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QUANTITATIVE ANALYSIS OF EMOTIONAL PERCEPTION IN 3D INTERIOR ANIMATION USING CINEMATIC LIGHTING AND FUZZY LOGIC

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Abstract— *Cinematic visual aspects such as lighting, color, and camera framing play an important role in shaping emotional and narrative experiences in 3D animation. However, their translation into measurable computational emotional outputs remains limited. This study proposes a computational framework for modeling audience emotional perception in a static 3D animated environment by integrating visual hermeneutics, quantitative analysis, and fuzzy logic inference. A total of 450 animation frames from a single 3D interior setting were analyzed across three narrative phases: beginning, climax, and resolution. Qualitative shot-by-shot analysis was used to interpret the symbolic function of visual elements, while quantitative data were obtained from light intensity and color temperature measurements and an emotional perception questionnaire analyzed using repeated measures ANOVA. The results show significant differences in depression, tension, and hope across narrative phases ($p < 0.001$), corresponding to systematic changes in lighting, color, and framing. The study formalizes cinematic visual parameters as fuzzy input variables and produces a measurable emotional index through defuzzification, consistent with the ANOVA findings. The novelty of this study lies in integrating visual hermeneutics and fuzzy logic to model emotion in a static 3D environment and validate it statistically. Practically, the model can support animators and multimedia designers in planning emotion-oriented lighting strategies and evaluating visual scenes more systematically.*

Keywords: *3D Animation, Cinematic Lighting, Emotional Perception, Fuzzy Logic, Visual Hermeneutics.*

Intisari— *Aspek visual sinematik seperti pencahayaan, warna, dan framing kamera berperan penting dalam membentuk pengalaman emosional dan naratif pada animasi 3D. Namun, penerjemahan elemen-elemen tersebut ke dalam keluaran emosional komputasional yang terukur masih terbatas. Penelitian ini mengusulkan kerangka kerja komputasional untuk memodelkan persepsi emosional penonton pada lingkungan animasi 3D statis dengan mengintegrasikan hermeneutika visual, analisis kuantitatif, dan inferensi logika fuzzy. Sebanyak 450 frame animasi dari satu interior 3D dianalisis pada tiga fase naratif: awal, klimaks, dan resolusi. Analisis kualitatif per shot digunakan untuk menafsirkan fungsi simbolis elemen visual, sedangkan data kuantitatif diperoleh dari pengukuran intensitas cahaya, suhu warna, dan kuesioner persepsi emosional yang dianalisis menggunakan pengukuran berulang ANOVA. Hasil penelitian menunjukkan perbedaan signifikan pada dimensi depresi, ketegangan, dan harapan antar fase naratif ($p < 0,001$), yang sejalan dengan perubahan sistematis pada pencahayaan, warna, dan framing. Penelitian ini memformalkan parameter visual sinematik sebagai variabel input fuzzy dan menghasilkan indeks emosi terukur melalui defuzzifikasi yang konsisten dengan hasil ANOVA. Kebaruan penelitian terletak pada integrasi hermeneutika*

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visual dan logika fuzzy untuk memodelkan emosi pada lingkungan 3D statis dan memvalidasinya secara statistik. Secara praktis, model ini dapat membantu animator dan desainer multimedia dalam merancang strategi pencahayaan berorientasi emosi dan mengevaluasi adegan visual secara lebih sistematis.

Kata Kunci*: Animasi 3D, Pencahayaan Sinematik, Persepsi Emosional, Logika Fuzzy, Hermeneutika Visual.*

INTRODUCTION

Visual design in 3D animation has evolved considerably and now functions not only as an aesthetic component but also as a sophisticated narrative instrument. With advancements in visual technology, the cinematic technique in 3D animation has evolved into an emotional communication method that effectively conveys significant meanings using camera angles, color composition, and lighting. In this regard, design transcends simply visual esthetics, it constitutes a framework that influences the audience's experience and psychological perception. Contemporary animation design employs cinematic narrative to craft spatial and emotional illusions that are potent enough to change the audience's mental and emotional states. Recent studies indicate that visual framing can influence audience perception, affective reactions, and engagement, while cinematographic lighting contributes to the emotional interpretation of visual scenes [1], [2]. Together, these findings support the use of framing and lighting as important components of emotional communication in cinematic visual design.

This visual methodology necessitates that designers comprehensively grasp the relationship between visual components and the psychological responses they elicit. Recent studies of cinematographic and 3D animation aesthetics emphasize that framing, exposure, lighting, and visual style can be interpreted as meaningful narrative structures rather than merely technical image properties [3], [4]. This methodology corresponds with the interpretative paradigm in visual communication design research, wherein the audience's perception of space, light, and frame is perceived because of the interaction between the visual creator and the audience's emotional interpretation [5]. Lighting not only illuminates objects but also contributes to narrative by establishing atmospheres such as tension, grief, reflection, or hope. [6] asserted that light in animation serves as a crucial narrative instrument, capable of guiding attention, influencing the emotional aspects of characters, and infusing significance into each frame. Recent studies reinforce this perspective, showing that lighting operates as both an esthetic and psychological cue in animation. [7] found that warm and cool lighting schemes distinctly trigger affective contrasts of hope and fear in *Kubo and The Two Strings*, suggesting that cinematic illumination is a vehicle for emotional meaning rather than mere visibility. Shared cartoon stylization in CG animation is also recognized to amplify empathy through visual familiarity, creating what [8] describes as the Pixar Peak effect of emotional resonance.

The same applies to any colors. Color of movie video also plays a central role in shaping emotional interpretation [9]. In 3D animation video, specific color choices can influence character perception and narrative progression [10]. Recent experimental evidence further shows that illuminance and correlated color temperature are associated with perceptual and affective responses in virtual environments, including changes in perceived arousal and pleasure [11]. These findings reinforce the importance of color temperature as a measurable visual variable in emotion-oriented digital environment design. Simultaneously, camera movement not only captures but also organizes perspective as a mechanism for the audience to experience the character's position. Employing methods such as extreme close-up, low-angle shot, or point-of-view can profoundly alter the audience's empathy with a specific event. Visual framing and scene organization can influence audience attention, interpretation, and emotional engagement across cinematic and interactive storytelling contexts [1], [12].

Although prior studies have established that lighting, color, and framing influence mood and audience engagement in animation, three important gaps remain. First, research on lighting in animation has predominantly focused on aesthetic quality, visual storytelling, or technical rendering, but has rarely transformed cinematic lighting features into a formal computational representation of emotion. Second, studies on emotion recognition generally emphasize facial expressions, physiological signals, or multimodal human data, rather than emotion construction through environmental cinematic design in a static 3D scene. Third, fuzzy logic research in multimedia has mainly been applied to control systems, automation, and classification tasks, but its role as an interpretive-computational bridge for mapping cinematic visual configurations to emotional outcomes is still underexplored.

Based on these gaps, this study moves beyond descriptive discussion of visual atmosphere toward a measurable computational model of emotion in 3D animation. The study focuses on how cinematic variables lighting intensity, color temperature, and camera framing can be systematically interpreted, quantified, and translated into an emotional index using fuzzy inference. In this way, the research does not only explain how visual design affects emotion, but also offers a computational mechanism for representing that relationship in a form that can be analyzed and validated statistically.

Table 1. Comparison of the Proposed Framework with Related Recent Studies

Study	Main focus	Computational method	Emotional source	Validation	Limitation relative to this study
[13]	Emotion recognition from multiple faces	Fuzzy system	Facial expressions	Recognition accuracy	Does not model emotion from cinematic environments
[12]	AI-supported visual storytelling	Interactive computational storytelling	Visual narrative and character symbols	User evaluation	Does not develop a fuzzy emotional index from cinematic lighting
[14]	Cinematographic lighting of the human face	Experimental visual analysis	Facial lighting	Viewer perception	Focuses on facial illumination rather than static 3D environments
[4]	Visual aesthetics of 3D narrative animation	Aesthetic analysis	Visual style	Interpretive analysis	Does not integrate fuzzy inference and statistical validation
[15]	Lighting dynamics in virtual simulation	Quantitative virtual simulation	Lighting parameters	Statistical analysis	Does not combine hermeneutics, framing, and fuzzy emotional indexing
Proposed study	Emotional modeling in static 3D interior animation	Visual hermeneutics fuzzy inference + ANOVA	Lighting, color temperature, and framing	Statistical and computational comparison	Context-specific rule base

Source: (Research Results, 2025)

The novelty of this research lies in the integration of three previously separated research directions. Studies on cinematic lighting have primarily examined aesthetic or perceptual effects, studies on emotion recognition have mainly relied on facial or physiological signals, and fuzzy multimedia studies have commonly focused on control or classification. This study combines visual hermeneutics, measurable cinematic parameters, fuzzy emotional inference, and repeated measures ANOVA in a single framework. Its main contribution is therefore not merely the use of fuzzy logic, but the computational translation of lighting, color temperature, and framing in a static 3D narrative environment into an interpretable emotional index validated against audience perception. This method facilitates the encoding of confusing emotional qualities as quantifiable data for systematic analysis. Fuzzy logic has been used to represent uncertainty in both emotional recognition and animation-related visual control. [16] demonstrated the applicability of fuzzy inference to emotion recognition from multiple facial cues. In the more specific context of 3D animation, [17] proposed a two-stage fuzzy inference system for autonomous lighting control. Although the latter study falls outside the preferred five-year publication window, it is retained because it represents a directly relevant original method on which the present computational approach is conceptually based. Consequently, fuzzy logic offers a computational approach that adapts to the uncertainties of visual perception, aligning methodologically with the hermeneutic interpretative framework.

Fuzzy logic has demonstrated potential for transforming emotional experiences into quantifiable computational representations. Recent fuzzy-based emotion research indicates that linguistic inference can accommodate uncertainty across multiple visual cues and generate interpretable emotional classifications [13]. This property is relevant to the present study because cinematic lighting and framing also operate through overlapping rather than discrete perceptual categories. [15] further demonstrated that

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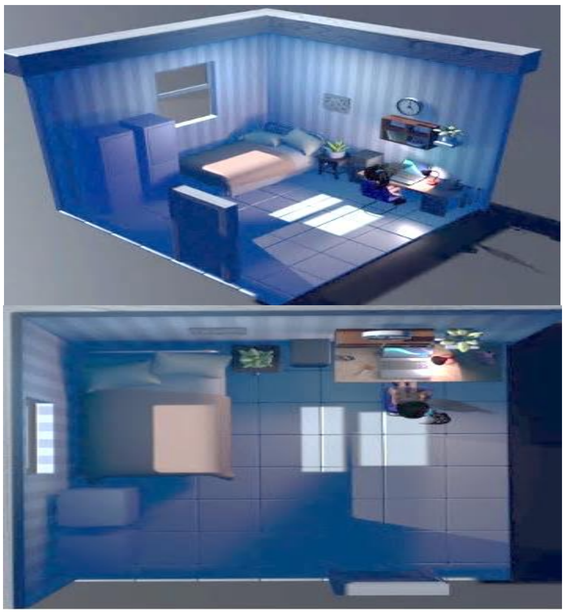
systematic changes in virtual lighting parameters can be quantitatively associated with emotional perception, supporting the use of measurable lighting variables in affective virtual-environment design. These findings align with the research conducted by [16], which verifies that fuzzy-based illuminance management is more responsive to fluctuations in natural illumination compared to traditional deterministic methods. This study proposes to include a fuzzy inference model into visual hermeneutic analysis to develop an AI-driven simulation framework that translates symbolic meaning into quantifiable data, subsequently tested statistically by ANOVA.

Despite the growing recognition that cinematic elements such as lighting, color, and framing influence audience emotion in animation, the research problem addressed in this study is that these visual elements are still rarely formulated into a measurable computational model, especially within a static 3D environment. Existing studies tend to discuss emotional effects descriptively, focus on facial or multimodal emotion recognition, or apply fuzzy logic only for technical control and automation. As a result, there remains limited evidence on how cinematic visual configurations in a static 3D animated space can be interpreted, quantified, and validated as predictors of audience emotional perception. To clarify the scientific positioning of this study, Table 1 compares the proposed framework with recent studies on fuzzy emotion recognition, cinematic visualization, lighting-based emotional perception, and 3D animation aesthetics. The comparison shows that previous studies generally focused on one of three aspects: visual interpretation, technical lighting analysis, or computational emotion recognition. In contrast, the present study integrates these aspects within a single framework and applies them to a static 3D narrative environment.

The proposed approach differs from the related studies in three principal ways. First, the emotional input is derived from cinematic environmental variables rather than facial or physiological signals. Second, visual hermeneutic interpretation is operationalized through fuzzy membership functions and rules, producing a measurable emotional index. Third, the computational output is compared with audience-based statistical results, providing both interpretive and empirical validation. Accordingly, this study aims to analyze the influence of cinematic lighting, color temperature, and camera framing on audience emotional perception across narrative phases in a static 3D interior animation. In addition, this study aims to develop and validate a fuzzy-based computational model that translates these cinematic variables into a measurable emotional index. Through this objective, the research seeks to bridge visual interpretation, emotional perception, and computational modeling within the context of 3D animation and multimedia design.

MATERIALS AND METHODS

This research employs a mixed-methods approach to examine how a 3D animated space constructs and communicates emotional meaning. The study combines visual hermeneutics, technical visual measurement, and audience perception analysis. A visual hermeneutic approach was used to interpret cinematic elements as affective and narrative signs rather than merely technical representations. Recent cinematographic and animation studies support this interpretive perspective by demonstrating that exposure, framing, visual style, and spatial composition contribute to the construction of emotional and narrative meaning [3], [4].



Source: (Research Results, 2025)
Figure 1. Static 3D Interior Environment used as the Experimental Setting Across the Three Narrative Phases

The case study used in this research is a static digital interior environment created in Blender, as shown in Figure 1. The units of analysis consisted of 450 animation frames divided into three narrative phases: beginning, climax, and resolution. Each phase represented five seconds of animation and was analyzed shot by shot to identify the symbolic role of camera angle, lighting variation, and color transition. For audience perception analysis, 124 respondents aged 18–35 years participated in a questionnaire-based assessment. Accordingly, this study combines two empirical datasets: frame-based visual measurements and respondent-based emotional perception scores.

Lighting intensity and color temperature were measured to support the visual analysis. Light intensity was recorded using an Extech EA33 lux meter for key light, fill light, and back light across the three narrative phases, while color temperature was measured using a Datacolor SpyderX colorimeter. These measurements were used to identify systematic visual transitions from cool and low-intensity lighting at the beginning phase to warmer and stronger lighting at the resolution phase. This procedure supports the interpretation that lighting functions not only as an aesthetic element but also as a perceptual and emotional cue in 3D animation. Recent VR-based research has shown that changes in color temperature influence subjective perceptions of spatial brightness, warmth, spaciousness, and relaxation [18], while illuminance and correlated color temperature are also associated with measurable affective responses [19].

Framing analysis was conducted by classifying the 450 animation frames into four techniques: close-up, medium shot, medium long shot, and long shot. The frequency of each framing type was documented to represent shifts in emotional emphasis and spatial perception across the narrative. This step is consistent with previous studies showing that camera orientation and visual composition contribute to emotional engagement and mood formation [20] [21]. The emotional perception questionnaire was developed using validated indicators from previous studies on visual emotion and animation [4]. Content validity was assessed by three experts in visual communication design and psychology. A pilot test involving respondents with similar demographic characteristics was conducted to evaluate item clarity and consistency, and the instrument showed good reliability with a Cronbach's alpha value of 0.81.

The main survey involved 124 respondents aged 18–35 years, of whom 55% were women. Participants evaluated each narrative phase on a 1–5 Likert scale across three emotional dimensions: depression, tension, and hope. The resulting scores were analyzed using repeated measures ANOVA in SPSS v27 at a significance level of 0.05 to determine whether emotional perception differed significantly across narrative phases. Similar quantitative validation has been observed by [22], who used randomized online experiments to demonstrate statistically significant emotional shifts after exposure to animated short films with varying valences, confirming the empirical potential of animation for emotion elicitation. The methodological contribution of this study lies in integrating visual interpretation, technical measurement, audience-based statistical analysis, and fuzzy inference within a single analytical framework. [4] elaborate on that thesis by highlighting visual realism and the camera's capacity as a narrative device. Recent research on lighting in virtual and animated environments has increasingly moved toward measurable relationships between rendering parameters and perceptual outcomes [14], [15]. Audience-based experimental evidence also confirms that animated short films can produce measurable changes in emotional state, supporting the use of controlled animation stimuli for quantitative emotion research [22].

Fuzzy logic was selected in this study because the relationship between cinematic visual cues and emotional perception is inherently gradual, subjective, and not easily represented by rigid binary classification. Lighting intensity, color temperature, and framing do not produce emotional responses in an absolute way, instead, they operate within overlapping perceptual ranges. Therefore, fuzzy logic is methodologically suitable because it can represent linguistic categories such as low, medium, high, warm, cool, or hopeful through membership functions and inference rules, while preserving interpretive nuance from the visual hermeneutic analysis. In this study, fuzzy logic functions not merely as a technical tool, but as a computational bridge between qualitative interpretation and statistical validation.

This study employs fuzzy logic as a linkage between interpretive visual hermeneutic analysis and the quantitative validation procedure with ANOVA. This method transforms illumination data and cinematographic attributes, previously described linguistically as warm, chilly, intense, or soft, into numerical variables utilizing membership functions defined within a range of 0–1. This method enables the model to grasp the ambiguity of the audience's emotional interpretation of lighting and frame while preserving the semantic context obtained by hermeneutic analysis. Consequently, the fuzzy system functions as an inference layer that incorporates qualitative interpretation into the framework of computational analysis [23]. The fuzzy inference system has been developed with three operational inputs which were measured or coded directly from the animation scenes, key-light

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intensity, color temperature and dominant camera framing. The intensity of the key-light was expressed in lux, the color temperature in Kelvin and the framing of the camera in categorical values (close-up, medium shot, medium long shot, and long shot). These inputs were picked because they were always available for all the three narrative stages and could be directly associated with the audience's emotional perception scores as suggested by [17]. A Mamdani-type fuzzy inference system was chosen, because it permits the representation of language rules in an understandable way and is well suited to describe progressive transitions in visual and emotional perception. The AND operator in each rule was implemented by utilizing the minimum function and the results of all active rules were aggregated using the maximum function. The final emotional index was derived by centroid defuzzification over a normalized output range of 0–1.

The variables serve as input for the first-stage inference process, which establishes the first anticipated value for the predominant emotion of a scene. Each variable is characterized by three to five degrees of membership, such as low, medium, and high for intensity, and warm, neutral, and cold for color temperature. The inference process utilizes IF-THEN rules developed from the outcomes of visual hermeneutic analysis; for instance: IF color temperature is warm AND light intensity is medium THEN emotional tone is hopeful. The defuzzification results yield an output value represented as a measured emotion index, which is then utilized for comparison in the ANOVA statistical test. The computational model was evaluated by comparing the fuzzy emotional index with the respondent-based emotional perception results. First, the mean questionnaire score for the dominant emotion in each narrative phase was normalized to a 0–1 scale. Second, the association between the fuzzy index and the normalized perception score was examined using a correlation coefficient. Third, prediction error was assessed using mean absolute error (MAE) and root mean square error (RMSE). Finally, categorical agreement was evaluated by comparing the dominant emotion predicted by the fuzzy system with the dominant emotion identified from the respondent scores. The questionnaire mean score was normalized using (1):

$$y\ norm = \frac{(y-1)}{(5-1)} \quad (1)$$

where y is the original mean score on the 1–5 Likert scale.

$$MAE = \left(\frac{1}{n}\right) \Sigma\, |y_i - Y_i| \quad (2)$$

$$RMSE = \sqrt{[}\left(\frac{1}{n}\right)\, \Sigma(y_i - Y_i)^2 \quad (3)$$

Equations (2) and (3) where yi is the normalized respondent-based score and Yi is the fuzzy emotional index for narrative phase i.

RESULTS AND DISCUSSION

Table 1 summarizes the measured light intensity and color temperature across the three narrative phases. The beginning phase used cooler lighting (6600 K) and lower intensity, the climax phase showed increased intensity with a more neutral temperature (5120 K), and the resolution phase presented the warmest lighting condition (3300 K) with the highest intensity levels.

Source: (Research Results, 2025)
Figure 2. Changes in Ambient Lighting Color Across Narrative Phases and Their Emotional Effect

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These visual changes indicate a deliberate emotional transition from estrangement and tension toward comfort and hope [24]. This interpretation is supported by recent experimental studies showing that both illuminance and correlated color temperature affect affective and perceptual responses in virtual environments [18], [19]. Lower color-temperature lighting has been associated with warmer and more relaxed spatial perception, while virtual interior studies have also reported that lower color temperature conditions can produce more pleasant emotional evaluations than higher or more neutral color temperatures [25]. These findings support the emotional transition observed in the present study from cool lighting at the beginning phase to warm lighting at the resolution phase. This change represents a calculated visual story approach: the progressive amplification of key and fill light enhances the emotional emphasis at the climax and signifies the conclusion, while the augmentation of backlight contributes spatial dimension and emotional significance to each segment. The transition in color temperature from 6600 K (cool) to 3300 K (warm), depicted in Figure 2, corresponds with the audience's psychological progression from tension to a state of comfort and optimism, underscoring the vital importance of lighting design in establishing an emotional ambiance devoid of verbal communication.

Table 1. Average Light Intensity and Color Temperature Across Narrative Phase

Narrative phase	Key Light (lux)	Fill Light (lux)	Backlight (lux)	Color temperature (K)
Beginning	210	105	55	6600
Climax	244	129	70	5120
Resolution	275	150	86	3300

Source: (Research Results, 2025)

Table 3. Average Emotional Perception Scores and ANOVA Results

Emotional Dimension	Beginning	Climax	Resolution	F (df = 2.38)	p-value
Depression	4.20	3.10	2.15	48.5	< 0.001
Tension	4.45	3.50	2.30	32.2	< 0.001
Hope	1.90	2.80	4.10	60.3	< 0.001

Source: (Research Results, 2025)

Recent controlled studies further indicate that lighting direction, light color, and shadow can alter emotional interpretation in both real and virtual human representations [14], [26]. These findings support the role of lighting transitions observed in the present 3D animation experiment. Table 2 presents the distribution of framing techniques across the 450 animation frames. Close-up was the most frequent technique (40%), followed by medium long shot (27%), medium shot (20%), and long shot (13%). This distribution indicates that the animation primarily relies on emotionally intimate framing while still maintaining spatial transitions across narrative phases.

Table 2. Distribution of Camera Framing Techniques

Technique	Frame	Proportion (%)
Close-up	180	40
Medium shot	90	20
Medium long shot	122	27
Long shot	58	13

Source: (Research Results, 2025)

The dominance of close-up framing strengthens emotional proximity and internal conflict, whereas medium and medium long shots help balance character emotion with spatial context. Overall, the framing pattern supports the narrative shift from tension to emotional release, as illustrated in Figure 3. Table 3 presents the average emotional perception scores for depression, tension, and hope across the three narrative phases. Depression was highest in the beginning phase ($M = 4.20$) and decreased toward the resolution phase ($M = 2.15$). Tension also declined from the beginning ($M = 4.45$) to the resolution ($M = 2.30$), whereas hope increased from 1.90 to 4.10.

Repeated measures ANOVA revealed significant differences across phases for all three dimensions: depression ($F = 48.5$, $p < 0.001$), tension ($F = 32.2$, $p < 0.001$), and hope ($F = 60.3$, $p < 0.001$). These results confirm that the combination of lighting, color, and framing effectively guided audience emotion along the intended narrative progression. These findings are consistent with previous studies showing that lighting and color temperature significantly shape emotional tone in animated and cinematic works. However, unlike earlier studies that mostly emphasized descriptive or aesthetic interpretation, the present study quantifies these transitions across narrative phases and relates them directly to statistically tested audience responses. In this regard, the contribution

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of this study is not only to confirm that cool-to-warm lighting transitions affect emotion, but also to demonstrate how such transitions can be modeled systematically within a phase-based visual narrative structure in static 3D animation.

Table 4. Correlation Between Camera Techniques and Emotional Dimensions

Camera Technique	Emotional Dimensions	Correlation (r)
Close-up	Depression	0.78
Medium shot	Tension	0.72
Medium long shot	Hope	0.65

Source: (Research Results, 2025)

Table 4 shows that close-up framing has the strongest correlation with depression (r = 0.78). By minimizing spatial context and emphasizing facial expression, this framing intensifies the audience's perception of alienation and emotional burden. Medium shot is strongly associated with tension (r = 0.72), as it balances character visibility and environmental context. This framing allows viewers to perceive both emotional reaction and situational pressure at the same time. Medium long shot is positively associated with hope (r = 0.65). By opening more surrounding space, this framing creates visual relief and suggests possibility, helping shift the audience from anxiety toward optimism.

Source : [research result, 2025]
Figure 3. Comparison of Framing Techniques Used to Emphasize Character Emotion and Spatial Perspective

These findings extend previous cinematographic studies linking framing to empathy and viewer engagement. While earlier works generally discussed close-up and wider shots in terms of cinematic effect, the present study offers a more specific phase-based emotional mapping: close-up with depression, medium shot with tension, and medium long shot with hope. This strengthens the positioning of framing as both a narrative and an emotional design variable in 3D animation.

Table 5. Membership Function Definitions for Light Intensity

Linguistic Term	a (Lux)	b (Lux)	c (Lux)	d (Lux)
Low	150	150	180	210
Medium	180	210	240	260
High	240	270	300	300

Source: (Research Results, 2025)

Table 6. Definition of Color Temperature Membership Function

Linguistic T	a (K)	b (K)	c (K)	d (K)	Interpretation
Cool	5500	6000	7000	7000	Alienation
Neutral	4500	5000	5500	6000	Tension
Warm	3000	3000	4000	4500	Hope

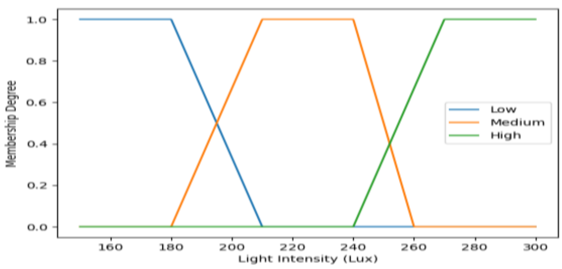
Source: (Research Results, 2025)

Table 7. Membership Function for Emotional Output

Emotion	a	b	c	d	Range
Depression	0.0	0.0	0.2	0.4	Low
Tension	0.3	0.45	0.55	0.7	Medium
Hope	0.6	0.75	1.0	1.0	High

Source: (Research Results, 2025)

Tables 5–7 and Figures 4–6 present the fuzzy membership functions for light intensity, color temperature, and emotional output. The overlapping ranges among categories indicate that cinematic visual and emotional changes occur gradually rather than discretely. This structure allows one visual condition to contribute to more than one emotional interpretation at the same time. Such overlap is important because emotional perception in cinematic scenes is rarely absolute. The fuzzy model therefore captures transitional states, especially in the climax phase, where emotional tone is neither fully negative nor fully positive. This provides the basis for defuzzification and for translating visual ambiguity into a measurable emotional index.



Source: (Research Results, 2025)
Figure 4. Fuzzy Membership Functions for Light Intensity Showing Overlap Among Low, Medium, and High Categories

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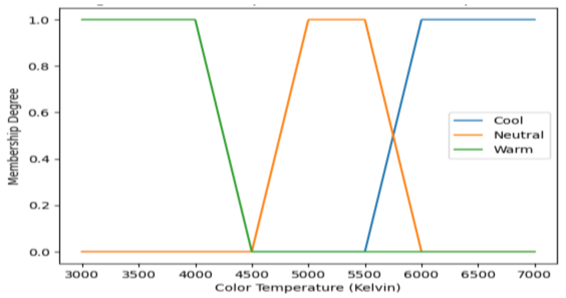
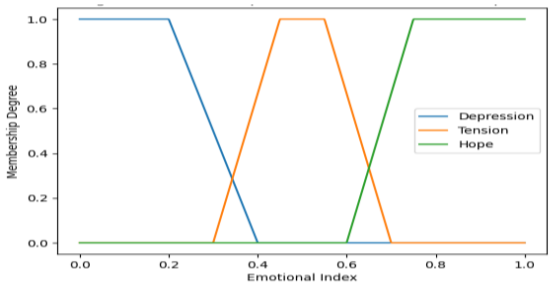


Source: (Research Results, 2025)
Figure 5. Fuzzy Membership Functions for Color Temperature Representing Cool, Neutral, and Warm Lighting Conditions



Source: (Research Results, 2025)
Figure 6. Fuzzy Membership Functions for Emotional Output Used in Defuzzification and Emotional Index Computation

The input and output variables were represented using trapezoidal membership functions. For a linguistic variable defined by four parameters a, b, c, and d, the membership value was calculated using Equation (4).

$$\mu(x) = \{0, x \leq a \text{ } or \text{ } x \geq d; \frac{x-a}{b-a}, a < x < b; 1, b \leq x \leq c; \frac{d-x}{d-c}, \text{ } c < x < d\} \quad (4)$$

where a and d define the lower and upper boundaries of the membership function, while b and c define the interval of full membership. This formulation enables smooth transitions between adjacent linguistic categories and avoids rigid boundaries between low, medium, and high lighting conditions, as well as between cool, neutral, and warm color temperatures.

Table 8. Fuzzy Inference Rule Base for Cinematic-Emotional Mapping

Rule	Light intensity	Color temperature	Dominant framing	Output emotion
R1	Low	Cool	Close-up	Depression
R2	Medium	Cool	Close-up	Depression
R3	Medium	Neutral	Medium shot	Tension
R4	High	Neutral	Medium shot	Tension
R5	Medium	Warm	Medium long shot	Hope
R6	High	Warm	Medium long shot	Hope
R7	High	Warm	Long shot	Hope
R8	Low	Neutral	Close-up	Depression
R9	Medium	Neutral	Close-up	Tension

Source: (Research Results, 2025)

As shown in table 8, the rule base was formulated from the combined results of visual hermeneutic interpretation and the observed emotional pattern across narrative phases. Each rule links a combination of lighting intensity, color temperature, and dominant framing to one emotional output. For example, cool lighting with low intensity and close-up framing was associated with depression, whereas warm lighting with medium-to-high intensity and wider framing was associated with hope. The rules were reviewed to maintain consistency with the measured scene configurations and respondent-based emotional scores.

Table 9 shows the defuzzification outcomes of the fuzzy system, incorporating the numerical findings as an emotional index for each narrative phase. The defuzzification value is computed using the centroid approach to signify the current emotional disposition caused by the intersection of membership functions for light intensity, color temperature, and framing techniques. During the beginning phase, an emotional index value of 0.22 signifies the prevalence of depressive emotions, however, the climax phase presents a value of 0.48, indicating an unclear emotional state or tension. The resolution phase attains a peak value of 0.78, suggesting the dominance of hopeful emotions. The results indicate that cinematic visual transitions can be objectively converted into measurable emotional trajectories.

The emotional index value obtained via defuzzification in Table 9 exhibits a pattern that aligns with the ANOVA statistical results shown in Table 3. The initial phase, exhibiting the lowest emotional index (0.22), was significantly linked with the greatest depression scores ($p < 0.001$). The index value during the climax phase (0.48) was within the tension range, along with a significant increase in tension scores. meanwhile, the resolution phase produced the greatest index (0.78), consistent with the increase in hope scores and the peak F-value for the hope dimension. This consistency verifies that fuzzy inference embodies empirically proven emotional preferences.

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Compared with previous fuzzy logic applications in multimedia, which often focused on automation, lighting control, or classification, this study positions fuzzy inference as an emotion modeling mechanism for cinematic visual design.

Table 9. Fuzzy Defuzzification Results for Each Narrative Phase

Narrative Phase	Key Light (Lux)	Color Temp (K)	Dominant Shot	Emotional Index (Defuzzified)	Dominant Emotion
Beginning	210	6600	Close-up	0.22	Depression
Climax	244	5120	Medium Shot	0.48	Tension
Resolution	275	3300	Medium Long Shot	0.78	Hope

Source: (Research Results, 2025)

Fuzzy logic is useful for system control and representing affective tendencies from visual narrative composition, as the defuzzified emotional index and ANOVA results are consistent. This strengthens the scientific contribution of the study in the intersection of animation, affective multimedia, and computational modeling. From a practical perspective, the proposed framework may assist animators, lighting artists, and multimedia designers in planning scene atmosphere more systematically during pre-visualization and production. By linking measurable visual parameters with predicted emotional outcomes, the framework can support design decision-making, scene evaluation, and iterative refinement of emotion-oriented visual storytelling.

Beyond the present case study, the framework has broader applicability for other forms of digital visual media that rely on atmosphere construction, including animated shorts, virtual environments, game cutscenes, and immersive storytelling interfaces. Although the fuzzy rule base remains context-dependent, the underlying approach of combining visual interpretation, empirical measurement, and computational emotion modeling can be adapted to other environments with appropriate recalibration. Overall, the findings show that visual strategies in a static 3D space can shape audience emotion in a structured manner. The shift from cool to warm lighting, the gradual increase in intensity, and the use of emotionally focused framing together guided the audience from tension and depression toward hope. These results support previous studies highlighting the affective role of lighting and framing in animation and cinematography [27], [15].

The present study also strengthens previous findings on non-verbal visual storytelling and emotional immersion in animation [4] [28]. However, unlike earlier studies that mainly emphasized descriptive interpretation or stylistic comparison, this research provides phase-based quantitative validation within a single static environment. In this respect, the study contributes a more explicit connection between cinematic design variables and measured audience emotion.

Nevertheless, the findings on the power of camera framing in influencing audience perception are also reinforced by [1], who concluded that visual framing (conflict vs solidarity) has a significant effect on audience affective reactions and engagement in a social context. In the context of 3D animation, framing, such as medium shots, creates visual pressure and internalizes the characters' emotions to the audience. Furthermore, [29] demonstrated in their study on emotion-based visual manipulation in music how combinations of color and lighting can be cinematically repurposed to adjust mood, supporting the validity of the lighting schemes and color gradients used in this study to mark narrative phases. This affirms that the integration of technical and narrative elements can optimize the affective experience in virtual spaces.

From the perspective of visual style development, [30] highlights the importance of alignment between visual innovation and emotional experience in animation, particularly through a minimalist approach and hybrid media integration. These findings are consistent with the narrative visual style in this study, which opts for a simple yet emotionally powerful esthetic approach. The trend of transformation in the 3D animation industry, as discussed by [31], also shows a shift from technical to narrative-emotional as the focal point of design. This study reinforces this direction by demonstrating that even within a static digital space, the integration of color, lighting, and framing can create dynamic narratives that resonate. Furthermore, [32] research on visual storytelling in marketing shows that visual emotional elements have a significant impact on audience behavior, indicating that the same principles can be applied across contexts, including animation art and visual communication design.

This study employs a methodology that integrates hermeneutic visual analysis with quantitative ANOVA, offering a dual-layered perspective. Comparable to [33] one-way ANOVA study on emotional responses to animated character expressions, the present results affirm that quantifiable differences in affective perception can be statistically validated across distinct narrative phases. This approach represents an advancement over previous studies, such as [10], [34], which primarily focused on qualitative or technical lighting aspects. The mixed-methods approach enhances the causal relationship between visual cues and observed emotional responses. In contrast to [20], who examined cinematic techniques in interactive visualization and emphasized user interactivity, our research shows that even in non-interactive, static digital environments, careful manipulation of cinematic techniques can elicit significant emotional variation. This distinction highlights the effectiveness of visual narrative as a means of emotional communication that transcends interactivity.

Despite the fuzzy approach employed in this work effectively converting cinematic visual transitions into quantifiable and consistent emotional indices, as evidenced by ANOVA results, some limitations deserve consideration. The definition of membership functions and fuzzy inference rules in this work remains contextual and is derived from a singular static 3D environment and a single narrative flow. Thus, the resulting defuzzification value is significantly influenced by the particular lighting arrangement, color temperature, and framing in this case study. Extending the fuzzy model to other 3D locations, diverse visual styles, or non-linear storylines necessitates the recalibration of membership parameters and the rule base to ensure precise depiction of emotional perception. The computational evaluation indicates that the proposed framework does more than reproduce the intended narrative sequence. It provides an interpretable mapping between measurable cinematic parameters and emotional categories. The model correctly identified the dominant emotional state in each narrative phase and produced defuzzified values located near the center of the corresponding output categories. This result supports the use of fuzzy inference as a transparent alternative to black-box prediction methods for small-scale, design-oriented animation studies.

Compared with recent studies, the proposed framework occupies a distinct position. Fuzzy emotion-recognition studies commonly infer emotion from facial expressions, whereas cinematic-lighting studies typically analyze mood without producing a computational emotional index. Research on narrative visualization also discusses framing and attention but does not usually integrate audience-based statistical validation. The present study combines these components by translating environmental cinematic variables into an interpretable fuzzy output and comparing the result with repeated-measures audience data. The computational results should nevertheless be interpreted within the scope of the present case study. The model was calibrated using one static 3D interior environment and a limited set of narrative configurations. Its rule base therefore represents context-specific relationships rather than universal emotional laws. Application to other genres, spatial layouts, cultural audiences, or nonlinear narratives requires recalibration and independent validation.

These results corroborate existing knowledge in the field while also highlighting new opportunities. Research by [29] on multimodal emotional manipulation indicates that the integration of audio-visual elements may enhance affective experiences. Future research may investigate the interplay of auditory and visual stimuli, as well as the implementation of these methods in interactive media or virtual reality, to determine their potential for eliciting enhanced emotional responses. The results of this study are constrained using a singular static 3D environment, a comparatively small sample of respondents, and the subjective characteristics intrinsic to hermeneutic analysis. Instrumentation and reaction biases may also affect outcomes. Subsequent research should examine these parameters to enhance the generalizability and robustness of the findings.

CONCLUSION

This study shows that a structured combination of lighting, color temperature, and camera framing can significantly shape audience emotional perception in a static 3D animation environment. The ANOVA results confirmed significant differences in depression, tension, and hope across narrative phases, while the fuzzy inference model translated cinematic visual configurations into a measurable emotional index. Thus, the study contributes a fuzzy-based computational framework that connects visual interpretation, audience perception, and emotion-oriented multimedia design. The study is limited by its focus on a single static 3D interior environment, one narrative structure, and a context-dependent fuzzy rule base. Future research should test the framework in more diverse visual environments, with larger respondent groups and multimodal scenarios, to improve robustness and generalizability.

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