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Colouring Space in Virtual Reality: A-Chromatic and chromatic composition and color saturation affecting visual perception

Yulyta Kodrat P[1*], Mutia Nurdina[2], Rafeah Legino[3]
*Corresponding Author

[1] Interior Design Study Programme, Faculty of Visual Art Institut Seni Indonesia Yogyakarta, Yogyakarta, Indonesia
[2] Media Design Study Program, Faculty of Visual Art Institut Seni Indonesia Yogyakarta, Yogyakarta, Indonesia
[3] College of Creative Arts, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

yulyta_kodrat@isi.ac.id; mutianurdina@isi.ac.id; leginorafeah@gmail.com
Tel: +6281904138654

Abstract
Interior design is one field that employs three-dimensional perspective presentations to illustrate space. This study investigated the variations in colour composition and saturation affecting visual impressions. The method tests the three-dimensional rendering of images through virtual reality (VR). The variables connect to the differences in room and furniture colour composition. The visual simulation test conducted on two experiments included 20 participants who replied to a group of chromatic-achromatic and achromatic-chromatic, with saturation levels ranging. The findings reveal that colour composition impacts the clarity of space, and the variation in colour saturation influences the impression of the room's depth.

Keywords: Virtual reality; colour saturation; chromatic; achromatic

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1.0 Introduction

In the past decade, virtual Reality (VR) has seen rapid expansion. VR products in cyberspace allow us to visit and experience the ambience of tourist spots worldwide and explore interior developments using this technology. But what exactly is virtual reality? It is a technique that transforms real-world views into virtual 3D graphics. Designers can utilise visual reality to improve comprehension of the built environment; the process of representation and interpretation can be viewed as an act of knowledge production or as a type of complicated reasoning (Bosselmann, 1999; Macheachren, 1995) in (Whyte, 2002). In simpler terms, VR allows us to create and interact with virtual environments that mimic real-world settings. This understanding of VR is crucial to grasp the potential it holds for interior design and architecture.

The field of design, mainly interior design, can benefit from this VR technology as a medium for presenting concepts and designs to clients. Although most Indonesian interior designers are more accustomed to using 3D animation media and visual presentations such as 3D Max or Sketchup, presenting using VR is also an alternative. VR technology is an animated rendering advancement that allows users to interact with and feel the atmosphere of the interior as if they were in the real world. Because consumers can sense the mood

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in the area, the interior appearance becomes more distinct and appealing. Through VR, the user may move his head around the space, feeling proportion, material, colour, and light in great detail. VR is a headset-mounted device that is connected to the user's eyes. Users can view the inside room and the objects exhibited by the device projector using this feature.

Interior designers typically employ 2D, 3D, and 3D animation rendering images for internal modelling. Because presenting 3-D animation necessitates a huge file and a lengthy rendering time, one of the advances in the usage of 3D rendering packaged in 360 º and shown in VR has a quality comparable to 3D animation. Interior modelling that can only be seen with the naked eye looks very different when viewed through VR. As a result, colour and light element configurations play an essential part in displaying a perspective that appears in volume, exhibiting the depth of space, three-dimensional objects, material details, and textures.

The biggest challenge in displaying 3D modelling with VR is producing three-dimensional graphics close to actual visuals. The use of shading is an essential aspect of 3D modelling for VR. A colour saturation configuration scheme and lighting contrast setup are required for virtual reality (VR) interior modelling. This study aims to test interior modelling using various colour saturation and light contrast settings in virtual reality (VR) to determine how the configuration impacts visual perception.

2.0 Literature Review

2.1 Virtual Reality

Shields (2005) describes "virtual" is frequently used to denote absence, unreality, or non-existence. Virtual is an authentic experience without the exact, ideal without the abstract. Furthermore, *virtual reality* is defined as VR media or VR systems. Whyte (2002) emphasises virtual environments and models made within computers. Immersive virtual reality has been identified as a valuable interior design and architecture method. Paes, Arantes, and Irizarry (2017) conducted a study to quantitatively validate the capabilities of specific immersive systems to provide users with a better spatial knowledge of virtual mock-ups. This method contrasts users' spatial awareness when utilising traditional workstations against immersive platforms. The study concludes that immersive settings can improve professional understanding of the spatial organisation of virtual models, which can assist existing design methods. When utilised for different objectives, different styles of exhibits generate distinct sets of explicit knowledge about the natural world (Whyte, 2002). Zhang's finding (2019) has revealed the concept, characteristics, mode of expression, scope of application, and basic types of virtual reality display design which can be achieved through the perspective of three-dimensional (3D) virtual reality technology to achieve the most intuitive display of interior design effects.

The depiction of three-dimensional models helps us to see the spatial features of the current and projected built environment. 3D modelling for interior design is generated by various tools, including AutoCAD, 3DMax, Sketchup, Blended, Archicad, and others that are widely used, both paid and free. Additional rendering applications, such as VRay, are required to create visual quality similar to reality. The rendering technique utilised for virtual reality demonstrates that combining virtual and real mixed-reality applications may improve the interactive efficiency and user experience of mixed-reality applications (Ping et al., 2021). Before rendering, 3D picture imagery must meet visual graphics quality standards such as light intensity, light source, light direction, contrast, shadow, and colour selection (Boughen, 2005).

Several previous studies have shown that modelling simulations using such software affect the perception and understanding of space and 3D models (Abdullah et al., 2022; Carmona-Medeiro et al., 2021; Kaleja & Kozlovská, 2017; Paes et al., 2017). 3D rendering—360º panoramic presentation is a progression of 3 Dimensions produced utilising panoramic techniques. Panoramic images provide us with a 360-degree view of the room's contents.

2.2 Hues, Saturation, Chromatic, and Achromatic Colours

Hue is the quality or attribute that distinguishes one hue from another. The second characteristic that distinguishes a colour is its saturation. It denotes the purity of a given colour, the property that differentiates it from a greyed-down hue. It is also known as strength, intensity, or chroma. The third dimension in the description of colour is lightness, or its synonymic value, which distinguishes dark hues from bright ones (Meerwein et al., 2007).

Further, Meerwein explains how to combine colours; it is often practical to use several different contrasts. The first is light-dark contrasts, most visible when combined with the achromatic colours black, white, and grey. Also, it can be made using combinations of chromatic colours and colours of the same hue yet with different degrees of lightness values. The lightness contrasts are ideal for generating spatial differences.

The second is chromatic-achromatic contrast, which results when chromatic and achromatic colours come together. Chromatic, pure, and highly saturated colours generate intense impressions and spontaneously stimulate attention when interacting with achromatic colours. The degree of prominence of chromatic-achromatic contrasts depends on the intensity of hue and brightness contrast. Chromatic-achromatic contrast is a principle widely used in interior design. In the visual arts, colour saturation is effectively controlled to balance opposing feelings and moods and to foster the illusion of relative distance within the pictorial plane.

Contrast polarity and its interplay with colour saturation influence the proportion of responses to contrast that are assimilated and have no impact. The findings show that colour saturation impacts figure-ground organisation directly by determining depth and indirectly by influencing background brightness through interaction with contrast polarity (Dresp-Langley & Reeves, 2014). The application of colour configurations directly related to high and low colour saturation to objects such as furniture and the background colour of walls, floors, and ceilings significantly impacts visual quality. Recent research on visual perception in virtual media demonstrates that lighting and colour are the foundation for constructing renderings that represent virtual images (Díaz-Barrancas, Cwierz, Pardo, Pérez, & Suero, 2020; Krupinski, 2020; Lindemann & Ropinski, 2011).

Using continuous colour composition, grayscale, and a colour spectrum that considers colourblindness will improve an object's visual look (Díaz-Barrancas et al., 2020; Dresp-Langley & Reeves, 2014; Farné, 1977; Hedrich et al., 2009). Other studies have also shown that depth of field can be experienced through hue, colour brightness, and saturation changes. Egusa (1983) discovered that when achromatic colours were combined, the depth of field rose as the difference in brightness increased. However, no depth difference was felt when we combined achromatic-chromatic colours. Furthermore, in chromatic-chromatic pairings, the perceived depth of field is determined by the sequence of the red, green, and blue hues, with the perceived depth difference increasing as the saturation difference increases.

3.0 Methodology

This research uses descriptive research methods to test the model. Firstly, the test determines the visual acuity level and space depth. The model uses a rendered perspective from the Sketchup and Vray application in 3D rendering - 360º Panoramic and transferred into VR oculus. A space design should incorporate variable saturation colours as a background and object configurations. Secondly, in experiment 1, the floor, wall, and ceiling colours use achromatic, and the furniture use chromatic (see Fig. 1a). In experiment 2, the floor, wall, and ceiling colours use chromatic, and the furniture uses achromatic (see Fig. 2b).

The experiment used 20 male and female respondents with a background in visual arts education, aged between 18 and 40. The test was conducted through VR Oculus to see each respondent's response to the perspective images. Respondents were asked to complete a questionnaire with a semantic differential measurement scale of 1 to 7, modified from Flynn's experiment (Flynn et al., 1979). Finally, the measurement scale tested is related to the impression of visual and spatial understanding and depth of field. The test data will be analysed using descriptive statistical analysis (see Figure 1). Then, it will be categorised into a model showing that chromatic-achromatic and saturation colour composition affect visual three-dimensional space perceptions.

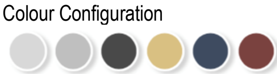
Fig. 1: (a) Achromatic (space-forming elements)-Chromatic (furniture); (b) Chromatic (space-forming elements)-Achromatic (furniture)
(Source: SketchUp's rendering 2023)

4.0 Findings

Perception is intimately tied to cognitive comprehension, stored in the human brain since acquiring information and knowledge. Similarly, visual perception of space is always connected to the things that make up space, which physically limits both. In our imaginations, physical space is a three-dimensional structure with space-forming elements seen in the shapes of floors, walls, and ceilings. Additionally, additional design elements such as lines, textures, patterns, colours, and light can enhance the visual experience of space. The test carried out in this study was connected to the rendering volume produced by 3D rendering 360**º** panoramic. Variables for colour composition and saturation are examined to determine the colour composition and saturation that bring clarity to objects, space, and depth of space.

The hypothesis expressed in this study is based on some of the outcomes of prior colour research and theories, namely, that chromatic and achromatic colour compositions significantly change visual clarity in objects, space, and depth of field. Colour saturation also affects the optical clarity of objects, space, and depth of field. The following data from 3D modelling rendering with Sketchup and Vray applications are grouped according to chromatic, achromatic, and colour saturation colour categories.

Table 1. 3D Rendering of AChromatic – Chromatic Colour Configuration

Colour Configuration 	Space-forming elements	Saturation (%)	Reflection/ Specular (%)	Roughness (%)
	Floor Wall Ceiling	100 100 100	50 50 50	20 70 70

	Floor Wall Ceiling	50 75 100	50 50 50	20 70 70
	Floor Wall Ceiling	100 25 50	50 50 50	20 70 70
	Floor Wall Ceiling	75 100 25	50 50 50	20 70 70

(Source: Experiment's Data 2023)

Table 2. 3D Rendering of Chromatic – AChromatic Colour Configuration

Colour Configuration 	Space-forming elements	Saturation (%)	Reflection/ Specular (%)	Roughness (%)
	Floor Wall Ceiling	100 100 100	50 50 50	20 70 70
	Floor Wall Ceiling	50 75 100	50 50 50	20 70 70
	Floor Wall Ceiling	100 25 50	50 50 50	20 70 70
	Floor Wall Ceiling	75 100 25	50 50 50	20 70 70

(Source: Experiment's Data 2023)

5.0 Discussion

5.1 The factors that influence subjective opinions

We aim to provide a comprehensive and evidence-based understanding of the elements influencing subjective opinions. We quantify the impacts of colour arrangement on the clarity of space and object and the depth of space on mean opinion ratings. According to Table 3 and Figure 2, respondents prefer an achromatic-chromatic (AC3) configuration with 100% floor colour saturation, 25% wall colour saturation, and 50% ceiling colour saturation to represent clarity of space and object and depth of space. The chromatic-achromatic (CA3) arrangement with 100% colour saturation on the floor, 25% on the walls, and 50% on the ceiling depicts hazy and flat sights of space.

Table 3. Measurement Colour Configuration

Colour Configuration	Clarity of space and object	Depth of space
AChromatic-Chromatic 1 (AC1)	1,6	2,5
AChromatic-Chromatic 2 (AC2)	1,9	2,2

AChromatic-Chromatic 3 (AC3)	1,6	1,7
AChromatic-Chromatic 4 (AC4)	2,7	1,9
Chromatic-AChromatic1 (CA1)	2,8	2,2
Chromatic-AChromatic 2 (CA2)	3,3	2,3
Chromatic-AChromatic 3 (CA3)	3,6	3,6
Chromatic-AChromatic 4 (CA4)	2,8	2,1

(Source) Statistical Analysis 2023)

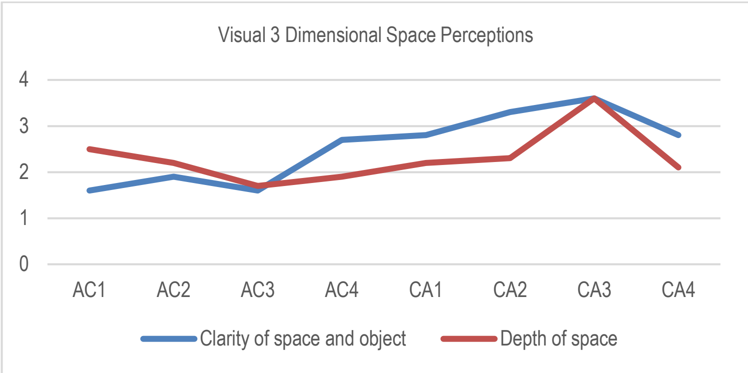


Fig. 2. Measurement Scale Diagram: Visual 3-Dimensional Spaces Perceptions
(Source: Statistical Analysis 2023)

Other studies have also proven that depth of field is constructed through hue, colour brightness, and saturation differences (Egusa, 1983). Depth of field can also be experienced through changes in hue, colour brightness, and saturation, according to this experiment. It was discovered that the depth of space in the combination of achromatic-chromatic colours is not dependent on the difference in brightness increases. In contrast, the clarity of space and object is experienced in various achromatic-chromatic colours. Furthermore, in chromatic-chromatic combinations, the perceived clarity of space and object and the perceived depth of space are affected by the hue combination, with the reported depth difference increasing as the saturation difference grows. The results also showed a correlation between colour saturation and achromatic-chromatic colour composition, thus providing a depth-of-field effect. Other research has found that colour saturation directly impacts the figure-ground organisation in grey by defining depth and indirectly influencing background brightness (Dresp-Langley & Reeves, 2014).

This paper explains the tests carried out to see if the colour composition of the achromatic and chromatic background and object affects visual clarity and depth on the display of 3-dimensional objects through visual reality, based on the theory and results of previous research. The analysis selection uses Anova with two dependent variables: visual clarity and depth of space. There are two independent variables, and the first is the colour configuration of achromatic-chromatic and chromatic-achromatic. Second is colour saturation with 25%, 50%, and 100% percentages. The results of the analysis can be concluded that differences in colour configuration significantly affect visual clarity (sig. 0.002) and have no significance on the depth of space (sig.0,106) (see Table 4). When the achromatic colours black, white, and grey are combined as a space element, the composition of light-dark contrasts affects visual clarity. When using chromatic colour combinations as a space element and colours of the same saturation, no spatial difference is generated because they have different degrees of lightness values.

Table 4. Anova Test of Between–Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	Clarity	40,387[a]	7	5,770	3,597	0,002
	Depth	23,088[b]	7	3,298	1,771	0,106
Intercept	Clarity	515,113	1	515,113	321.109	0,000
	Depth	427,812	1	427.812	229,698	0,000
Configuration	Clarity	40,388	7	5,770	3,597	0,002
	Depth	23,088	7	3,298	1,771	0,106
Error	Clarity	115,500	72	1,604		
	Depth	134,100	72	1,863		
Total	Clarity	671,000	80			
	Depth	585,000	80			
Corrected Total	Clarity	155,888	79			
	Depth	157,188	79			

a. R Squared = 0,259 (Adjusted R Square = 0,187)
b. R Squared = 0,147 (Adjusted R Square = 0,064)

(Source) Statistical Analysis 2023)

The results of the Table 5 analysis show that the configuration of AC3 as a combination impacts visual three-dimensional space perceptions. AC3 configuration with achromatic colours (white, grey, and black) for the furniture's floor, walls, and ceiling and chromatic colours (red, blue, and yellow). This conclusion corresponds to Egusa's statement (1983). An achromatic colour-black backdrop colour necessitates increased brightness to achieve the depth of field; in this test, the light was quite bright, and the brightness levels for all stimulants were the same. Even though the colour saturation is the same, there is no sense of depth variation in the chromatic colour of the space element. The CA3 configuration demonstrates that chromatic colours (blue, green, and yellow) for the floor, walls, and ceiling, but achromatic colours (black, grey, and white) for the furniture do not affect the clarity and depth of space.

Table 5. Colour Configuration that Affects Clarity of Space and Object and Depth of Space

Configuration	Colour	Saturation		Colour	
AC3	AChromatic 	Floor Wall Ceiling	100 25 50	Chromatic 	Furniture Accessories
CA3	Chromatic 	Floor Wall Ceiling	100 25 50	AChromatic 	Furniture Accessories

(Source: Statistical Analysis 2023)

5.0 Conclusion

Our findings confirm that creating the correct colour configuration influences visual 3-dimensional space perception. A configuration that generates contrast between objects and space so that the depth of space is visible, as well as comparison to clarify space with objects in it. Designing a three-dimensional space that can be viewed using virtual Reality (VR) is critical. The discovery demonstrates that combining achromatic colours for space elements and chromatic colours for object colours provides greater depth of field perception than chromatic combinations. Suppose the colour combination is due to the lack of high contrast in the chromatic composition. In that case, the space will appear deep, combining colours with lightness/brightness that contrasts—combining chromatic colours results in chromatic contrast. It is most noticeable when combining three or more pure, highly saturated colours. The greater the number of similar colours, the more vivid and robust the contrast effect. Combinations located far apart on colour circles, such as yellow, red, and blue, produce the most significant possible difference and, thus, the most noticeable contrast. The chromatic contrast created by pure colours is striking, vibrant, and powerful, attracting attention.

The results for visual clarity with achromatic-chromatic and chromatic-achromatic combinations significantly influence the clarity of space and objects. As a result, the percentage of colour saturation in achromatic and chromatic colours with a composition of 100% for floors, 25% for walls, and 50% for ceilings can be concluded. This insight is priceless in digital media, particularly visual reality. Benefits for the development of colour configurations in virtual spaces: (1) need patrons of achromatic and chromatic colour configurations resulting from advanced research programs; (2) providing new predictions of colour configurations that affect visual perception; (3) naturally generalise in a broader context; and (4) encourage researchers to address the boundary conditions between art and aesthetics within virtual boundaries.

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Paper Contribution to Related Field of Study

This paper relates to the field of interior study, focusing on developing the final presentation project in a commercial interior design course and the student final project.

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