Lighting Dynamics for Emotional Perception: A Technology-Driven Virtual Simulation Approach

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ABSTRACT

This research examines the effects of light color (Light Color), light intensity (Intensity), and time (Time) on emotional responses through a simulation created with the Unreal Engine. The controlled experiment carried out included 162 participants, the emotional perception of whom was assessed following scenarios with differing lighting conditions. The two-way ANOVA results revealed the significant influence of Light Color, Intensity, and Time ($p < 0.001$), along with that of the Light Color-Intensity and Intensity-Time interactions on human perception. The fuzzy logic examinations demonstrated that warm, low-intensity lighting during the day yields the highest perception score (7.8), while cold (cool), high-intensity lighting at night produces the lowest (3.6). The predictive regression model achieved a good accuracy ($R^2 = 0.96$), showing that the ideal lighting combination improves emotional experience. This research provides novel perspectives on dynamic lighting design for cinematography, gaming, and immersive media. However, further research is required to scale these findings on a wider population and diverse spatial environments.

Keywords-emotional perception; lighting design; virtual environments; unreal engine

I. INTRODUCTION

Lighting is a fundamental element in visual design and cinematography that affects the emotional and psychological state of the audience [1]. In a virtual environment generated using technologies, such as game engines or Virtual Reality (VR)-based simulations, lighting settings have a high flexibility degree so that they can be manipulated to dynamically support visual narratives [2]. Lighting aspects, involving Light Color, Intensity, and Time can be customized to create a deeply immersive experience, rendering them a key component in the development of modern visual content, including virtual cinematography content.

Previous studies have displayed a significant relationship between lighting parameters and human emotions [3, 4]. Warm light, such as orange and red, is often associated with comfort and happiness, while Cool or cold light, like blue, evokes feelings of loneliness or tension. On the other hand, Intensity is known to either enhance or weaken perception; Low Intensity creates a calmer atmosphere, while High Intensity tends to increase tension [5]. Related research has examined how lighting affects emotions, but it frequently focuses on one or two parameters, such as Light Color or Intensity, without investigating their intricate relationships. A few lighting studies have included changeable Time components, like day and night influence on outer environment circumstances, as major variables, even though they affect how viewers interpret emotions in specific scenarios [6]. In [7], it was found that nighttime lighting plays an important role in enhancing the sense of security, indicating that Time factors influence the preferences of viewers or users.

Unreal Engine, a type of game engine technology, has enabled the creation of realistic and adaptive virtual scenes, with real-time dynamic lighting settings that can be utilized as realistic experimental tools [8-10]. Research has demonstrated that the Unreal Engine can be used as a valid lighting design tool, with results comparable to those of a specialized software, like DIALux evo, and physical measurements equivalent to the ones performed in building lighting planning [11, 12]. Technology-driven methods, encountered in blockchain-based landslip mitigation systems, indicate efficacy in real-time environmental data processing and transparent decision-making [13]. However various lighting compositions with user perception in a virtual environment were not integrated. The current study examines how the combination of Light Color, Intensity, and Time can affect virtual emotional responses. The Unreal Engine is deployed to experiment with these three parameters in an immersive virtual environment. ANOVA and fuzzy logic are also utilized to assess virtual lighting emotional perception, as in [14]. Fuzzy logic is employed because the human perception of lighting is generally a continuous spectrum with considerable uncertainty. People may perceive illumination as "fairly comfortable" or "a bit too bright," which is difficult to classify using statistical methods [15]. Since fuzzy inference systems may connect lighting characteristics (Light Color, Intensity, and Time) to emotional perception scores more easily, they can better explore users' subjective experiences in virtual environments. In addition, the present research aims to contribute to the enhancement of virtual cinematography and technology-driven immersive experiences.

The influence of lighting on perception has been investigated in various contexts. Authors in [6, 16-18] indicated that Light Color affects emotional perception. That is, Warm light tends to enhance positive feelings, such as comfort, while Cool light often triggers negative emotions, like tension. Although the importance of selecting Light Colors in space design was highlighted, their effects or interactions in virtual environments were not explored. Authors in [19] found that Intensity affects the levels of comfort and tension experienced. Low Intensity is more often associated with tranquillity, whereas High Intensity creates a more intense atmosphere. However, this research is limited to the physical environment, and has not explored the virtual context. Authors in [20] showed that the VR environment is closer to physical lighting compared to videos and photos. In [21, 22], VR technology was combined with a hands-on educational approach to support stage lighting learning in the metaverse. Authors in [23] developed and evaluated a VR system named Metashadow, which offers an innovative solution to overcome the limitations of physical soundstages in cinematography lighting education. It was concluded that the empirical results or studies on the real environment can influence the virtual environment or vice versa. This is in line with the theory developed in [24], according to which, there are four categories regarding the relationship between the physical and digital environment, or vice versa, referred to as the digital twin. In the medical field, VR can help understand user perceptions of digital architecture environments in stroke rehabilitation design and healthcare facilities [25]. The current study promotes VR technology utilization by investigating how lighting characteristics affect the emotional experience in virtual cinematography. Most lighting studies have focused on one or two characteristics, neglecting the complex correlations between Color, Intensity, and Time. The current research focuses on physical environments, while virtual environment studies are mostly indoor simulations. The ways Color, Intensity, and Time affect perception in Unreal Engine-based virtual simulations are studied. The findings provide virtual cinematography designers with ways to improve the scene's emotional impact and efficacy.

II. RESEARCH METHODOLOGY

The present research deploys an experimental quantitative method, where the Light Color, Intensity, and Time (day/night) are set as independent variables, while the respondents' perception of the drama scene constitutes the dependent variable. This research was conducted in a virtual environment, built for the drama set, with Non-Player Characters (NPCs), lighting composition using specific parameters, and filming techniques adhering to cinematographic principles. The NPCs and environmental assets were designed utilizing Blender 3D and were integrated into the Unreal Engine. The lighting parameter employed was the Light Color, including Warm color (orange), Neutral color (white), and Cool color (blue). This light hue is used in 3-point lighting with a singular color type. The three light sources utilized a singular color type, as the combination of colors from each source might have led to mixing, particularly in daylight, complicating the discernment of their effects.

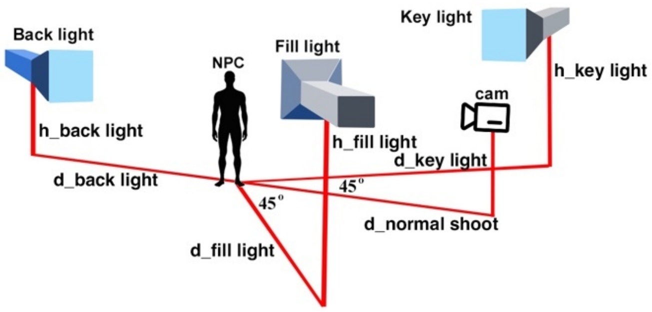

Fig. 1. 3-Point lighting layout scheme.

As shown in Figure 1, where the 3-point lighting layout is implemented in the Unreal Engine virtual environment, the NPC actor is surrounded by the key light, fill light, and back light, with the lighting heights (h) being equal to each other, and the distance (d) of the lighting from the actor also being equal. The lighting distance (d) and height (h) in each scene are dynamically adjusted considering the visualization on the camera recording the scene, while the principle of Intensity adjustment is based on the ideal exposure range of the actor's shadow. The camera shooting technique is adjusted according to the shoot type, namely normal shoot or long shoot, and the camera configuration and illumination setup align with the concepts presented in [26, 27]. The daytime condition of the scene is recorded with a layout of directional light or sunlight positioned parallel to the key light or camera. However, for the dark nighttime condition, the lighting layout becomes more dynamic by being adjusted to the exposure quality of the actor's recorded image.

The utilized Intensity is categorized into Low with a range of 1-5 cd, Medium with a range of 6-10 cd, and High with a range of 11-20 cd. The illumination from the three lighting configurations is depicted using RGB values in decimal format through Unreal Engine, resulting in a Warm or orange tone (R: 0.98, G: 0.78, B: 0.31), a Neutral or white tone (R: 1.0, G: 1.0, B: 1.0), and a Cool or blue tone (R: 0.588, G: 0.784, B: 0.980). The lighting conditions are based on the Time used, day and night, in an outdoor setting. For daytime conditions, a directional light is utilized with the criteria of: Intensity 20,000 lux, Light Color 6500K, skylight feature activation with an Intensity value of 3, sky atmosphere feature activation with an aerosol density of 0.1, exposure compensation of 1.2, and dynamic global illumination feature activation. In nighttime conditions, the directional light was activated to simulate moonlight with an Intensity of 500 lux and a Light Color of 4500K. The skylight feature was activated with an Intensity of 1, a sky atmosphere aerosol density of 0.01, an exposure compensation of 0.5, while the global illumination feature was also activated.

The study included 162 design majors who had completed the videography course. In this study, respondents used the Oculus Quest 2 HMD VR to watch scenarios. NPCs executed the scenarios, which were illuminated using the Intensity, Light Color, and Time variables that varied in every scene. The latter involved: a favorite tourist area representing happiness, an earthquake scene at a tourist destination representing tension, a damaged tourist spot representing sadness, and a repaired tourist spot representing tranquility. After having seen each scene, the respondents filled out a Likert scale-based questionnaire to rate their happiness, sadness, tension, and calmness. The questionnaire covered visual perceptions and lighting impact on narrative interpretation.

III. RESULTS AND DISCUSSION

The mean score of the respondents' evaluation was 5.368, accompanied by a standard deviation of 1.169. Respondents were assigned the lowest rating score of 3 and the highest rating score of 8. According to the results, the respondents showed a preference for happy scenes with bright and Warm lighting, as displayed in Figure 2(a), while sadness peaked in the Cool light, Low Intensity, and nighttime, as portrayed in Figure 2(b), in accordance with the melancholic atmosphere produced. Meanwhile, the highest tension atmosphere was observed under Neutral light, High Intensity, and nighttime, as depicted in Figure 2(c), while the calm atmosphere peaked under Warm light, Low Intensity, and daytime, as shown in Figure 2(d). The ANOVA test results, outlined in Table I, demonstrate that each of the examined variables had significant effects on perception scores ($p < 0.001$).

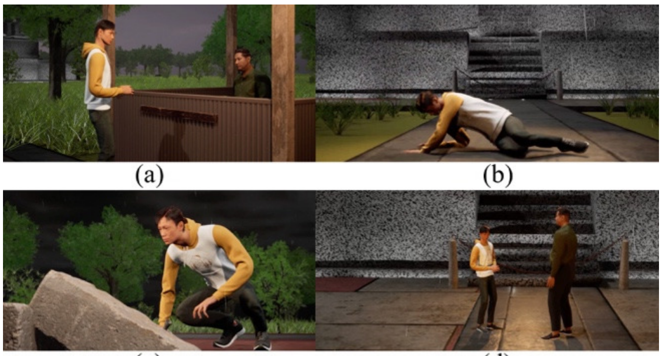
(a) (b) (c) (d)

Fig. 2. Scene and lighting combinations conveying a mood of: (a) happiness, (b) sadness, (c) tension, and (d) calmness.

TABLE I. ANOVA RESULTS

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	25	95.7349	3.8294	134.11	0.000
Linear	8	93.2882	11.6610	408.38	0.000
Mood	3	0.1045	0.0348	1.22	0.313
Light Color	2	47.1435	23.5718	825.51	0.000
Intensity	2	36.4854	18.2427	638.88	0.000
Time	1	9.5548	9.5548	334.62	0.000
2-Way Interactions	17	2.4467	0.1439	5.04	0.000
Mood-Light_Color	6	0.0988	0.0165	0.58	0.747
Mood-Time	3	0.1618	0.0539	1.89	0.145
Light_Color-Intensity	4	1.4559	0.3640	12.75	0.000
Light_Color-Time	2	0.1936	0.0968	3.39	0.042
Intensity-Time	2	0.5365	0.2683	9.39	0.000
Error	46	1.3135	0.0286		
Total	71	97.0484			

The two-way interaction exhibits that the Light Color-Intensity and Light Color-Time combinations had a significant impact on perception, since Time strengthens the effect of certain Light Colors. Similarly, the influence of Intensity-Time was equivalently important, denoting that the Intensity impact varies at different Times. Thus, the Light Color, Intensity, and Time combinations had a relatively strong effect on perception. In contrast, mood had minimal influence on audience perception. This conclusion empirically proves that various aspects contribute to shaping audience perception. As illustrated in Figure 3(a), respondent perceptions are consistent at Low and Medium Intensity when the Light Color is Cool and Neutral. Respondent perception scores are greater when the Light Color is Warm and with Low Intensity. Figure 3(b) presents the Intensity-Time data. As can be seen, respondents rated Low Intensity during daytime higher, while High Intensity at night obtained the lowest rating. As displayed in Figure 3(c), daytime and Warm light provided the most perceptual information.

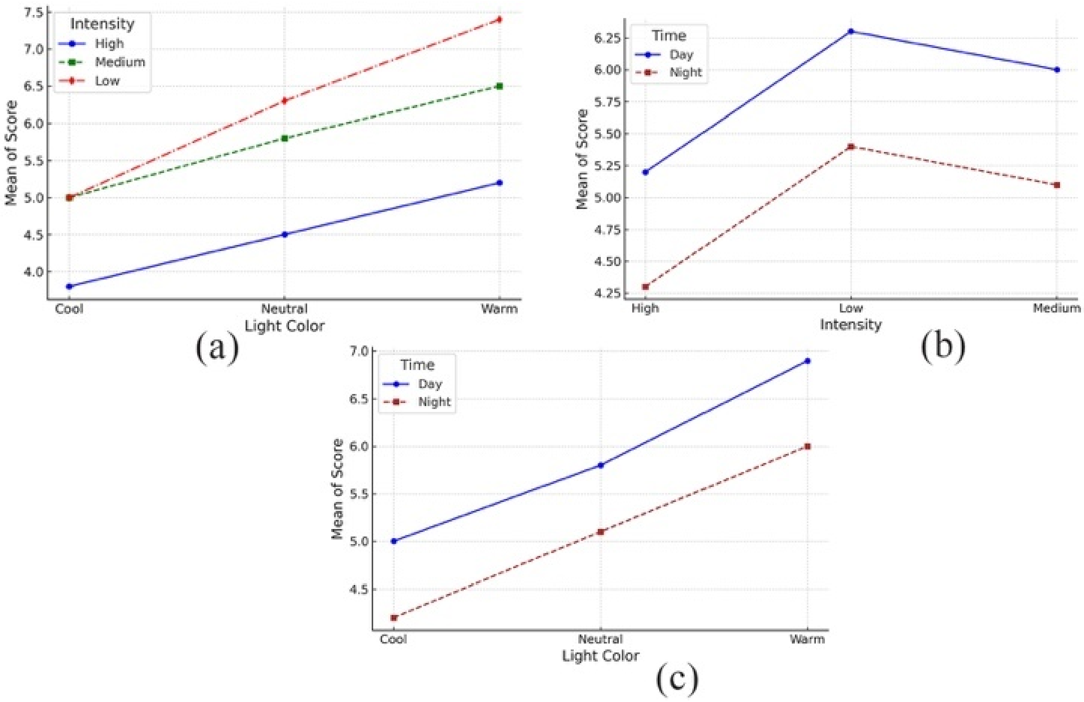

Fig. 3. Graph interaction plot for: (a) intensity-time, (b) light color-intensity, and (c) light color-time.

Based on the linear regression analysis results using the three-way ANOVA data, a linear regression equation was created:

$$YScore=3.8301+0.7780(Light\_Color\_Neutral)+1.9678(Light\_Color\_Warm)+1.6525(Intensity\_Low)+1.3082(Intensity\_Medium)-0.7286(Time\_Night) \quad (1)$$

Equation (1) shows how the Light Color, Intensity, and Time variables predictively affect the Y perception score. The intercept (3.8301) is the baseline score for Cool light, High Intensity, and daytime. If the Light Color changes to Neutral, the score increases by 0.778, and if it becomes Warm, the score increases even more, that is, by 1.967. This indicates that Warm Light Color has the highest positive impact on perception. In terms of Intensity, Low Intensity provided a score increase of 1.652 compared to High Intensity, while Moderate Intensity increased the score by 1.308. This indicates that Low Intensity tends to support a more positive perception. However, nighttime reduced the perception score by 0.7286 compared to daytime, exhibiting that daytime was more conducive to a better perception. Overall, the combination of Warm Light Colors, Low Intensity, and daytime resulted in the highest perception scores, indicating that the proposed model had optimal performance (R-squared = 0.960). So, it can be used to predict perception scores based on the investigated variables' combination in applications that prioritize perception enhancement, such as environmental design and cinematography.

This study's fuzzy inference system entails three input and one output variables. The input variables are: Light Color, grouped into Warm (orange), Neutral (white), and Cool (blue); Light intensity, categorized into Low (1–5 cd), Medium (6–10 cd), and High (11–20 cd); and Time, classified into day (20,000 lux daytime lighting simulation) and night (500 lux nighttime lighting). The output variable is the perception score, which is categorized as Low (3–4), Medium (5–6), or High (7–8). Fuzzy representation triangle functions are deployed to build the membership function. The membership range is altered based on the experimental data to reflect the actual conditions. The membership function for Light Colors is orange for Warm, white for Neutral, and blue for Cool. Three Intensity levels are available: 1–5 cd for Low, 6–10 for Medium, and 11–20 for High. Daytime and nighttime define Time. The Likert scale perception scores range from 3 to 8, with membership functions indicating the Low, Medium, and High categories, as shown in Figure 4. Fuzzy rules are based on experimental data linking lighting characteristics to perception scores. Examples of these rules are: If "Light Color" is "Warm", "Intensity" is "Low", and "Time" is "Day", "perception Score" is "High". If "Light Color" is "Cool", "Intensity" is "High", and "Time" is "Night", "perception Score" is "Low". If "Light Color" is "Neutral", "Intensity" is "Medium", and "Time" is "Day", "perception Score" is "Medium".

The Max-Min Composition activates the fuzzy rules by their minimal premise value. The fuzzy output value is calculated using all criteria by the maximum technique. This study weights fuzzy values by discourse universe membership and position using the weighted average/centroid. Lighting arrangements determine defuzzification's perceptual score. Table II demonstrates that Warm Light Color, Low Intensity, and midday light have the highest perception score of 7.8. The minimum score is 3.6 for Cool Light Color, High Intensity, and night, while Neutral Light Color, Medium Intensity, and day obtained a score of 5.6. A linear relationship and interaction between the components help identify the lighting characteristics' effects on perception. Warm orange with Low Intensity and daylight settings relaxes and pleases, confirming the prior findings that Warm Light Colors are comforting. Intense Cool night light causes tension. Heatmap graphs of Light Color, Intensity, and Time perception scores are depicted in Figure 5. Some main patterns included Day-Low and "Warm," which had the highest perception score (7.8), and Night-High and "Cool", which had the lowest perception score (3.2). Regardless of the situations, the "Neutral" color scored well. As evidenced in Table III, the present research is compared to illumination studies in a more systematic way, while each study's research variables, methodology, context, unique contributions, and limitations are provided.

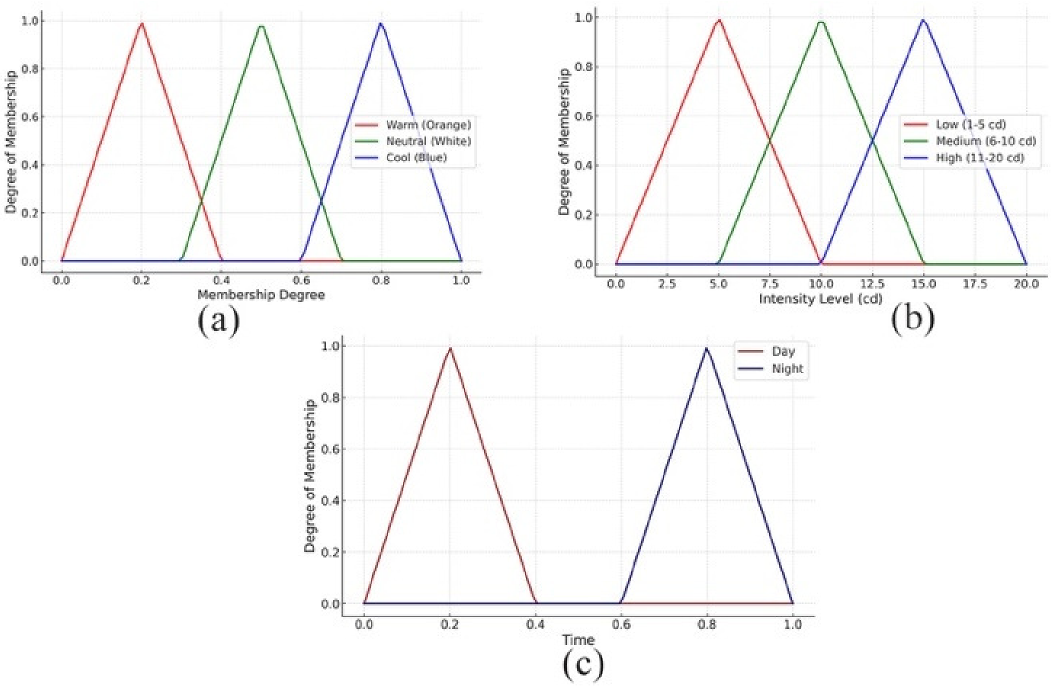

Fig. 4. Fuzzy membership function for: (a) light color, (b) intensity, and (c) time.

TABLE II. FUZZY INFERENCE RESULT

Light Color	Intensity	Time	Score(crisp)
Warm	Low	Day	7.8
Cool	High	Night	3.6
Neutral	Medium	Day	5.6

Fig. 5. Perception score heatmap.

In Table III, it is evident that the current research follows a more comprehensive approach by integrating Light Color, Intensity, and Time in a virtual environment based on Unreal Engine. On the contrary, most other studies have only examined one or two lighting parameters, without having considered their dynamic interactions. Authors in [17] studied lighting in a virtual environment but did not take into account factor interactions. Authors in [18, 19] examined the relationship between lighting and emotions but were limited to physical environments. Meanwhile, Authors in [20] compared virtual and physical lighting but did not focus on emotional effects. Authors in [2, 22, 23] placed more emphasis on the educational aspects of lighting in metaverse and cinematography. Human elements in lighting design can affect emotional perception and user experience. Understanding the relationship of Light Color, Intensity, and Time can assist in developing a better user-responsive visual experience.

TABLE III. RESULT MAPPING AND DISCUSSION

Ref.	Research variables	Methods used	Research context	Contribution	Limitations
Current	Light color, Intensity, Time, and emotional perception in the VR	Unreal Engine-based experiment with ANOVA and fuzzy logic	Virtual environments in cinematography and gaming	Integration of color, intensity, and lighting time in VR with fuzzy logic models	Does not test spatial factors and the population is limited to the design students.
[17] (2022)	Lighting and human perception in virtual environments	Qualitative analysis and experimentation in a virtual environment	Virtual Environment in general	Initial studies on the human perception of virtual lighting	Does not consider the interaction of the lighting factors
[18] (2024)	Illumination, color temperature, emotional and behavioral responses	Experiments with psychological measurements and lighting	Physical environment and user behavior	Examining how lighting affects emotions and adaptive behavior	Does not test in the context of a virtual environment
[19] (2022)	Daylight-ing design and its impact on emotional well being	A survey-based study of home-dwellers	Physical environment of the housing	Demonstrate the impact of natural lighting on psychological well- being	Did not study lighting in virtual environments
[20] (2019)	Comparison of the physical and virtual lighting	A comparative experiment between the physical and virtual lighting	Virtual and physical (comparison)	Analyze the key differences between physical and virtual lighting	Does not specifically address the emotional impact
[2] (2024)	Stage lighting education in the metaverse	Exploration of learning systems in the metaverse	Metaverse (stage and education)	Highlighting the role of lighting in metaverse education	Does not explore the emotional effects of users
[22] (2023)	Virtual cinematography and lighting effects education	Experimentation and implementation in cinematography education	Metaverse (cinematography)	Exploration of virtual cinematography and lighting effects	Focus on education, not on emotional response
[23] (2023)	Meta-shadow for cinematographic lighting in the metaverse	Meta-shadow system design and evaluation	Virtual Environment for lighting education	Development of Meta-shadow technology for lighting simulation	Does not specifically examine the emotion perception of the users

This research may act as a valuable tool for cinematographers, game designers, and virtual content designers. In specific, Warm Light Colors, Moderate Intensity, and sunshine lighting produce a good and comfortable mood, while High-Intensity lighting with Neutral Light Colors works for high-tension scenes. The predictive algorithm can also help cinematographers and game designers build emotive atmospheres in virtual spaces. The highest perception score is achieved by the warm Light Colors, Low Intensity, and daytime, creating a cozy and happy mood. Advanced VR equipment can increase accuracy and provide deep insights into immersive experiences. Future studies may examine additional aspects to improve this model's virtual cinematography applicability, while a better data-driven design is possible with this research.

IV. CONCLUSION

This study demonstrates that the combination of Light Color, Intensity, and Time significantly influences emotional experience in virtual environments created with Unreal Engine. The experiment involving 162 participants demonstrated that Warm, Low-Intensity lighting during the day yielded the highest positive perception (score 7.8), whereas Cool, High-Intensity lighting at night heightened tension and resulted in the lowest perception (score 3.6), as confirmed by the fuzzy inference system. The two-way ANOVA statistical analysis indicated that Light Color ($p < 0.001$), Intensity ($p < 0.001$), and Time ($p < 0.001$) had significant impact on emotional perception. Moreover, substantial interactions were identified among Light Color-Intensity ($p < 0.001$), Light Color-Time ($p = 0.042$), and Intensity-Time ($p < 0.001$), suggesting that the effects of lighting are dynamic and contingent upon the parameter combinations employed. The predictive regression model demonstrated good accuracy ($R^2 = 0.96$), underscoring the significance of a data-driven methodology in creating lighting that enhances emotional experiences in digital media.

These findings offer novel perspectives on dynamic lighting design for cinematography, gaming, and immersive media. This study confirms that selecting appropriate lighting combinations can improve the quality of the user experience in virtual worlds. This research employs the Unreal Engine to develop adaptive lighting conditions, thereby broadening the field of virtual lighting studies and providing practical insights for designers and content makers. Although the research findings indicate a distinct trend, this study is constrained by its demographic, which comprises design students. Therefore, further research is proposed to evaluate the generalizability of these findings across a wider population and to investigate the impact of narrative and spatial elements in virtual lighting design.

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