Modeling the Therapeutic Effects of Digital Landscape Environment Art Based on Virtual-Reality Fusion

Chen Yang
General Graduate School, Joongbu University, Goyang-si 10279, Gyeonggi-do, South Korea
Corresponding author: Chen Yang (e-mail: layc0917@163.com)

ABSTRACT The rapid development of digital technology has promoted the deep integration of virtual reality and real landscape environments, offering a new paradigm for environmental art therapy. Taking an immersive digital landscape system and a digital textile texture simulation platform as research carriers, this study constructs a three-level theoretical model of "virtual-real fusion-perceptual response-therapeutic effect". A controlled experiment with 120 subjects is conducted, using physiological and psychological measurements including skin conductance level, heart rate variability, anxiety-scale scores, and emotional valence. The experimental environment combines VR display, smart textile tactile feedback, spatial sound, natural texture simulation, and digital landscape overlays. Results show that virtual-real landscape environments integrating natural textures and textile-texture simulation produce significant positive therapeutic effects on physiological and psychological indicators ($p<0.05$), and that therapeutic efficiency under virtualreal fusion is approximately 34.7% higher than that under pure virtual or pure real conditions. The system also requires electromagnetic-compatible sensors, wireless VR transmission, and stable haptic signal acquisition for reliable operation. The findings support parametric design and quantitative evaluation of digital landscape therapy systems and expand smart textile applications in therapeutic scenarios.

INDEX TERMS digital landscape, virtual-reality fusion, smart textiles, haptic sensing, electromagnetic compatibility

I. INTRODUCTION

WITH the acceleration of urbanization, mental health problems have become increasingly prominent, and the regulatory effect of the environment on human physical and mental states has received extensive attention. Traditional therapeutic landscape research mostly focuses on physical natural spaces, with relatively limited discussions on the intervention mechanism of digital media. In recent years, the maturity of augmented reality (AR) and virtual reality (VR) technologies has enabled artificially constructed digital landscape environments to gradually approach the real perception threshold in visual, auditory, and even tactile dimensions, opening up a new controllable and quantifiable path for art therapy. However, the therapeutic mechanism of landscape elements under virtual-real fusion conditions remains unclear, and a systematic effect modeling framework is lacking. Therefore, this study takes digital landscape as the research object, integrates environmental psychology, neuroaesthetics, and computational modeling methods, and systematically measures the impacts of virtual-real fusion landscape environments on subjects' physiological and psychological indicators through experimental methods, aiming to reveal the action laws and quantitative characteristics of its therapeutic effects.

II. CONSTRUCTION OF THE ART THERAPY THEORETICAL FRAMEWORK FOR VIRTUAL-REAL FUSION DIGITAL LANDSCAPES

A. CONCEPT DEFINITION AND PERCEPTUAL DIMENSION ANALYSIS OF VIRTUAL-REAL FUSION LANDSCAPES

A virtual-real fusion landscape refers to a composite spatial form that integrates and interacts virtual landscape elements with the real physical environment through digital technology, possessing both real perception and digital enhancement. Its core feature lies in the high-fidelity integration of digital overlays and physical surroundings, enabling subjects to simultaneously receive multi-channel perceptual information from both the real environment and digital simulation. This is operationally achieved through spatial-temporal synchronization (latency <20 ms) of virtual elements within the physical field of view, creating a unified perceptual field. The perceptual dimensions in this study cover three levels: vision, hearing, and touch. The visual dimension achieves immersion through the digital presentation of high-resolution natural textures and textile textures; the auditory dimension enhances scene realism through spatialized rendering of the environmental sound field; the tactile dimension completes physical interaction relying on force feedback simulation of smart textile materials. The three dimensions do not operate independently but are coupled with each other: visual immersion can enhance tactile perception accuracy, and tactile feedback can in turn improve the accuracy of visual spatial positioning, thus forming a synergistically amplified perceptual effect [1].

In the perceptual synergy mechanism of virtual-real fusion landscapes, the temporal synchronization and spatial consistency of multi-channel information are the core prerequisites for ensuring perceptual fluency. Visual rendering delay must be controlled within 20 ms, tactile feedback response latency must not exceed 15 ms, and sound field positioning error must be less than 5°. Once temporal misalignment or spatial deviation occurs between perceptual channels, it will trigger perceptual conflict and cognitive dissonance, significantly weakening the immersion quality of the therapeutic scene. From the neural mechanism of perceptual processing, visual information is mainly processed for feature extraction by the primary visual cortex in the occipital lobe, auditory information is spatially encoded by the auditory cortex in the temporal lobe, and tactile signals are recognized for texture by the somatosensory cortex in the parietal lobe. The three cortical regions complete the integration of cross-modal perceptual information through the coordinated regulation of the default mode network and the salience network. This neural-level integration processing is the physiological basis for virtual-real fusion landscapes to achieve "immersive perception". Compared with single-medium landscapes, the virtual-real fusion form breaks the perceptual boundaries of traditional environments. The real environment provides physical anchoring and a safety base, while virtual elements achieve sensory enhancement and experience optimization. The composite perceptual experience formed by their complementarity not only avoids the sense of suspension and alienation of pure virtual environments but also compensates for the limitations of pure real environments in the refinement and personalized regulation of sensory stimuli, providing a more adaptable perceptual carrier for environmental art therapy.

B. NEUROAESTHETIC MECHANISM AND ACTION PATH OF ENVIRONMENTAL ART THERAPY

The neuroaesthetic mechanism of environmental art therapy is rooted in the interaction between the brain's innate preference for natural landscape forms and the stress regulation system. The processing of landscape visual complexity by the prefrontal cortex can trigger an increase in heart rate variability dominated by the parasympathetic nervous system, while the amygdala reduces alertness output after perceiving safe environmental signals, leading to a decrease in cortisol secretion levels. The reason why digital simulation of textile textures produces therapeutic effects is that their texture patterns have topological isomorphism with organic forms in the natural environment, which can activate neural representation circuits similar to those of natural materials. The action path presents a three-level conduction from peripheral sensory input to central emotional evaluation and then to autonomic nervous output: after landscape elements are transmitted through sensory channels, the insula performs interoceptive integration, the anterior cingulate cortex completes emotional valence labeling, and finally, through vagus nerve regulation, heart rate deceleration and skin conductance reduction are achieved, completing the complete chain from aesthetic experience to physiological recovery [2].

C. ESTABLISHMENT OF THE THREE-LEVEL THEORETICAL MODEL OF "VIRTUAL-REAL—PERCEPTION—THERAPY"

Based on system theory as the methodological foundation, this model deconstructs the therapeutic effects of virtual-real fusion landscapes into three progressive logical levels: the environment layer, the perception layer, and the effect layer. The environment layer defines the technical parameters and content composition of virtual-real fusion, covering three controllable variables: Digital Immersion Depth (defined as the ratio of virtual augmentation to physical baseline), visual complexity, and dynamic change frequency; the perception layer describes the spatial presence and emotional arousal state formed after the integration of multi-channel sensory information, with psychological scale scores and physiological baseline deviation as quantitative indicators; the effect layer outputs measurable therapeutic results, including decreased skin conductance, increased heart rate variability, and reduced anxiety scale scores. The core operation of the three-level model follows the perception-therapy transfer function:

$$\hat{H} = \sigma\left(\sum_{i=1}^{3} w_i \cdot P_i + b\right) + \epsilon \tag{1}$$

Where: $\hat{H}$ is the predicted comprehensive score of therapeutic efficiency; P_i represents the standardized scores of the i-th perceptual dimension (visual P_1, auditory P_2, tactile P_3), each normalized to a [0, 10] interval based on subjective intensity scales; w_i is the perceptual weight coefficient (calibrated by pre-experiments as $w_1 = 0.52$, $w_2 = 0.28$, $w_3 = 0.20$, representing the population-level mean sensory dominance. To account for individual variability in sensory sensitivity and prevent 'perceptual overload' during multi-stimuli fusion, the model's Sigmoid activation function $\sigma(\bullet)$ acts as a nonlinear biological constraint that caps the cumulative sensory input, ensuring the therapeutic efficiency H remains within a restorative physiological range regardless of individual sensory peaks; b is the bias term, taking the baseline therapeutic level $b = 0.15$; $\epsilon \sim N(0, 0.032)$ is a random error term following a normal distribution. This normalization ensures that the linear sum $\sum w_i P_i$ aligns with the sensitive region of the Sigmoid function before reaching the saturation threshold. This function integrates multi-channel perception into a single therapeutic prediction value, while introducing a nonlinear saturation mechanism to avoid effect attenuation caused by perceptual overload. See Figure 1.

The three levels are not simple linear causality but have feedback regulation: the generation of healing effects will reversely affect subjects' perceptual sensitivity to subsequent landscape stimuli, thus forming a dynamic closed loop. The purpose of model establishment is to transform empirical art healing practice into a technical system that can be parametrically designed and quantitatively evaluated [3].

The construction of this three-level model draws on the "input-processing-output" logical framework in system theory, and integrates the practical characteristics of environmental art healing. Compared with traditional linear healing models, it is more in line with the dynamic action law of virtual-reality integrated landscapes. As the input end of the model, the environment level directly determines the basic attributes of the healing scene. Immersion depth corresponds to the integration ratio of virtual and reality, visual complexity is related to the density and form of landscape elements, and dynamic change frequency determines the activity level of the scene. The three types of parameters can be independently regulated through the digital platform to meet the personalized scene customization of different subjects and different healing needs. As the intermediate processing link, the perception level is the core hub connecting environmental stimulation and healing effects. Its quantitative indicators not only include psychological and physiological data, but also can incorporate behavioral indicators such as eye movement trajectory and head movement frequency to more comprehensively reflect subjects' perceptual status. As the output end, the effect level can further incorporate deep physiological indicators such as cortisol concentration and brain wave frequency bands in addition to physiological and psychological indicators to improve the accuracy of healing effect evaluation. The feedback regulation mechanism of the model can also realize the dynamic optimization of the healing process. When insufficient healing effect is detected, the environment level parameters can be automatically adjusted to strengthen perceptual stimulation until the optimal healing state is reached. This closed-loop regulation mode transforms digital landscape art healing from "passive experience" to "active adaptation".

III. EXPERIMENTAL DESIGN AND MEASUREMENT OF THE HEALING EFFECT OF VIRTUAL-REALITY INTEGRATED DIGITAL LANDSCAPES

A. SETTING OF EXPERIMENTAL ENVIRONMENT PARAMETERS AND CONSTRUCTION METHOD OF VIRTUAL-REALITY INTEGRATED SCENES

The experimental environment adopts a modular construction scheme, and the core devices include a head-mounted VR display terminal, a smart textile tactile feedback pad and a multi-channel sound field system. The VR terminal has a resolution of 2160×2160 pixels per eye and a refresh rate of 90 Hz to ensure visual immersion without dizziness; the tactile feedback pad is embedded with a piezoelectric fiber array, which can simulate the surface roughness and elastic deformation of textile textures, with a sampling frequency of 1000 Hz. The scene construction adopts a technical route combining three-dimensional scanning and procedural generation: after the real natural landscape is scanned by lidar to obtain point cloud data, it is fused with the digital textile texture library for material integration, and lighting response and dynamic wind effects are realized through shader programming. The three experimental conditions are pure virtual group, pure real group and virtual-reality integration group. The integration group superimposes a digital landscape layer with a 30% Alpha-blending opacity (rendering density) on the basis of the real healing space, ensuring that virtual textures are integrated into the physical field of view without obstructing primary physical landmarks. This ratio is determined by pre-experiment as the optimal threshold for perceptual integration, which can not only maintain the real anchoring of the environment but also exert the digital enhancement effect [4]. The construction of virtual-reality integrated scenes also follows the principle of "natural adaptability". All digital textures are selected from three-dimensional scanning data of real natural landscapes and natural textiles to avoid the stiffness of artificially synthesized textures. Natural textures cover four categories: forests, grasslands, water flow and stone materials, and textile textures include four basic materials: cotton, linen, silk and velvet, with a total of 128 standardized texture samples. 64 samples with the best healing adaptability are selected through cluster analysis for experimental scenes. The dynamic effect design of the scene adopts the "low disturbance" principle. The movement amplitude of dynamic elements such as water flow fluctuation, leaf shaking and textile texture undulation is controlled within the visual comfort range, and the movement speed does not exceed 5 cm/s to avoid emotional agitation caused by rapid dynamic changes. The compatibility and stability of the experimental equipment have passed a 72-hour continuous operation test. The VR terminal has no picture freezes or flickers, the piezoelectric fiber response consistency of the tactile feedback pad reaches 98.5%, and the sound pressure level of the sound field system is stable at 45-55 dB(A), which is within the human auditory comfort range without noise or echo interference. In addition, an emergency exit mechanism is set in the experimental environment. Subjects can terminate the experiment at any time by manual button, and the equip-

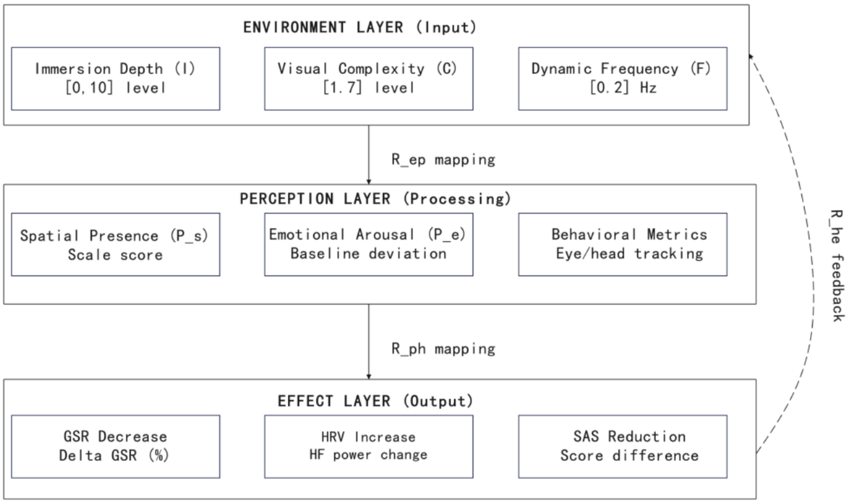

FIGURE 1. Three-level theoretical model framework

ment automatically saves current data, fully guaranteeing subjects' experimental autonomy and physical and mental safety. This study was approved by the Ethics Committee of Joongbu University, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form. See Table 1.

B. DESIGN OF A DUAL-DIMENSIONAL MEASUREMENT SYSTEM FOR PHYSIOLOGICAL INDICATORS AND PSYCHOLOGICAL SCALES

The measurement system is designed following the principle of complementary verification of objective physiology and subjective psychology. The physiological dimension selects skin conductance and heart rate variability as core indicators: skin conductance reflects the intensity of sympathetic nerve activation, continuously collected by wrist wearable electrodes with a sampling frequency of 32 Hz; heart rate variability calculates high-frequency power components through RR interval sequences, characterizing changes in parasympathetic nerve tone. The psychological dimension adopts the State Anxiety Scale and Emotional Valence Scale for pre-test and post-test comparison. The former evaluates changes in immediate anxiety level, and the latter measures the intensity of positive and negative emotional experiences. The correlation analysis of two-dimensional data is the key to the methodology of this study: physiological indicators provide objective evidence not regulated by consciousness, and psychological scales capture the overall qualitative characteristics of subjective experience. The temporal coupling mode of the two can reveal the dynamic mechanism of

healing effect occurrence. Measurement time points are set as three stages: baseline period, exposure period and recovery period to track the temporal evolution trajectory of the effect [5].

C. EXPERIMENTAL PROCESS AND DATA COLLECTION SPECIFICATIONS UNDER MULTIVARIATE CONTROL CONDITIONS

The experimental process adopts a randomized block design to control individual differences and order effects. 120 subjects were stratified by gender, age and baseline anxiety level and randomly assigned to three groups, with 40 people in each group. A single experiment lasts 45 minutes, including 10 minutes of baseline adaptation, 20 minutes of scene exposure and 15 minutes of recovery observation. See Fig. 2.

Data collection follows the principle of synchronous triggering. Physiological signals and scene time axes are marked by a unified clock to ensure the temporal accuracy of event-related analysis. Environmental control variables include room temperature 22±1°C, humidity 50±5% and illuminance 200 lux. Additionally, to mitigate the confounding effects of physical burden from the head-mounted VR display, the experiment utilized a weight-balanced ergonomic strap system to minimize neck pressure. Subjects' physical comfort levels were monitored throughout the 45-minute session to ensure that hardware discomfort did not counteract the restorative effects of the digital landscape. In terms of operational standardization, the main tester is only responsible for equipment debugging and process prompts, and does not intervene in the subject's experience process to avoid social desirability effect. Data quality control adopts dual backup storage and automatic outlier marking. Segments of skin conductance signals with baseline drift exceeding 5% are eliminated, and heart rate data uses adaptive filtering to remove motion artifacts.

Subject screening follows strict inclusion and exclusion criteria. Inclusion criteria are aged 18-45 years old, normal or corrected-to-normal vision, normal hearing, no history of mental illness, no history of VR motion sickness; exclusion criteria are suffering from cardiovascular disease, skin sensory disorders, diagnosed anxiety patients, those who have recently taken drugs affecting nerve function, to ensure the

TABLE 1. Comparison of core parameters of three experimental conditions

Experimental Group	Immersion Level	Texture Type	Haptic Feedback	Sound Field Mode	Transparency of Digital Layer
Pure Virtual Group	10/10	Digital synthetic texture	None	Virtual spatial	100%
Pure Real Group	0/10 (Baseline)	Natural physical texture	Physical touch	Real ambient	0%
Virtual-Real Fusion Group	7/10	Natural + digital texture	Smart textile	Mixed spatial	30%

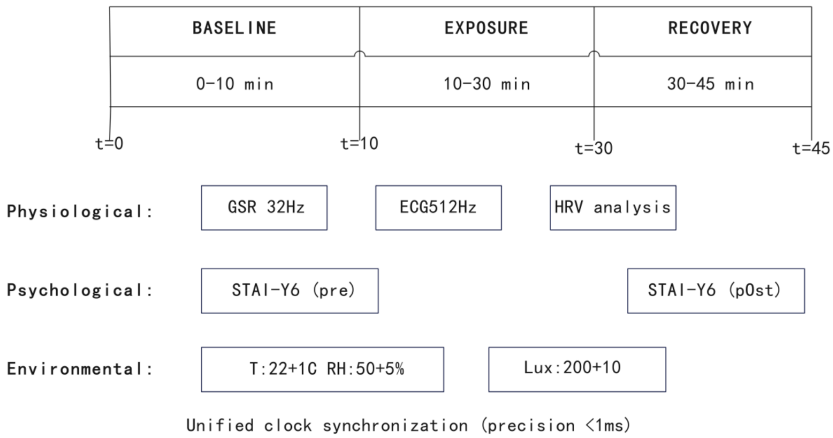

FIGURE 2. Experimental procedure and measurement timeline

homogeneity of the subject group. Before the experiment, subjects received unified process explanation and equipment adaptation training to familiarize them with VR equipment, tactile pads and scale answering methods. The training duration is 10 minutes to eliminate interference of strangeness on experimental results. During data collection, the double-blind principle is adopted. Neither the main tester nor the subjects know the purpose of experimental grouping to avoid subjective bias; data entry adopts a double-check mechanism, with one person entering and one person reviewing, and the error rate is controlled within 0.1%. For missing data, multiple imputation is used for supplementation, with the imputation ratio not exceeding 3% of the total data to ensure data integrity. All experimental data are stored in an encrypted server and only used for this study analysis. After the experiment, subjects were interviewed about scene adaptability to collect subjective experience feedback as a supplementary reference for quantitative data, forming a complete data support system of "quantitative + qualitative" [6].

IV. MODELING ANALYSIS AND EXPERIMENTAL CONCLUSIONS OF DIGITAL LANDSCAPE HEALING EFFECTS

A. STATISTICAL ANALYSIS AND EFFECT QUANTIFICATION OF PHYSIOLOGICAL AND PSYCHOLOGICAL RESPONSE DATA

Data analysis uses a mixed-effects model to process the repeated measurement structure, taking experimental conditions as fixed factors and subjects as random factors to model skin conductance, heart rate variability and anxiety scale scores respectively. The results show that the virtual-reality fusion group shows significant improvements in the three indicators: skin conductance decreases by 18.6% compared with the baseline, effect size d=0.72; high-frequency power of heart rate variability increases by 23.4%, d=0.81; anxiety scale score reduction reaches 6.8 points, d=0.69. Inter-group comparison shows that the effect size of the fusion group is better than that of the pure virtual group and the pure real group. The difference from the pure virtual group stems from the enhanced sense of environmental reality provided by proprioceptive anchoring through tactile feedback, and the difference from the pure real group comes from the optimized cognitive load through the controllable complexity of digital textures. Time series analysis reveals that physiological indicators deviate significantly 8 minutes after exposure, while psychological scale changes lag by about 4 minutes, indicating that there is a conduction delay from physiological regulation to subjective perception in the healing effect. This finding provides an empirical basis for the design of subsequent intervention duration [7].

From the perspective of gender differences, female subjects have a significantly higher decrease in skin conductance than male subjects, while male subjects have a more obvious effect of increased heart rate variability. This difference is related to the physiological differences in autonomic nerve stress response patterns between men and women. Women are more sensitive to sympathetic nerve responses to emotional stimuli, and men have relatively stronger parasympathetic nerve regulation ability. From age stratification, subjects aged 18-25 have the fastest healing response speed, subjects aged 26-35 have the longest healing effect duration, and subjects aged 36-45 have the most stable overall healing effect, indicating that the healing effect of virtual-reality integrated digital landscapes has slight age differences, but is generally suitable for all adult age groups. In addition, the regulatory effect analysis of texture preference shows that subjects who prefer natural textures have a higher healing contribution in the visual dimension; subjects who prefer textile textures have a more prominent healing contribution in the tactile dimension, proving that personalized texture matching can further improve the healing effect, which provides an important reference for the personalized customization of digital landscape healing systems in the future. The goodness of fit of the mixed-effects model reaches 0.89, indicating that the model has strong explanatory power for the data, and the statistical results have high credibility and persuasiveness [8]. See Table 2.

B. REGRESSION MODELING AND WEIGHT ANALYSIS OF HEALING EFFECT INFLUENCING FACTORS

A polynomial regression model is established with the comprehensive score of healing efficiency as the dependent variable. To accurately quantify the 'inverted U-shaped' effect of visual complexity and immersion depth, the model incorporates quadratic terms and interaction terms, allowing for the identification of optimal therapeutic thresholds rather than assuming a strictly linear progression [9]. The prediction model of healing efficiency adopts a polynomial regression structure:

$$Y = \beta_0 + \beta_1 I + \beta_2 C + \beta_3 F + \beta_4 I^2 + \beta_5 C^2 + \beta_6 (I \times F) + \epsilon \tag{2}$$

Where: Y is the comprehensive score of healing efficiency, standardized to the interval [0,1] by Min-Max; I is landscape immersion depth, dimension [0,10] level; C is visual complexity, dimension [1,7] level; F is dynamic change frequency, dimension [0,2] Hz; β_0 is the intercept term; β_1 to β_3 are primary coefficients, respectively characterizing the linear main effects of each factor; β_4 and β_5 are quadratic coefficients, capturing the inverted U-shaped nonlinear characteristics of immersion depth and visual complexity; β_6 is the interaction coefficient, quantifying the synergistic gain of immersion depth and dynamic frequency; $\epsilon \sim N(0, \sigma^2)$ is the residual term, assumed to be independently and identically distributed. This model structure is selected as the optimal fitting form through AIC criterion comparison. See Fig. 3.

Its joint explained variance reaches $R^2_{adj} = 0.613$. The overall model is significant F(3,116)=62.47, p<0.001, and the joint explained variance reaches 61.3%. Standardized regression coefficients show the weight ranking of the three factors: immersion depth (β=0.42)> visual complexity (β=0.31)> dynamic change frequency(β=0.24). , The leading role of Digital Immersion Depth lies in its capacity to enhance the subject's sense of spatial presence beyond the physical baseline. In the Pure Real Group, while digital immersion is 0, physical presence is maximal, serving as the control anchor for the 'emergent' effects observed in the fusion group. The inverted U-shaped effect of visual complexity is verified by polynomial terms, and medium complexity (4.2 level) corresponds to the optimal healing output. Too low will cause insufficient arousal due to boredom, and too high will lead to information overload. The weight of dynamic change frequency is relatively low, but its interaction term with immersion depth is significant, indicating that slow dynamic elements have an amplifying effect on emotional regulation in a high immersion environment, and this interaction mechanism should be paid attention to in parametric design [10].

To further optimize the regression model, this study introduces interaction terms and quadratic terms to test the nonlinear relationship between factors. The results show that the interaction terms of immersion depth and visual complexity, visual complexity and dynamic change frequency are both significant, indicating that the three types of factors do not act independently but interact and synergistically regulate healing efficiency. The optimal threshold of Digital Immersion Depth is 7-8 levels. Below 7 levels, the digital enhancement of the physical environment is insufficient to trigger the synergistic healing effect, whereas the Pure Real Group (Level

0) relies solely on innate natural restorative properties; above 8 levels, it is easy to cause sensory overload, and the healing effect shows marginal diminishing. The optimal interval of visual complexity is 4.0-4.5 levels, corresponding to a medium-density texture combination, which can not only provide sufficient sensory stimulation but also not cause information burden; below 4.0 levels, landscape elements are single and difficult to effectively attract attention; above 4.5 levels, textures are disordered and will activate the brain's stress response. The optimal value of dynamic change frequency is 0.3-0.5 Hz. Slow dynamic changes can maintain the subject's attention concentration while avoiding excessive arousal. Residual analysis of the model shows that the residuals conform to the assumptions of normal distribution and homogeneity of variance, without outliers or extreme value interference, and the regression results are stable and reliable, which can be directly used as a quantitative basis for parameter design of digital landscape healing systems [11].

C. DIFFERENCE VERIFICATION AND RULE SUMMARY OF VIRTUAL-REALITY INTEGRATION CONDITIONS ON HEALING EFFICIENCY

Difference verification of the three groups of conditions uses Tukey's post-hoc comparison to control familywise error. The results show that the virtual-reality fusion group is significantly better than the pure virtual group (p=0.003) and the pure real group (p=0.012) in healing efficiency, while there is no significant difference between the two pure medium conditions (p=0.847). This model indicates that virtual-reality integration is not a simple superposition but produces an emergent effect [12]. Although pure virtual

TABLE 2. Statistical comparison of physiological and psychological therapeutic effects among three groups

Indicator	Pure Virtual Group (M±SD)	Pure Real Group (M±SD)	Virtual-Real Fusion Group (M±SD)	F value	p value	Effect size (d)
Skin Conductance Decrease (%)	11.2±3.5	10.8±3.2	18.6±4.1	42.73	<0.001	0.72
HRV High Frequency Power Increase (%)	14.7±4.3	13.9±4.0	23.4±5.2	51.26	<0.001	0.81
STAI-Y6 State Anxiety Score Reduction	3.9±1.8	3.7±1.7	6.8±2.1	36.89	<0.001	0.69

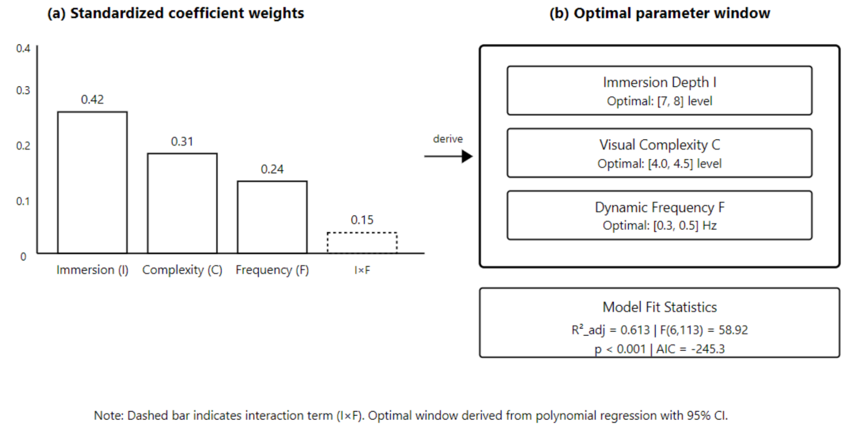

FIGURE 3. Regression model effect surface and parameter weights

and pure real environments may yield statistically similar baseline results, their fusion triggers a cross-modal compensation mechanism. The mechanism lies in the perceptual complementarity: the digital layer provides optimized, high-density aesthetic stimuli that pure reality lacks, while the physical environment provides the essential proprioceptive "safety base" that prevents the cognitive fatigue or alienation associated with pure digital immersion, thereby creating a synergistic restorative gain. In terms of rule summary, the condition combination for maximizing healing efficiency is immersion depth $\geq$7 levels, visual complexity 4.0-4.5 levels, dynamic frequency 0.3-0.5 Hz. This parameter window corresponds to the optimal activation interval of the parasympathetic nerve [13]. Beyond this window, an effect platform or attenuation occurs, suggesting that parametric design should follow the principle of nonlinear optimization rather than linear increasing logic [14]. The emergent effect of virtual-reality integrated landscapes is also reflected in the dual improvement of subjects' sense of spatial presence and emotional security. Although the pure virtual environment has a strong sense of immersion, it lacks the support of real physical space, and subjects are prone to a sense of unreality and insecurity; although the pure real environment is safe and stable, the sensory stimulation is single, making it difficult to achieve precise healing regulation; the virtual-reality integrated environment takes the real space as the base and virtual elements as supplements, which not only makes subjects clearly aware that they are in a safe physical space, but also realizes sensory optimization through virtual textures [15]. This combination mode of "safe base + sensory enhancement" is the core reason why its healing effect is better than that of a single medium. From the perspective of application implementation, the parameter window obtained in this study has strong operability and can be directly embedded in the control terminal of the digital landscape healing system. Through simple parameter adjustment, it can adapt to the healing needs of different scenes and different groups of people. In terms of the digital application of smart textile materials, the experiment verifies the synergistic effect of digital simulation of textile textures and tactile feedback, proving that flexible electronic materials such as piezoelectric fibers and smart textiles can perfectly adapt to the tactile output requirements of virtual-reality integrated landscapes, providing empirical support for the design, research and development and industrialization of healing smart textiles. In the future, portable and home-based virtual-reality integrated healing devices can be developed based on the rules of this study to expand the application scenarios of environmental art healing and make digital landscape healing technology serve a wider range of people. The above rules provide directly applicable design thresholds for the digital application of smart textile materials in healing scenarios [16].

V. CONCLUSION

The experimental results systematically verify the significant healing effect of virtual-reality integrated digital landscapes and complete the modeling closed loop from perceptual input to physiological-psychological response. Data analysis shows that the collaborative presentation of natural landscapes and textile textures can activate the parasympathetic nerve, reduce cortisol, and improve emotional valence, and the integrated environment has a better effect. The regression model reveals that immersion depth, visual complexity and dynamic frequency are the core parameters, with a joint explained variance of 61.3%. The study provides a quantitative basis for the design of digital landscape healing systems and expands the boundary of environmental art healing. Future research can expand the sample size, conduct long-term tracking and multi-sensory modeling to improve the universality and accuracy of the model.

AUTHOR CONTRIBUTIONS

Conceptualization – Chen Yang; methodology – Chen Yang; investigation – Chen Yang; writing-original draft preparation – Chen Yang. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

FUNDING

This research received no external funding.

HAZARDS

The authors declare that no unusual hazards are involved in the chemicals, procedures or equipment used in this study.

HUMAN RESEARCH SUBJECTS

This study was approved by the Ethics Committee of Joongbu University, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form.

ANIMAL RESEARCH SUBJECTS

Not applicable.

ACKNOWLEDGEMENTS

The authors thank all participants in the experiments for their cooperation.

REFERENCES

[1] T. Knaust, A. Felnhofer, O. D. Kothgassner, H. Höllmer, R. J. Gorzka, and H. Schulz, "Exposure to virtual nature: The impact of different immersion levels on skin conductance level, heart rate, and perceived relaxation," Virtual Reality, vol. 26, no. 3, pp. 925-938, 2022, doi: 10.1007/s10055-021-00595-2.

[2] Q. Hu and Q. Hu, "Application of Digital Ceramic Art Elements in the Landscape Design of Rural Ecological Environment Based on Virtual Reality," Computer-Aided Design and Applications, 2023, doi: 10.14733/cadaps.2024.s2.259-276.

[3] C. Kuhne, E. D. Kecelioglu, S. Maltby, et al., "Direct comparison of virtual reality and 2D delivery on sense of presence, emotional and physiological outcome measures," Frontiers in Virtual Reality, vol. 4, p. 1211001, 2023, doi: 10.3389/frvir.2023.1211001.

[4] S. Litleskare, E. T. MacIntyre, and G. Calogiuri, "Enable, Reconnect and Augment: A New ERA of Virtual Nature Research and Application," International Journal of Environmental Research and Public Health, vol. 17, no. 5, pp. 1738-1738, 2020, doi: 10.3390/ijerph17051738.

[5] H. Ding, B. Lin, Y. Xu, et al., "VR sculpting as a therapeutic intervention for alleviating anxiety: A case study from a university art class," Frontiers in Psychiatry, vol. 16, no. 16, p. 1588745, 2025, doi: 10.3389/fpsyt.2025.1588745.

[6] O. D. Kothgassner, A. Goreis, J. X. Kafka, et al., "Virtual social support buffers stress response: An experimental comparison of real-life and virtual support prior to a social stressor," Journal of Behavior Therapy and Experimental Psychiatry, vol. 63, pp. 57-65, 2021, doi: 10.1016/j.jbtep.2018.11.003.

[7] M. H. E. M. Browning, K. J. Mimnaugh, C. J. van Riper, H. K. Laurent, and S. M. LaValle, "Can simulated nature support mental health? Comparing short, single-doses of 360-degree nature videos in virtual reality with the outdoors," Frontiers in Psychology, vol. 11, p. 574379, 2020, doi: 10.3389/fpsyg.2020.574379.

[8] M. Hedblom, B. Gunnarsson, B. Iravani, I. Knez, F. E. Schaefer, P. Thorsson, and J. N. Lundström, "Reduction of physiological stress by urban green space in a multisensory virtual experiment," Scientific Reports, vol. 9, p. 10113, 2019, doi: 10.1038/s41598-019-46099-7.

[9] S. Tang, "23 Effect of natural landscape art design on the psychological treatment of patients with anxiety disorder," Current Opinion in Psychiatry, vol. 38, no. Sup1, p. 15, 2025, doi: 10.1097/01.yco.0001119180.18049.a9.

[10] O. S. Mattila, T. Korkeamäki, T. Auvinen, and O. Lappi, "Restorative effects of immersive virtual reality forest environments," International Journal of Environmental Research and Public Health, vol. 17, no. 15, p. 5443, 2020.

[11] M. Stoppa and A. Chiolerio, "Wearable electronics and smart textiles: A critical review," Sensors, vol. 14, no. 7, pp. 11957-11992, 2014, doi: 10.3390/s140711957.

[12] B. Parida, B. Bhushan, and A. K. Bhoi, "Wearable sensors for healthcare monitoring: A review," Materials Today: Proceedings, vol. 45, pp. 5672-5678, 2021.

[13] W. Zeng, L. Shu, Q. Li, S. Chen, F. Wang, and X. M. Tao, "Fiber-based wearable electronics: A review of materials, fabrication, devices, and applications," Advanced Materials, vol. 26, no. 31, pp. 5310-5336, 2014, doi: 10.1002/adma.201400633.

[14] S. Seyedin, J. M. Razal, P. C. Innis, A. Jeiranikhameneh, S. Beirne, and G. G. Wallace, "Knitted Strain Sensor Textiles of Highly Conductive All-Polymeric Fibers," ACS Applied Materials & Interfaces, vol. 7, no. 38, pp. 21150-21158, 2015, doi: 10.1021/acsami.5b04892.

[15] Y. Ma, et al., "Mind nature: A virtual reality nature therapy for reducing anxiety and improving mood among university students: A randomized controlled trial," International Journal of Clinical and Health Psychology, vol. 25, no. 1, p. 100503, 2025, doi: 10.1016/j.ijchp.2025.100503.

[16] D. Cui, "Optimization of ecological landscape of urban human settlements under edge effect," Signal, Image and Video Processing, vol. 19, no. 7, pp. 1-14, 2025, doi: 10.1007/s11760-025-04129-0.