Contribution of Natural Lighting in Workspaces to Visual Comfort Improving User Productivity

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Abstract. Visual comfort is an essential aspect of workspace interior design, especially architecture studios where creativity and productivity can affect the health and well-being of users. Poor visual conditions can lead to eyestrain, headaches, and decreased work productivity. This study the factors that affect visual comfort in architecture studio workspaces against user perceptions. This research method uses SketchUp simulation experiments, VR (Virtual Reality), and questionnaires to determine the user's response to visual comfort in the architecture studio workspace. The variables used in this evaluation look at the amount of light entering, window openings (WWR), wall materials and colors, perceptions of visual comfort, and work productivity. The results showed that natural lighting plays an important role in creating visual comfort, with the right lighting intensity, so that it has a positive impact on user health. In addition, the use of bright wall colors such as white and orange tends to make a positive contribution to the user's visual environment which can directly improve work performance and productivity. This study proves that workspace design with the right lighting and color selection can have a positive visual impact on users with sustainable lighting distribution techniques and methods.

1 Introduction

Use Visual comfort is an essential aspect of workspace design, where a good visual environment can support productivity and health[1]. Studies by Boyce (2003) in "Human Factors in Lighting" emphasize the importance of natural lighting in workspaces, which can improve mood and productivity[2]. Reasonable and appropriate lighting in the workplace can improve cognitive performance and productivity.

Architectural studio workspace lighting is one of the environmental components that must be considered because it provides visual comfort that affects users' work, health, and productivity [3]. Inadequate lighting in workspaces can visually cause computer vision syndrome, which includes symptoms such as dry eyes, eyestrain, and headaches[4].

The architecture studio workspace is specifically designed to support the activities of architects in working on projects that require high accuracy, such as planning, drawing, modeling, the structure and construction of buildings[5]. Architectural studio workspaces are

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characterized by the arrangement of chairs and tables, flat TVs for studio work exposure, and whiteboards for brainstorming, and studio workspaces must meet room lighting of 350 lux - 750 lux based on the Illuminating Engineering Society (IES)[6].

Visual comfort is related to the ability to see clearly, how space elements are arranged to provide comfortable visual comfort, reduce eye fatigue and create good work productivity [7]. According to Robert Gifford [8] the physical environment of a space can be influenced by human behavior. Gifford stated that design elements, such as wall color and lighting can affect productivity and psychological well-being[8]. Proper color selection and contrast in interior design can affect visual comfort. According to research by Küller et al. [9], wall colors that are flashy or too dark can cause eyestrain. Using bright colors such as neutral and warm colors and appropriate contrast in architectural studio spaces can help create a comfortable and efficient working environment.

Good workspace interior design helps create a comfortable environment that supports productivity. Cuttle explain the importance of flexible organization in architectural studio workspaces. Proper placement of monitors, tables, and chairs can reduce neck and eye strain and help architects and designers work more comfortably and efficiently[10]. Natural lighting in workspaces not only supports visual comfort and productivity, but also contributes to environmental sustainability and the overall well-being of workers.

This study aims to evaluate the factors that influence visual comfort in architectural studio workspaces, enhancing work productivity and thus creating a healthy and comfortable work environment. This research focuses on lighting, proper use of colors in the studio space, and work productivity that can provide long-term well-being for architects and designers.

2 Method

This research method uses Sketchup simulation experiments, VR (Virtual Reality), and questionnaires to directly measure the users' response to the architecture studio space, which increases work productivity. The study's respondents amounted to 12, consisting of 6 architecture master students and 6 architecture bureau consultant workers. Research in the context of simple experiments uses experimental and control groups of 10-20 people [11] and [12].

2.1 Material variables and components

The variables used in this study are incoming light conditions, window openings (WWR), wall materials and colors, perceptions of user visual comfort and work productivity to present the data obtained and varied information. The variables that will be used can be seen in Table 1.

Table 1. Research variables

Parameter	Variable	Indicator	Method
Natural Lighting	Time condition	Morning Afternoon Afternoon	*Skechup, Virtual reality (VR) and Questionnaire*
	Window Opening (WWR)	WWR 50%	
Space Elements	Material	Ceramic Floor Plain Wall Gypsum Ceiling	
	Color	Neutral, Cool and Warm	
Visual Comfort	Perceived Visual comfort	Color Characteristics Texture Proportion Atmosphere Lighting Effect	
Productivity	Aspects of Work Productivity	Brainstorming Critical Thinking 3D Designing Level of Focus Team Collaboration	

Space component elements refer to physical components such as floors, walls, and ceilings. The arrangement of interior spatial material components is essential to see the visual comfort conditions in the workspace.

The simulation test model looks at the lighting conditions in the architecture studio workspace where the room is designed with 3 types of color and arrangement of the architecture studio workspace, namely: neutral color (white), excellent color (blue), and warm color (orange). With window openings of 50%, the conditions of light entry are at 08.00, 12.00, and 16.00. It can be seen in the picture below as follows.

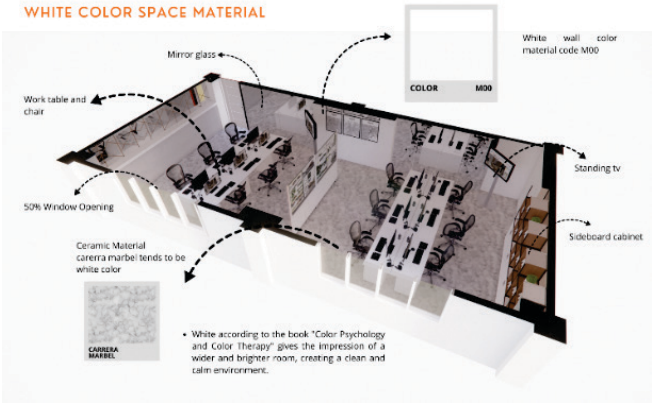

Fig 1. Layout of white color space components

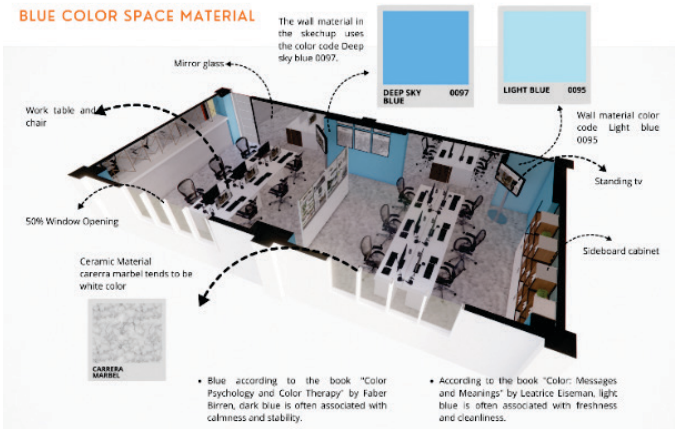

Fig 2. Layout of white blue color space components

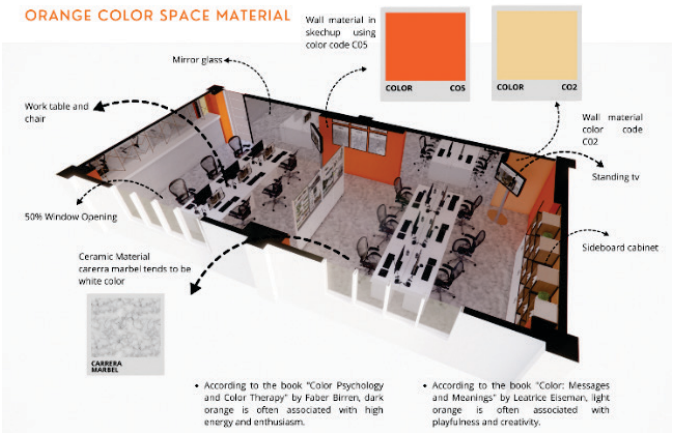

Fig 3. Layout of Orange Color Space Components

2.2 Questionnaire completion procedure

The questionnaire procedure instructions for simulating virtual reality in the architecture studio workspace, are as follows:

- In the simulation experiment, we will evaluate the feeling of visual comfort of the workspace user by using the HMD device (Gear VR).

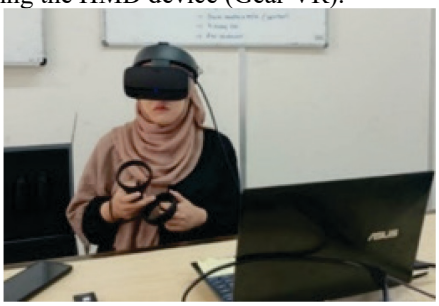

Fig 4. Virtual Reality (VR) Simulation Experiment

- This experimental test contains 3 samples of white, blue and orange colors with the interior arrangement of an architectural studio workspace displayed to the subject a visual reality simulation system called D-vision. The following workspace Interiors that will be used can be seen in Table 2.

Table 2. Workspace Interior Based on White, Blue and Orange Colors

	Natural Lighting Entry Condition		
	08.00 AM	**12.00 AM**	**16.00 AM**
Window Opening (WWR) 50%	 **Object A:** • Neutral Color Wall	 **Object A:** • Neutral Color Wall	 **Object A:** • Neutral Color Wall
	 **Object B:** • Cold Color Wall	 **Object B:** • Cold Color Wall	 **Object B:** • Cold Color Wall
	 **Object C:** • Warm Color Wall	 **Object C:** • Warm Color Wall	 **Object C:** 50% opening • Warm Color Wall

- The simulation system will be connected to the leptop using an HDMI projector, which consists of a flat and cylindrical screen, with a wide field of view (360 degrees horizontally and vertically).

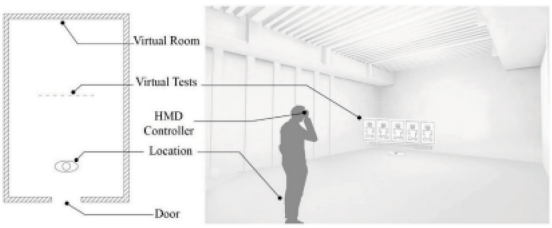

Fig 5. Virtual Room Layout

- There are 12 respondents in this experiment using architecture master's students and architecture bureau consultants, who will to various experimental conditions on the visual comfort atmosphere of the architecture studio workspace and user perceptions of color.
- The experiment started with a sample architecture studio workspace displayed for 5 - 10 seconds.

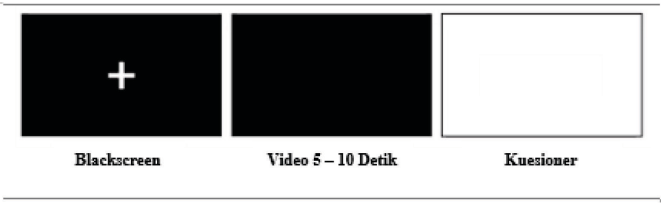

Fig 6. Virtual Reality (VR) Experiment Transition

- The motion of the image projected on the screen will be synchronized with the subject's steps on a pressure sensor (stepping interface) mounted in front of the screen.
- The experiment was conducted in a seated position.
- After conducting experiments using the HMD device (Gear VR) participants will be given a questionnaire to provide their responses to the architecture studio workspace as a visual comfort in increasing user work productivity.

This research questionnaire focuses on visual comfort to determine how lighting and interior design factors affect user perceptions of work productivity. Characterization of visual comfort aspects in the architecture studio workspace was carried out using a 5-point semantic differential scale assessment (1 No, Very Little to Very Much 5) to measure the level of visual comfort. The data obtained were then analyzed using the SPPS (Statistical Package for the Social Sciences) application to see a comparison of the measurement results of user responses to the gap in the three colors of the architecture studio workspace which are considered the most ideal that space users like according to their needs to provide a level of satisfaction with work productivity that improves user health and well-being. The following questionnaire questions that will be used in the study can be seen in Tables 3 and 4.

Table 3. Visual Aspect Questionnaire for User Perception

Visual Aspects	Semantic Differential Questionnaire						
	Measurement Scale/Value						
		1	2	3	4	5	
Color Charasteristics	Warm	○	○	○	○	○	Cold
Texture	Smooth	○	○	○	○	○	Rough
Proportion	Wide	○	○	○	○	○	Narrow
Ambience	Off	○	○	○	○	○	Life
Lighting Effect	Dim	○	○	○	○	○	Bright

Table 4. Wall Color Questionnaire Affects Work Productivity

No	Description Of Research Question	Measurement Scale/Value				
		1	2	3	4	5
1	Does the studio space support brainstorming skills?	Not Supportive - Strongly Supportive				
2	Does the studio space support critical thinking skills?	Not Supportive - Strongly Supportive				
3	Does the studio space support 3d design skills?	Not Supportive - Strongly Supportive				
4	Does the studio space support your focus level?	Not Supportive - Strongly Supportive				
5	Does the studio space support your team collaboration?	Not Supportive - Strongly Supportive				

3 Results and Discussion

Visual comfort of the workspace is strongly influenced by wall color, texture, proportion, atmosphere and lighting because it can affect mood, productivity, and health. The following are the results of the discussion of visual comfort based on the perception of space users as follows:

3.1 Visual comfort to user perception of neutral color (white)

The results of the analysis of visual comfort in neutral colors (white) against the user's perception of the architecture studio workspace are as follows:

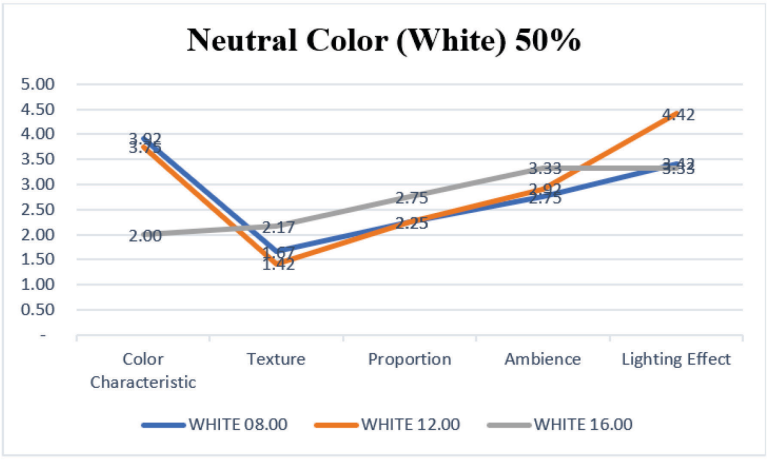

Fig. 7 Visual comfort of neutral color (white) at 08.00, 12.00 and 16.00 hours

White at 08.00
One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
Color Charasteristics	15.070	11	.000	3.91667	3.3446	4.4887
Texture	11.726	11	.000	1.66667	1.3538	1.9795
Proportion	10.340	11	.000	2.25000	1.7711	2.7289
Ambience	8.370	11	.000	2.75000	2.0268	3.4732
Lighting Effect	7.566	11	.000	3.41667	2.4228	4.4106

White at 12.00
One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
Color Charasteristics	10.085	11	.000	3.75000	2.9316	4.5684
Texture	9.530	11	.000	1.41667	1.0895	1.7438
Proportion	7.386	11	.000	2.25000	1.5795	2.9205
Ambience	9.324	11	.000	2.91667	2.2282	3.6052
Lighting Effect	15.358	11	.000	4.41667	3.7837	5.0496

White pm 16.00
One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
Color Charasteristics	7.266	11	.000	2.00000	1.3942	2.6058
Texture	6.734	11	.000	2.16667	1.4585	2.8749
Proportion	9.869	11	.000	2.75000	2.1367	3.3633
Ambience	10.761	11	.000	3.33333	2.6515	4.0151
Lighting Effect	10.000	11	.000	3.33333	2.5997	4.0670

It can be seen in the graphic image above shows:

- Morning visual comfort shows that the white wall color tends to be cold with an average value of 3.92, the texture of the space tends to be smooth with an average value of 1.68, the proportion of space tends to be wide with an average value of 2.25, the atmosphere of the space tends to be dead with an average value of 2.75, and the lighting entering the room tends to be bright with an average value of 3.45.
- During the day, visual comfort shows that the white wall color tends to be cold with an average value of 3.75, the texture of the space tends to be smooth with an average value of 1.42, the proportion of space tends to be wide with an average value of 2.25, the atmosphere of the space tends to be alive with an average value of 2.92 and the lighting entering the room tends to be bright 4.42.
- While the afternoon visual comfort shows changes in white color tends to be warm with an average value of 2.00, the texture of the space tends to be smooth with an average

value of 2.17, the proportion of space tends to be wide with an average value of 2.75, the atmosphere of the space tends to be alive with an average value of 3.33 and the lighting entering the room tends to be bright with an average value of 3.33.

Therefore, white provides good visual comfort throughout the day, from morning to afternoon and evening. Although the afternoon lighting dims, the incoming afternoon light is still sufficient.

3.2 Visual comfort against user perception of cold color (blue)

The results of the analysis of visual comfort in cold colors (blue) against the user's perception of the architecture studio workspace are as follows:

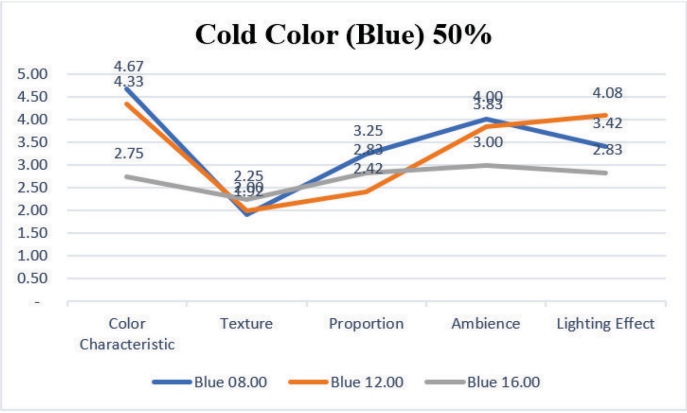

Fig 8. Visual comfort of cold color (blue) at 08.00, 12.00 and 16.00 hours

Blue am 08.00
One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
Color Charasteristics	32.833	11	.000	4.66667	4.3538	4.9795
Texture	6.665	11	.000	1.91667	1.2837	2.5496
Proportion	10.668	11	.000	3.25000	2.5795	3.9205
Ambience	18.762	11	.000	4.00000	3.5307	4.4693
Lighting Effect	9.025	11	.000	3.41667	2.5835	4.2499

Blue am 12.00
One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
Color Charasteristics	16.912	11	.000	4.33333	3.7694	4.8973
Texture	6.141	11	.000	2.00000	1.2832	2.7168
Proportion	8.403	11	.000	2.41667	1.7837	3.0496
Ambience	18.501	11	.000	3.83333	3.3773	4.2894
Lighting Effect	15.711	11	.000	4.08333	3.5113	4.6554

Blue pm 16.00

One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
Color Charasteristics	7.021	11	.000	2.75000	1.8879	3.6121
Texture	6.413	11	.000	2.25000	1.4778	3.0222
Proportion	8.805	11	.000	2.83333	2.1251	3.5415
Ambience	7.036	11	.000	3.00000	2.0615	3.9385
Lighting Effect	8.805	11	.000	2.83333	2.1251	3.5415

It can be seen in graphic image above shows:

- Morning visual comfort shows that the blue wall color tends to be cold with an average value of 4.67, the texture of the space tends to be smooth with an average value of 1.97, the proportion of space tends to be narrow with an average value of 3.25, the atmosphere of the space tends to be alive with an average value of 4.00 and the lighting entering the room tends to be bright with an average value of 3.42.
- During the day, visual comfort shows that the blue wall color tends to be cold with an average value of 4.33, the texture of the space tends to be smooth with an average value of 2.00, the proportion of space tends to be wide with an average value of 2.42, the atmosphere of the space tends to be alive with an average value of 3.83 and the lighting that enters the room is more likely to be bright with an average value of 4.08.
- While the afternoon visual comfort shows a change in blue color tends to be warm with an average value of 2.75, the texture of the space tends to be smooth with an average value of 2.25, the proportion of space tends to be wide with an average value of 2.83, the atmosphere of the space tends to die with an average value of 3.00 and the lighting entering the room tends to be dim with an average value of 2.83.

Therefore, the excellent blue color provides good visual comfort in the morning and afternoon, especially with the proportion of space and lively atmosphere. However, in the afternoon, it experiences discoloration and sub-optimal lighting that can reduce visual comfort.

3.3 Visual comfort against user perception of warm color (orange)

The results of the analysis of visual comfort in warm colors (orange) on the perception of users of the architecture studio workspace are as follows:

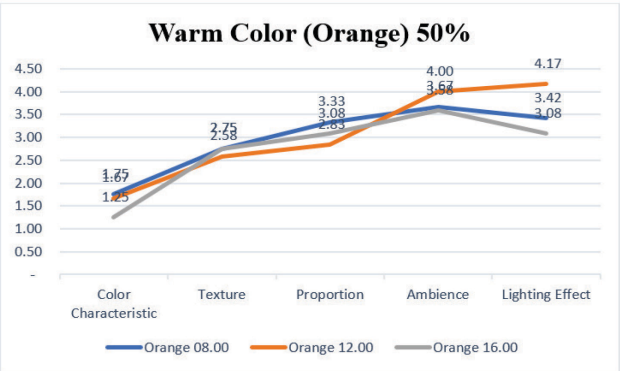

Fig 9. Visual comfort of warm color (orange) at 08.00, 12.00 and 16.00 hours

Orange am 08.00
One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
Color Charasteristics	7.000	11	.000	1.75000	1.1998	2.3002
Texture	7.396	11	.000	2.75000	1.9316	3.5684
Proportion	10.000	11	.000	3.33333	2.5997	4.0670
Ambience	12.899	11	.000	3.66667	3.0410	4.2923
Lighting Effect	10.922	11	.000	3.41667	2.7282	4.1052

Orange am 12.00
One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
Color Charasteristics	8.864	11	.000	1.66667	1.2528	2.0805
Texture	8.983	11	.000	2.58333	1.9504	3.2163
Proportion	10.470	11	.000	2.83333	2.2377	3.4290
Ambience	18.762	11	.000	4.00000	3.5307	4.4693
Lighting Effect	25.000	11	.000	4.16667	3.7998	4.5335

Orange pm 16.00
One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
Color Charasteristics	6.966	11	.000	1.25000	.8551	1.6449
Texture	6.698	11	.000	2.75000	1.8464	3.6536
Proportion	8.613	11	.000	3.08333	2.2954	3.8713
Ambience	11.455	11	.000	3.58333	2.8948	4.2718
Lighting Effect	11.863	11	.000	3.08333	2.5113	3.6554

It can be seen in the graphic image above shows:

- Morning visual comfort shows that the orange wall color tends to be warm with an average value of 1.75, the texture of the space tends to be smooth with an average value of 2.75, the proportion of space tends to be narrow with an average value of 3.33, the atmosphere of the space tends to be lively with an average value of 3.67 and the lighting entering the room tends to be bright with an average value of 3.42.
- During the day, visual comfort shows that the orange wall color tends to be warm with an average value of 1.67, the texture of the space tends to be smooth with an average value of 2.58, the proportion of space tends to be wide with an average value of 2.83, the atmosphere of the space tends to be alive with an average value of 4.00 and the lighting entering the room tends to be bright with an average value of 4.17.
- While in the afternoon, visual comfort shows that the orange wall color tends to be warm with an average value of 1.25, the texture of the space tends to be smooth with an average value of 2.75, the proportion of space tends to be wide with an average value of 3.08, the atmosphere of the space tends to be alive with an average value of 3.58 and the lighting entering the room tends to be bright with an average value of 3.08.

Overall, the color provides good visual comfort throughout the day, both in the morning, afternoon, and evening. It creates a lively and energetic atmosphere, supporting dynamic activities and interactions at various times.

According to Odabaşıoğlu Seden [13] visual aspects include various elements that affect how users see and feel space such as the characteristics of color, texture, proportion, atmosphere, and lighting effects. The findings of visual comfort on user perception indicate that white and orange colors provide bright and optimal visual comfort in the morning, afternoon, and evening. At the same time, the blue color allows for bright and optimal visual comfort in the morning and afternoon. However, in the afternoon, it will experience changes that can reduce user visual comfort. Of the 12 respondents involved, the results have been statistically tested using SPSS and proven valid. The use of daylighting in workspaces can increase visual comfort and productivity while reducing artificial energy consumption, thus supporting sustainable practices[14].

3.4 Wall color affects work productivity

The wall color in the workspace significantly influences work productivity, as color can affect mood, energy levels, and the ability to focus [9]. The following discussion results regarding wall color can affect work productivity as follows:

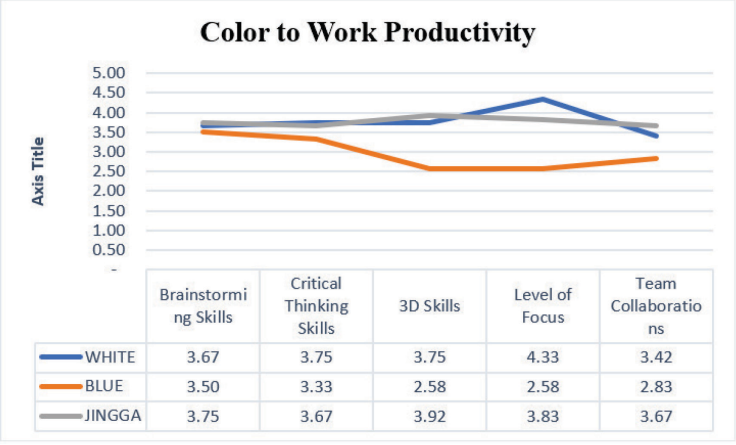

Fig 10. Work Productivity Against White, Blue and Orange Wall Colors

White

One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
Brainstorming Skills	9.750	11	.000	3,66667	2.8390	4.4943
Critical Thinking Skills	12.310	11	.000	3,75000	3.0795	4.4205
3D Skills	12.310	11	.000	3,75000	3.0795	4.4205
Level of Focus	23.047	11	.000	4,33333	3.9195	4.7472
Team Collaborations	10.922	11	.000	3,41667	2.7282	4.1052

Blue

One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
Brainstorming Skills	11.153	11	.000	3,50000	2.8093	4.1907
Critical Thinking Skills	10.000	11	.000	3,33333	2.5997	4.0670
3D Skills	8.258	11	.000	2,58333	1.8948	3.2718
Level of Focus	11.285	11	.000	2,58333	2.0795	3.0872
Team Collaborations	9.530	11	.000	2,83333	2.1790	3.4877

Orange

One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
Brainstorming Skills	17.234	11	.000	3,75000	3.2711	4.2289
Critical Thinking Skills	16.316	11	.000	3,66667	3.1720	4.1613
3D Skills	11.651	11	.000	3,91667	3.1768	4.6566
Level of Focus	14.165	11	.000	3,83333	3.2377	4.4290
Team Collaborations	12.899	11	.000	3,66667	3.0410	4.2923

It can be seen in the graph above:

- Work productivity against white wall color for brainstorming ability tends to be supportive with a mean score of 3.66, critical thinking tends to be supportive with a mean score of 3.75, 3D ability tends to be supportive with a mean score of 3.75, level of focus tends to be supportive with a mean score of 4.33 and level of team collaboration tends to be supportive with a mean score of 3.41.
- Work productivity towards cold color (blue) for brainstorming ability tends to be supportive with an average score of 3.50, critical thinking tends to be supportive with an average score of 3.33. However, 3D skills tend to be unfavorable with a mean score of 2.58, focus level tends to be unfavorable with a mean score of 2.58 and team collaboration tends to be unfavorable with a mean score of 2.83.
- Work productivity towards warm colors (orange) for brainstorming ability tends to be supportive with a mean score of 3.75, critical thinking tends to be supportive with a mean score of 3.66, 3D ability tends to be supportive with a mean score of 3.91, level of focus tends to be supportive with a mean score of 3.83 and level of team collaboration tends to be supportive with a mean score of 3.66.

Work productivity, according to Allen and Iano [15], in architectural firms can consider several factors that affect their design performance. The aspects of productivity that must be regarded are brainstorming skills, critical thinking, 3D design, focus, and team collaboration to identify the best strategies to improve efficiency and performance [15]. The results of the discussion of wall colors that can affect user work productivity in the architecture studio workspace show that white and orange colors tend to be preferred by users in supporting brainstorming, critical thinking, 3D skills, focus level, and team collaboration. Meanwhile, the blue color tends to be moderately preferred by users in supporting brainstorming and critical

thinking. However, the blue color tends to be less supportive of 3D design skills, focus level, and team collaboration. Of the 12 respondents involved, the results have been statistically tested using SPSS and found to be valid.

Based on the theory of color psychology, choosing the right colors can improve the concentration, creativity, and well-being of employees and increase productivity [16]. In addition, the use of eco-friendly colors and materials in interior design can support sustainability efforts by reducing energy consumption and negative environmental impacts. According to Michael Toole' [17] applying sustainability principles in material selection and color design, workspaces can support environmental and health goal. The integration of color and sustainability in interior design is an effective strategy for creating a productive and environmentally friendly work environment.

4 Conclusion

Based on the results of the study show that user perceptions of visual comfort on wall colors show that white and orange colors tend to be preferred because they provide good visual comfort throughout the day, both morning, noon, and evening. In contrast, blue colors provide good visual comfort in the morning to noon, however, in the afternoon, color changes and lighting begin to dim so that it is less optimal and can interfere with visual comfort.
Work productivity against wall color shows that white and orange support all aspects of work productivity, including brainstorming, critical thinking, 3D skills, focus, and team collaboration. Meanwhile, the blue color supports brainstorming and critical thinking but less optimal for aspects of 3D skills, focus, and team collaboration.

Therefore, this research shows that daylighting plays an important role in creating a comfortable visual environment through the selection of the right wall color, as it is able to provide optimal lighting intensity. Interior design that maximizes daylighting in studio spaces not only improves the health and well-being of users, but also significantly increases work productivity and the sustainable quality of design outputs. In addition, the use of bright wall colors is proven to make a positive contribution to visual comfort, which has an impact on improving user productivity and health [19].

5 Recommendation

Neutral wall colors such as white and orange are recommended to create an optimal architecture studio workspace. Natural lighting should be maximized in the morning and afternoon, while adjustable artificial lighting is needed to cope with light changes in the afternoon. A lively space atmosphere with decorative elements strongly supports visual comfort that can improve users' productivity, health, and well-being.

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