virtual environment with a +35% increase in lightness (referring to #2) to be immersive, followed by the image with a -35% decrease in saturation (referring to #4), which was identified as immersive by 23.2% of participants. According to the results, only 14.5% of participants found the image with a -10% decrease in hue (referring to #3) to be immersive.

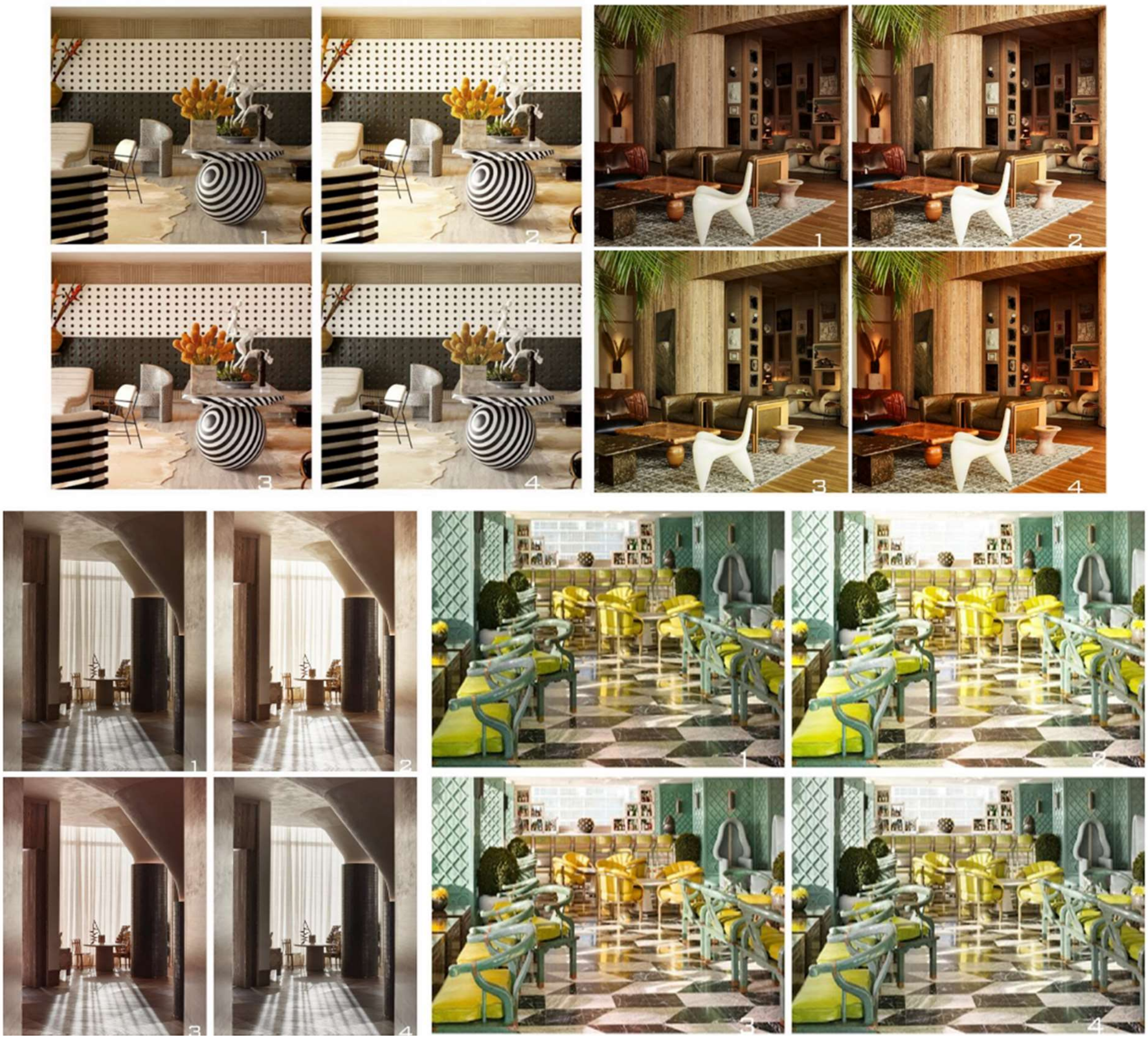

*Fig. 1. Interior images used in the study; in each image: 1) lightness: -35%, 2) lightness: +35%, 3) hue: -10%, 4) saturation: -35%*

In the third set of images (see Figure 1c), 33.3% of participants perceived the image with a +35% increase in lightness (referring to #2) as providing the most immersive virtual interior environment, followed by the image with a -35% decrease in saturation (referring to #4), which was identified as the second most immersive by 27.2% of participants. Meanwhile, 22.4% of participants regarded the image with a -35% decrease in lightness (referring to #1) as immersive, and 14.9% of them perceived the image with a -10% decrease in hue (referring to #3) as immersive.

In the final set of images (see Figure 1d), the majority of participants (55.7%) perceived the image with a +35% increase in lightness (referring to #2) as the most immersive virtual interior environment when compared to the other images. The next most immersive virtual environment was the with a -10% decrease in hue (referring to #3), which was considered immersive by 21.9% of participants. The image with a -35% decrease in lightness (referring to #1) and a -35% decrease in saturation (referring to #4) were perceived as immersive by 14.5% and 4.8% of participants, respectively. Figure 2 displays the frequency distributions of the sets of images.

The findings of the present study align with previous research that suggests that perception of colour plays a significant role in the sense of immersion in VEs. More specifically, the study revealed that decreasing the degree of lightness of colours in virtual interior environments enhances the sense of immersion in that environment. In addition, the findings indicate that increasing the degree of lightness of colours, whether in the context of natural or artificial lighting, heightens the sense of immersion in the VE. Previous research conducted by Siess and Wölfel (2019) has examined the effect of colour temperature on the sense of immersion, demonstrating that different nuances of colour can elicit diverse perceptions, leading to variations in the sense of immersion in VEs. Similarly, Kumoğlu's (2013) study on how colour temperature affects wayfinding behaviours in virtual airport simulations indicated that the participants' wayfinding performance varied depending on the colour temperature, as measured by factors such as time spent, deviations, indecision, and direction choice.

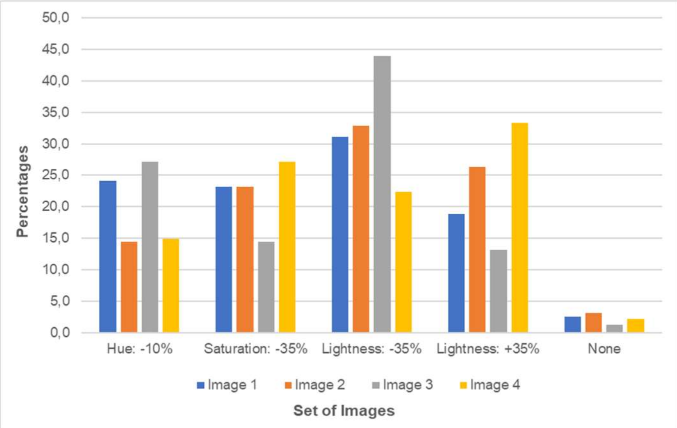


*Fig. 2. Frequency distribution of the sets of images*

The perception of space and mental construction of space in the virtual environment are linked to the colour temperature, which suggests that colour values can also influence the sense of immersion in virtual interior environments. Stachoň et al. (2018) found that participants' locations, directions, and sense of reality vary depending on the hue, and that the hue has an impact on the virtual environment. Taherzadeh (2018) investigated the effect of hue on task performance, and the study's findings suggest that changing the hue caused participants to behave differently. The various hues that cause differences in behaviour in the spatial setup differ in the sense of immersion of the participants in virtual environments.

The present study examined the impact of hue, saturation, and lightness on the sense of immersion in virtual interior environments. Consistent with prior research, the results suggest that colour perception plays a crucial role in shaping the sense of immersion in VEs. It is worth noting that the use of 2D virtual interior environment images in this study, along with the use of online surveys due to the pandemic restrictions, are potential limitations. Consequently, the findings can be considered as a preliminary investigation that provides a basis for further research on the impact of colour on the sense of immersion in 3D virtual interior environments.

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## 5. Conflict of interest declaration

The authors declare that there is no conflict of interest.

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## Licensing terms



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