Pak. j. life soc. Sci. (2024), 22(2): 18552-18575 E-ISSN: 2221-7630;P-ISSN: 1727-4915

Pakistan Journal of Life and Social Sciences

www.pjlss.edu.pk

https://doi.org/10.57239/PJLSS-2024-22.2.001360

RESEARCH ARTICLE

Research on Immersive Experience Design of Oceanarium under the Perspective of Embodied Cognition

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ARTICLE INFO

Received: Oct 19, 2024

Accepted: Dec 10, 2024

Keywords

AHP
CRITIC
Embodied cognition
Immersive experience
Oceanarium

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ABSTRACT

In recent years, the design of oceanariums, as an important space for conveying the awareness of marine ecological protection, has gradually developed towards immersive experience to enhance users' emotional resonance and immersion. Under the perspective of embodied cognition theory, users' physical participation and sensory experience have an important impact on their emotional connection and cognitive effect. This study aims to explore how to optimize the immersive experience of an oceanarium through embodied cognition design principles in order to enhance the depth of users' experience and educational effects. The study combines the AHP and CRITIC models to construct a multidimensional evaluation system for oceanarium immersive experience, taking eleven key indicators such as sensory experience, technological immersion, and emotional connection as the evaluation content, and selecting six globally renowned oceanariums as the research objects to quantify and compare the importance of the indicators in the user experience through a multilevel weighting analysis. The results of the study show that sensory experience, technology immersion and storyline have higher weights in immersive experience, indicating that users have significant needs for multi-sensory integration and emotional interaction. In particular, storyline plays a prominent role in emotional connection, while the weight of technological immersion reflects users' reliance on advanced technologies such as virtual reality (VR) and augmented reality (AR). In addition, environmental atmosphere and spatial perception also play an important role in supporting the immersion effect of users. Based on the findings, this study proposes optimization suggestions for future oceanarium design, including the construction of emotional experience routes, deep immersion solutions combining multi-sensory interactive technologies, and spatial atmosphere shaping with dynamic lighting and sound effects. Through the intervention of embodied cognitive design, this study contributes to the realization of a more interactive and educational oceanarium immersion experience, providing an innovative solution for the communication of marine ecological conservation.

INTRODUCTION

Research background

The oceans and seas are the largest ecosystems on Earth and are rich in biodiversity and natural resources (LI, SHEN M & MA R, 2022). However, with the intensification of human activities, marine ecology is facing serious threats, with problems such as pollution, overfishing and climate change becoming increasingly prominent (Krishnakumar, Sathees & Nallusamy,2024)(Zhang, Zhang & Yang B, 2024). Research shows that the health of marine ecosystems is critical to the planet's biodiversity and human well-being (Wang, Li & Zhou, 2024). Therefore, the protection and sustainable development of the marine environment has gradually become a core issue of concern for countries around the world. In this context, public awareness of marine conservation needs to be raised urgently, and as an important educational and publicity venue, oceanariums play a key role in promoting people's understanding of marine ecology and awareness of conservation (Quijada, Navarrete & López-Pérez, 2024). The design concept of oceanariums is evolving with the rapid development of science and technology and the rising expectations of audiences for cultural experiences. By introducing advanced technologies such as augmented reality (AR), virtual reality (VR) and interactive exhibits, many oceanariums aim to enhance the sense of participation and the depth of experience of the audience, strengthen the connection between the audience and the exhibits, and provide them with a deeper emotional and cognitive understanding of marine ecology and its importance (Yuan, Zhang L & Kim, 202)(Hutson & Hutson, 2024). These innovative exhibition methods have effectively attracted the attention of the audience and enriched their sensory experience to a certain extent. However, some scholars have pointed out that most of the current interactive exhibitions in oceanariums rely too much on visual and auditory experiences, and often lack the mobilization of other senses (e.g., touch, smell, etc.)(Vistisen, Selvadurai & Krishnasamy, 2022). It's hard to create full immersion relying only on these two sensory stimuli (O'Conaill, Provan & Schubel, 2020). In addition, current oceanarium designs often lack elements that promote physical engagement. That is to say, many displays are static and viewers can only passively observe them, lacking elements that promote physical participation and minimizing opportunities for active participation and interaction by users (Li, 2023). In general, the development of immersive experience design for oceanariums enables the audience to obtain a rich and real perceptual experience through visual, auditory and other multi-sensory participation, though. However, the current experience facilities mainly rely on technical means (e.g., virtual reality, augmented reality), lack of attention to the interaction between the user's body and the environment, and are difficult to fully stimulate the audience's emotional resonance and deep cognition.

In related theoretical studies, embodied cognition emphasizes the importance of the body in the cognitive process, arguing that our thinking, feeling, and understanding are deeply influenced by our bodily experiences and environment (Ianì, 2021). From this perspective, the design of oceanariums can be revisited to find innovative ways to enhance audience immersion through multi-sensory and physical engagement. This will not only help to enhance the audience's participatory experience, but also promote understanding of the marine ecosystem and awareness of its protection.

Purpose and significance of the research

From the perspective of embodied cognition, this study aims to explore how to enhance the immersive experience of oceanariums and the optimization path of the design through the design concepts of multi-sensory experience and body participation, with specific objectives including:

1. to systematically analyze the key elements of embodied cognition theory in immersive experience design, and to explore its impact on the audience's emotional resonance.

2.To propose an immersive experience design strategy for oceanariums based on embodied cognition, and to enhance the audience's sense of immersion through multi-sensory interaction and physical participation.

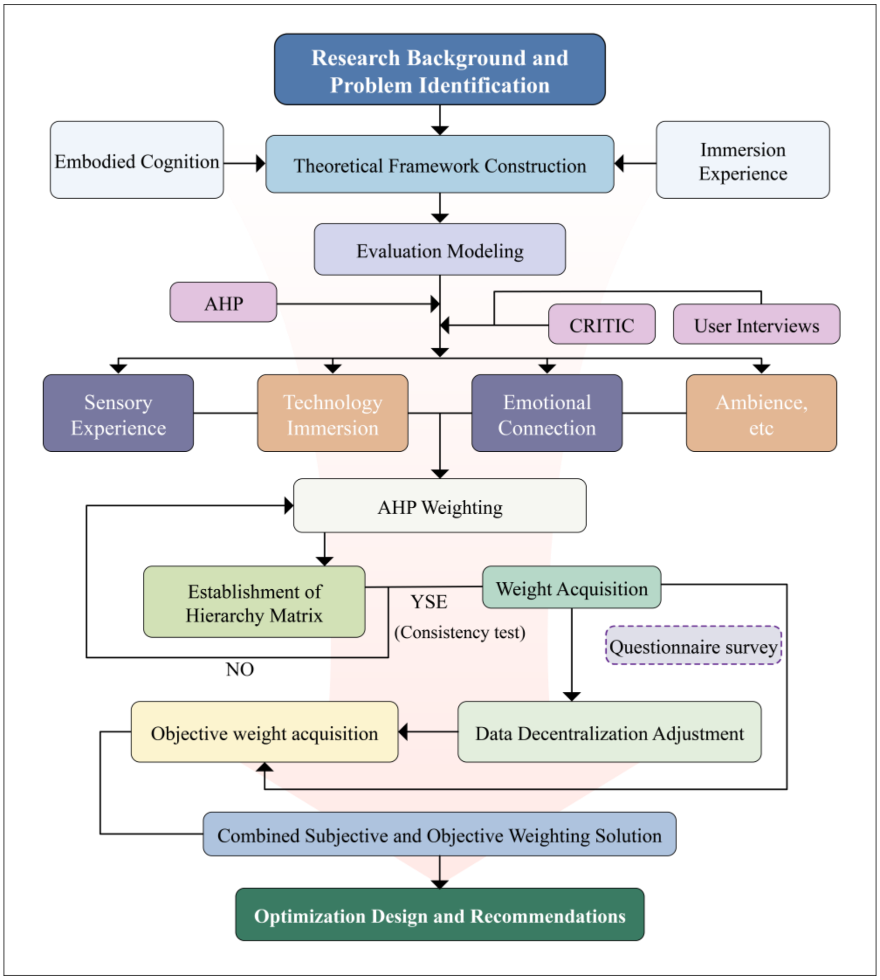

Figure 1: Research Flowchart

The specific research process is to obtain the target audience's expectation and preference for multi-sensory experience through semi-structured interviews. The collected sensory needs were evaluated by combining the hierarchical analysis method (AHP) and CRITIC method to quantify the importance of different sensory needs and to provide scientific data support (Li, Wei & Liu, 2021). Based on the results of the needs analysis and weighted evaluation, the study will provide actionable design suggestions for designers and decision makers to help them create more attractive and educational exhibition spaces, and the research process is shown in Fig. 1. Through the multi-sensory interactive design, the audience can gain a deeper learning and emotional experience through their participation, which will in turn enhance their understanding and love of the marine world. This study adopts a combination of quantitative and qualitative research methods to achieve the realization of the above research objectives, which will provide a scientific basis for the design practice of the Oceanarium and promote its development in a more user-oriented and sustainable direction. Through empirical research and case studies, this study will identify shortcomings in current oceanarium design and explore potential enhancement strategies for multisensory experiences.

Theoretical Examination

Immersive experience

Immersive experience is a kind of experience through multi-sensory participation and in-depth interaction, so that the user produces the feeling of 'being there' (Zhang, 2020). This kind of experience aims to maximize the mobilization of the user's perception and emotions, so that they feel a very high sense of concentration, authenticity and participation in a certain environment or situation. The application of immersive experience is wide-ranging, involving virtual reality (VR), augmented reality (AR), multimedia art exhibitions, immersive theater and many other fields, the core of which is to break the traditional passive experience mode, and instead build a more attractive and interactive environment through perception, action and contextual factors (Trunfio, Jung & Campana, 2022). A review of the relevant literature reveals that current scholars have categorized the key elements of immersive experiences into four main components, as shown in Table 1.

Table 1. Immersive Experience Impact Dimensions

Core Elements	Content	
Immersion	Realism	Realistic multi-sensory reproduction of sight, sound, touch and other senses allows the user to create real perceptions.
	Interactivity	Users are free to explore the environment and influence it, making them 'active participants' in the experience.
Mindstreaming	Immersive experiences guide users into a state of mind-flow through smooth interaction design and engaging plots, during which they are obliviously immersed in the task and achieve a high level of satisfaction.	
Multi-sensory integration	Immersive experiences enhance authenticity by integrating multiple senses such as sight, sound, touch, and even smell and taste.	
Emotional resonance	It tries to stimulate the user's emotional response, thus enhancing the memorability of the experience. The user not only 'enters' the experience sensually, but also resonates more deeply emotionally.	

Research shows that immersive experiences can significantly improve user learning and memory retention, and offer new possibilities for brand communication and consumer interaction (Baxter & Hainey, 2024). Combining the theory of immersive experience, WANG KEYU discusses the practical strategy of immersive experience games in the First Memorial Hall of the Communist Party of China, and finds that immersive experience has unique advantages in enhancing the brand communication effect of museums and the audience's sense of participation (Wang, 2024). WANYAN DENGDENG combines the theory of immersive experience to explore the constituent elements of user needs and their role paths in public digital cultural immersive experience space, and constructs a user needs model to provide theoretical basis and reference for improving the service practice of public digital cultural experience space (Wanyan & Song, 2024). It can be found that under the background of rapid technological development, the application scenes of immersive experience are more extensive, and the future design will pay more attention to emotional resonance and embodied interaction to promote the experience effect to a new height. This theory not only expands the way of user experience, but also brings new design perspectives and research directions for interaction design, media art, virtual reality and other fields.

Embodied cognition theory

Embodied Cognition theory (ECT) suggests that human cognition is not just a product of the brain, but is profoundly dependent on the interaction of the body and the environment (Caracciolo & Kukkonen, 2021). Originating in psychology and philosophy, this theory has evolved into a central concept explaining how humans construct meaning through bodily experiences and motor processes. Unlike traditional cognitive science, which views cognition as the processing of information within the brain, embodied cognition theory emphasizes the dynamic connection between the brain, body, and environment (Danish, Enyedy & Saleh, 2020). Specifically, an individual's perceptions and behaviors during real interactions affect and even shape the way they are perceived, and these perceptions in turn act on the person's perceptions, emotions, and motivations (Risku & Rogl, 2020). In the embodied cognition perspective, the individual's understanding process is not isolated, but is realized through the involvement of multiple senses (e.g., touch, smell, vision, etc.), as shown in Figure 2.This theory emphasizes that 'thinking' is not only a purely cerebral activity, but also involves adapting to and responding to the surrounding environment (Makransky & Petersen, 2021). Adaptation to the environment is not only gained through passive observation, but also constructed through active participation such as movement and tactile sensation, which leads to a deeper emotion and understanding of the individual. A review of the relevant literature reveals that scholars now generally categorize embodied cognition into three levels, namely the micro-level, meso-level, and macro-level, see Figure 3. The micro-level explores how one's own physical and physiological mechanisms influence and support cognitive processes. The meso-level, on the other hand, explores how cognition is realized through the body's interaction with the environment. The macro level emphasizes collaboration and shared cognitive processes across individuals.

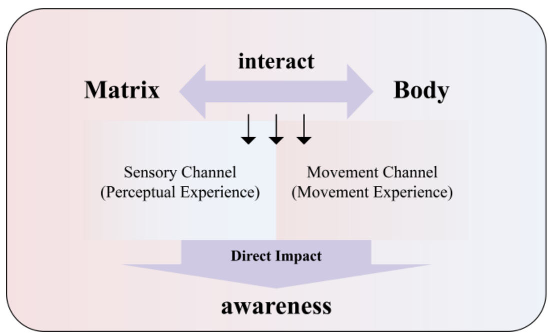

Figure 2: Correlation Diagram of the Impact of Embodied Cognitive Impact

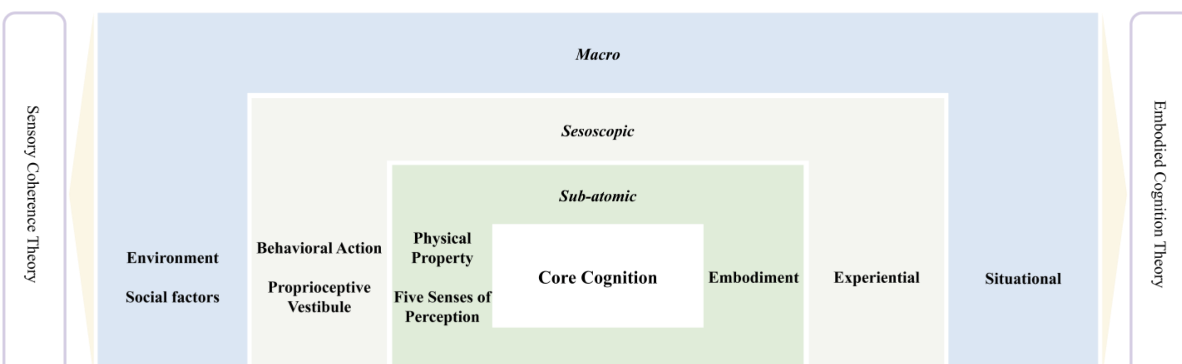

Figure 3: Three levels of embodied cognition

In the related embodied experience research, YE QING uses snow and ice symbols as the base, and integrates embodied cognition into the museum design by transforming snow and ice elements into architecture, urban furniture and multimedia interactive installations, so as to enable visitors to deepen their experience and understanding of snow and ice culture through physical interactions (e.g., tactile sensation, VR/AR, light and shadow, etc.) (Ye, Feng & Lu, 2024). SUN YUANXI satisfies users' sensory, motor and contextual needs in the three directions of 'perception, kinaesthesia and reflection', thus enhancing immersive experience and consumption atmosphere in the shopping street environment, and realizing the embodied design strategy of the interactive installation (Sun & Yi, 2024). Guided by the theory of embodied cognition, ZHANG XIAN constructs a multi-sensory interactive narrative space from four perspectives, from conceptual design to hardware selection, software authoring, and space construction, to enhance the user's immersive experience and emotional engagement (Zhang & Luo, 2023). Thus, the theory of embodied cognition provides an important theoretical basis for immersive experience design, i.e., by increasing physical participation and multi-sensory interaction, it enhances the emotional resonance and cognitive depth of users, so that they can better understand the content of the experience. In the design of multi-sensory narrative space, the application of embodied cognition theory can enrich the level of experience, and bring users a more immersive and interactive experience (Lin & Lu, 2024). Therefore, the theoretical revelation of embodied cognition is significant in the design of immersive experiences in oceanariums. By enhancing interactivity, introducing multi-sensory experiences, and increasing bodily participation, the audience is able to perceive the diversity of marine life, the complexity of the ecosystem, etc. more intuitively and vividly.

AHP-CRITIC composite weights

Analytic Hierarchy Process (AHP) is a quantitative method for decision analysis, proposed by Thomas Saaty in the 1970s (Qi, Zhang & Kim, 2024). This method is particularly suitable for the systematic analysis of complex decision-making problems, and is designed to provide a clearer assessment of the relative importance of factors by decomposing complex problems into multiple hierarchies.The basic steps of the AHP include defining the decision objectives, constructing hierarchies, performing pairwise comparisons, and calculating weights and consistency ratios (Qi, Kim & Lu, 2024). First, the overall objective of the study is clarified and decomposed into a number of related sub-objectives and evaluation indicators to form a hierarchical model. Next, pairwise comparisons of the hierarchical factors are made, and the factors are scored according to their importance, usually on a scale of 1 to 9, where 1 means that two factors are equally important and 9 means that one factor is absolutely more important than the other, as shown in Table 2, which helps to quantify the subjective judgments and lays the foundation for the subsequent calculation of the weights. After pairwise comparisons are made, the weights of the factors are calculated using the eigenvector method or the geometric mean method to further determine the contribution of each factor to the overall goal (Saremi, Maghsoudi & Hoseinzade,2024). In addition, in order to ensure the reliability of the decision-making process, AHP also includes consistency test, in which the decision maker needs to check the Consistency Ratio (CR) of his/her comparative judgments to ensure that the judgments are reasonable and reliable. If the CR value is less than 0.1, it means that the judgment has good consistency, and vice versa, the judgment process needs to be reevaluated (Elraaid, Badi & Bouraima, 2024). The strength of AHP lies in its ability to combine qualitative and quantitative data to provide a structured approach to decision-making that is applicable to a variety of areas, such as project evaluation, resource allocation, and risk management (Liu, Eckert & Earl, 2020). Therefore, AHP is widely used in academia and practical applications, becoming one of the important tools for decision analysis and providing clear and systematic solutions to complex decision problems.

Table 2. AHP Evaluation Indicators Scale

Rank	Judgmental Implications
1	Indicates that both are equally important
3	Indicates that one factor is more important than the other
5	Indicates that one factor is significantly more important than the other
7	Indicates that one factor is more important than the other
9	Indicates that one factor is absolutely more important than the other
2.4.6.8	Provides a more nuanced judgment of relative importance as an intermediate value

CRITIC (CRiteria Importance Through Intercriteria Correlation) is a method for multi-attribute decision analysis designed to assess the importance of each decision criterion and assign weights to them (Qi, Han & Lu, 2024). The core idea of the CRITIC methodology is to determine the relative importance of individual criteria by analyzing their correlation and variability. The method consists of several key steps:

1. constructing a decision matrix where the rows represent the different decision alternatives and the columns represent the individual evaluation criteria .

2. calculate the standard deviation of each criterion to assess the amount of information it provides in the decision. The larger the standard deviation, the greater the ability of the criterion to discriminate between decisions.

3. Calculate the correlation coefficients between the different criteria to assess their interrelationships. Criteria with higher correlation will provide redundant information in decision making, and therefore their importance will be relatively lower.

4. Combining standard deviation and correlation, a formula is used to calculate the final weight of each criterion to support decision making.

The advantage of the CRITIC method is that it can objectively reflect the importance of each criterion, reduce subjective bias, and has strong applicability and flexibility in multi-attribute decision-making, which makes it suitable for a variety of practical application scenarios, such as resource allocation, project evaluation and risk analysis (Žižović, Miljković & Marinković, 2020). The CRITIC method has gradually received widespread attention in academia and industry in recent years, and has been successfully applied in decision-making research in a variety of fields (Wang, Li & Zhao) (Zhan, Zhang & Yuan, 2024).

In complex multi-attribute decision-making problems, the combination of AHP and CRITIC methods can give full play to their respective advantages.AHP provides a structured decision-making process, which is suitable for dealing with subjective judgments, while the CRITIC method provides objective weight assessment for each indicator. By combining these two methods, decision makers are able to obtain a more scientific weight assignment based on data analysis while considering subjective opinions, thus improving the effectiveness and accuracy of decision making. In a related study, Pang N combines the AHP-CRITIC theory applied to the safety evaluation of driving behaviors of operating vehicles, calculates the weights of each indicator, and provides a clear safety evaluation and differentiation basis for driver types with different driving styles (Pang, Luo & Wu, 2023). In his study, Yu S used AHP to determine the subjective weights of the design of Fukunan wicker home products, followed by CRITIC to calculate the objective weights, thus providing a comprehensive basis for evaluating and ranking different design options (Yu, Zhu & Liu, 2024). It can be seen that the AHP-CRITIC method provides a clear basis for design decisions and helps the design team to make the best choice with limited resources. In this study, the design of the oceanarium immersive experience involves multiple interaction factors and their interrelationships, and the AHP-CRITIC method is able to flexibly cope with this complexity. By analyzing the interdependence between different factors, key drivers and potential problems can be identified, providing a scientific basis for design decisions.

Getting the User Experience Dimension

Constructing interview outlines

In order to obtain users' feelings about the immersion of the Oceanarium, this study adopts the semi-structured interview approach to conduct interview research with users and experts. This is because semi-structured interviews are suitable for exploratory research, helping the researcher to establish a theory or understand a particular phenomenon through in-depth conversations, and then laying the foundation for subsequent research evaluation (Adeoye - Olatunde & Olenik, 2021). This study combines the theory of embodied cognition to design an interview outline around the multisensory and physical interactive experience of the oceanarium immersive experience, in order to comprehensively explore the users' experiences and responses in multiple dimensions. Embodied cognition theory suggests that cognition is not only a product of the brain, but also the result of the integrated interaction between the individual and the environment, the body and the senses. In an immersive experience environment, multi-sensory stimulation and physical interaction create a deep emotional and cognitive experience for the user (Bandyopadhyay, Sarkar & Swain, 2023). Therefore, the design of the interview outline is based on the sensory and action interaction perspective in embodied cognition theory, specifically covering the core dimensions of five senses experience, body movement and emotional response to ensure that the interviews can capture comprehensive information about the user experience, and provide a basis for structured analysis of the user experience. The interview outline, guided by the theory of embodied cognition, covers the multidimensional responses of users in the oceanarium immersion experience. In the interview process, we follow the basic principle of 'easy before difficult', guiding the interviewees to start from the overall feeling and discussing the details of the use process in depth, so as to provide a scientific basis for analyzing the immersive experience of the users.

Table 3. Introduction to selected interview outlines

No.	Interview outline
1	What visual elements struck you during your visit? How did these elements affect your mood?
2	How did the background music or sounds you heard during your visit affect your experience?
3	When interacting with the exhibits, how did the texture of the touch affect your experience?
4	Have you ever smelled a particular odor? How did the odor affect you emotionally?
5	Did you spontaneously move or interact with the exhibits during your visit? How did these movements affect your experience?
6	Did you feel 'in the moment' during the experience? Which factors most enhanced this feeling?
......	......

User interviews and data organization

In order to ensure the representativeness and scientific validity of the interview data, this study conducted a rigorous screening of the interview users. Specifically, the selection criteria of users were based on three aspects: age, immersive experience experience and health status, in order to comply with the requirements of embodied cognition theory on multisensory interaction. User recruitment was conducted by posting an initial screening questionnaire through social media platforms to collect participants' basic information, immersive experience experience, and health status in order to screen users who met the requirements of the study (Dearnley, 2005). Fifteen users were finally selected, including 8 males and 7 females, spanning the age range of 24-41 years old, and the detailed information is shown in Table 4. The interview period lasted from September 2024 to October 2024, and all research participants signed an informed consent form before the start of the interview to ensure that they had a clear understanding of the content of the study, its purpose, the risks that might be involved, and the protection of their personal privacy. During the experiment, 20-40 minutes of in-depth communication was conducted with each participant around the content of the outline, and the participants were encouraged to describe and evaluate the relevant content outside the interview outline based on their actual experience of using it (Qi Y, Ni & Xue, 2024).

Table 4. Profiles of interviewed users

No.	Sex	Age	Degrees	Occupation	Immersive Experience Context	Health Status
1	Male	28	Master's Degree	Designer	VR□AR	Health
2	Female	34	Undergraduate	Teacher	VR	Health
3	Male	23	Bachelor's Degree	Marketing	AR	Health
4	Female	31	Master's Degree	Technology Developer	VR	Health
5	Male	40	PhD	Analyst	AR	Health
6	Female	27	Bachelor's Degree	Designer	VR□AR	Health
7	Male	33	Master's Degree	Internet Engineer	VR	Health
8	Female	24	Bachelor's Degree	Photographer	AR□VR	Health
9	Male	38	Bachelor's Degree	Freelancer	AR□VR	Health
10	Female	29	Master's Degree	Graphic Designer	AR□VR	Health
11	Male	26	Bachelor's Degree	Architecture	AR	Health
12	Female	30	Master's Degree	Housewife	AR□VR	Health
13	Male	41	PhD	Teacher	AR	Health
14	Female	36	Bachelor's Degree	Freelance	VR	Health
15	Male	32	Master's Degree	Freelance	AR□VR	Health

After obtaining the raw user data, the interview data is organized, and strict steps are followed in the organization process to ensure the accuracy and consistency of the data (Mukurunge, Nyoni & Hugo, 2024). First, the interviews were transcribed into text through audio recording, and the transcribed text was cleaned to remove irrelevant content. Then, the research team members discussed and negotiated to categorize and extract themes from the data, focusing on the dimensions of sensory experience, emotional response and motion perception. The data was analyzed using NVivo software, which helped to quickly identify key themes and patterns (Uibu, Binsol & Põlluste, 2024). Finally, to ensure the credibility of the data, triangulation was used for cross-comparison, and the reliability of the results was strengthened by expert review to finally obtain the three dimensions affecting users' immersive experience, of which there are three primary dimensions, 11 secondary dimensions, and 30 subdimensions, as shown in Table 5.This data collation process provides a solid foundation for the subsequent analyses and research conclusions.

Table 5. Three dimensions of immersive experience

Main Dimensions	Sub-dimension	Subdimensions
Perception & Cognition A1	Sensory Experience B1	Visual C1
		Hearing C2
		Tactile C3
		Taste C4
		Sense of smell C5

	Spatial perception B2	Sense of spatial depthC6
		Sense of direction C7
		Spatial Layout C8
	Motion perception B3	Body Movement C9
		Freedom of Movement C10
		Motion Feedback C11
	Time perception B4	Sense of Time Distortion C12
		Sense of time involvement C13
Emotion & Interaction A2	Emotional Response B5	Sense of identity C14
		Excitement C15
		Relaxation C16
	Social Interaction B6	Group Interaction C17
		Social Feedback C18
	Interactive Experience B7	Interaction Fluency C19
		User Sense of Control C20
		Feedback System C21
	Story and Plot B8	Story Coherence C22
		Plot Immersion C23
Environment & Technology A3	Environmental Atmosphere B9	Lighting DesignC24
		Scene Design C25
		Ambient Music C26
	Technology Immersion B10	Equipment Immersion C27
		Virtual Realism C28
	Contextual Adaptation B11	Contextual realism C29
		Adaptability of Context C30

Subjective and objective evaluation

AHP-based subjective evaluation

Evaluation modeling

In the subjective evaluation of immersive experiences, AHP is used to assess the importance of different experience dimensions.The AHP method can effectively quantify the relative contribution of each dimension to user immersion through expert review and quantitative analysis (Dobrodolac, Lazarević & Jovčić, 2024). In this study, an AHP was used to subjectively evaluate the key dimensions of immersive experience in order to reveal which factors have a dominant role in users' immersion perception. The subjective evaluation model based on AHP consists of three levels: the goal level, the criterion level, and the sub-criterion level. The goal layer is 'comprehensive evaluation of user immersion', the criterion layer includes perception and cognition, emotion and interaction, environment and technology, and the sub-criterion layer includes sensory experience, spatial perception, motion perception, interaction experience, emotional response, time perception, social interaction, story and plot, technology immersion, environmental atmosphere, and contextual adaptation dimensions. , as shown in Figure 4. The specific sub-dimensions under each dimension constitute the programmatic layer, reflecting the influence of different levels on immersion.

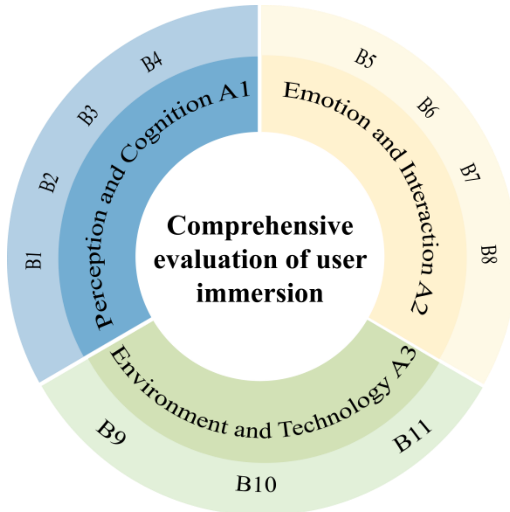

Figure 4: AHP evaluation model

Evaluation process and results

Based on the evaluation model, a total of 8 experienced experts in the field of immersive design were invited to evaluate the above user experience dimensions in terms of their academic background, industry experience, and knowledge of design and user experience. 62.5% of the 8 experts were male and 47.5% were female, aged between 30 and 50, and 75% of them possessed a doctoral degree, while 25% of them possessed a master's degree. 25%. The experts are highly educated in UX-related professional knowledge, design practices, and understanding of immersive environments. Referring to Table 2, a scale of 1-9 was used and the importance of each pair of dimensions was rated according to the actual situation. To ensure the consistency and rationality of the ratings, this study was tested by the consistency ratio (CR) after experts compared the dimensions two by two (Qi & Kim, 2024). A CR value of less than 0.1 is considered to have better consistency, meaning that the experts were more consistent in their judgments when making the ratings. If the CR value is greater than 0.1, the comparison matrix is adjusted to ensure the rationality and reliability of the decision-making process (Tayalati, Boukrouh & Bouhsaien, 2024). Based on the two-by-two comparison matrix of the experts, the weights of each dimension were calculated using the eigenvector method of AHP, and the detailed calculation process is as follows:

1. The matrix is first regularized:

$$\overline{a_{ij}} = a_{ij} / \sum_{i=1}^{n} a_{ij} (\mathrm{i.j} = 1\square 2\square \ldots\ldots \mathrm{n})$$

Where is the data in row i and column j of the judgment matrix A, and is the data in row i and column j of the regularization matrix.

2. Add the elements of the matrix:

$$\overline{w_i} = \sum_{j=1}^{n} \overline{a_{ij}} (\mathrm{i.j} = 1\square 2\square \ldots\ldots \mathrm{n})$$

3. for the above equation, regularization is implemented:

$$w_i = \overline{w_i} / \sum_{i=1}^{n} \overline{w_i} (i = 1，2，\ldots\ldots n)$$

4. Compute the maximum eigenvalue of the judgment matrix A:

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(Aw)_i}{w_i}$$

where n is the order of the matrix, A is the judgment matrix, and is the weight of the ith indicator. is the maximum eigenvalue of the judgment matrix A (Podvezko, 2009).

5. consistency test, for the vector obtained earlier, as well as the eigenvalues, consistency test, if you can pass the test, it means that the construction of the judgment matrix is reasonable, both the existence of the value of the interpretation. Assuming that CI stands for consistency index, the following is the arithmetic method:

$$CI = \frac{\lambda_{max} - \mathrm{n}}{n - 1}$$

Through the value of n, it is possible to obtain the value of RI, so that the consistency ratio is obtained, both when the CR < 0.1, then the test meets the requirements, as shown in Table 6.

Table 6. RI numerical indicator

N	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

(Randomized consistency indicator RI)

Through the AHP calculation and consistency test, the evaluation indexes and weight values of each experience dimension were finally obtained, see Table 7-10.After the consistency test all the indexes have CR<0.1, which passes the consistency test and proves that the evaluation indexes are valid.

Table 7. Normative level evaluation indicators

	A1	A2	A3	w_i	CR
A1	1	3	2	0.539	
A2	1/3	1	1/2	0.164	0.009
A3	1/2	2	1	0.297	

Table 8. A1 sub-criteria level evaluation indicators

	B1	B2	B3	B4	w_j	CR
B1	1	5/4	3/2	6/5	0.337	
B2	4/5	1	2	8/5	0.272	0.001
B3	2/3	5/6	1	4/3	0.223	
B4	1/2	5/8	3/4	1	0.168	

Table 9. A2 sub-criteria level evaluation indicators

	B5	B6	B7	B8	w_j	CR

B5	1	6/5	4/3	2	0.325	0.001
B6	5/6	1	10/9	3/2	0.264	
B7	3/4	9/10	1	3/2	0.244	
B8	1/2	2/3	2/3	1	0.167	

Table 10. A3 sub-criteria level evaluation indicators

	B9	B10	B11	w_j	CR
B9	1	5/4	3/2	0.405	0.003
B10	4/5	1	6/5	0.324	
B11	2/3	5/6	1	0.271	

After obtaining the combined weights of each indicator, they are used in the actual decision-making or scoring system. Indicators with larger weights indicate a greater influence on the final decision, while indicators with smaller weights have relatively less influence. With these combined weights, multiple indicators can be converted into a single score, as shown in table 11.

Table 11. Values of composite weights for AHP sub-criteria layers

Major level	w_i	Secondary level	w_j	w_{AHP}	sequence
A1	0.539	B1	0.337	0.182	1
		B2	0.272	0.147	2
		B3	0.223	0.120	3
		B4	0.168	0.091	5
A2	0.164	B5	0.325	0.053	7
		B6	0.264	0.043	8
		B7	0.244	0.040	9
		B8	0.167	0.027	10
A3	0.297	B9	0.405	0.120	3
		B10	0.324	0.096	4
		B11	0.271	0.081	6

The combined weight values of B1 and B2 indicators are 0.182 and 0.147, respectively, with high weights, indicating that this indicator should be prioritized in immersive experience design.The weight indicators of B7 and B8 are 0.040 and 0.027, respectively, with low weight values, representing that these two indicators have relatively little influence in the overall goal. Therefore, in decision-making, the priority of such indicators can be appropriately lowered with limited resources in order to focus resources on key influencing factors.

CRITIC-based objective weighting evaluation

Questionnaire Design and Research

In order to further enhance the subjectivity of the AHP analysis, the CRITIC method was combined to introduce the objective weight assessment in order to realize the comprehensive evaluation of subjective and objective weights. First, the questionnaire was designed based on the core indicators of immersive experience design under the perspective of embodied cognition derived from the interviews, including sensory experience B1, spatial perception B2, motion perception B3, temporal perception B4, emotional reflection B5, social interaction B6, interactive experience B7, stories and plots B8, environmental ambience B9, technological immersion B10, and situational adaptability B11. In order to make the research design more informative In order to make the research design more informative, relevant existing cases were included in the questionnaire research to evaluate the key indicators from the actual application of similar contexts (Qi, Wei & Wang, 2024). In this study, we refer to the recommendation lists of several world-renowned travel ranking platforms, such as Lonely Planet and National Geographic, to obtain representative immersive experience aquariums in some countries and number them, as shown in Table 12.These aquariums are highly recognized for their outstanding immersive design and experience, which provides the basis for the visitors' feedback, experience ratings, and evaluation of interactive space design. evaluation of the design of the interactive space provides the basis.

Table 12. Representative examples of immersive oceanariums

Georgia Aquarium	S1	Okinawa Churaumi Aquarium	S2
			
S.E.A. Aquarium	S3	Shanghai Ocean Aquarium	S4
			
Nausicaá - Centre National de la Mer	S5	Dubai Aquarium & Underwater Zoo	S6

To ensure that the questionnaire covers all types of key indicators. The specific cases were scored through a percentage system (0-30 indicating not acceptable, 31-50 indicating quite acceptable, 51-60 indicating good, 61-80 indicating excellent, and 81-100 indicating outstanding), and the subsequent data counting process averaged the scoring results as the final score for subsequent standard deviation and correlation analyses. The distribution of the questionnaires was done online, through social media platforms, covering participants from different backgrounds and regions, including ordinary tourists and experts in the field, to ensure the diversity and representativeness of the data (Campbell, Kuah & Hall-Craggs, 2022). A total of 400 questionnaires were distributed, of which 380 were validly collected, a recovery rate of 96%. After the data collection was completed, the data were cleaned and invalid or incomplete questionnaires were eliminated to ensure the quality of the data.

CRITIC Calculation and Analysis

The weights of each key indicator in the immersive experience design of oceanariums are quantified by the CRITIC method to support the optimization of experience under the perspective of embodied cognition.The CRITIC method utilizes the correlation and discretization between indicators to assess the amount of information in each indicator, so as to obtain a more objective weight assignment. In summary, for the comprehensive evaluation of user experience of mainstream e-commerce platforms in China, six representative venues were selected as research objects, and a decision matrix was constructed based on 11 indicators of user experience. The scores of the six platforms on each indicator are constructed into an original matrix, where denotes the platform number and denotes the user experience indicator number, and the following is the detailed calculation process.

1. Standardized processing: due to the inconsistency of the scale of different indicators, it is necessary to standardize the matrix X (Srinivasan, Eysenbach & Ha, 2020). Polar deviation standardization formula is used, where, $\mathrm{min}(\mathrm{x_j})$ and $\mathrm{max}(\mathrm{x_j})$ are the minimum and maximum values of indicator j, respectively, and $\mathrm{Z_{ij}}$ is the standardized score matrix element.

$$Z_{ij} = \frac{x_{ij} - min(x_j)}{max(x_j) - min(x_j)}$$

Calculation of the deviation value of each indicator: the deviation value indicates the degree of dispersion of the distribution of the indicator and is used to measure the objective information content of the indicator. The formula is: where $\mathrm{Z_{ij}}$ is the average value of indicator j and $\mathrm{D_j}$ is the deviation value of indicator j..

$$D_j = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(Z_{ij} - \bar{Z}_j\right)^2}$$

Calculation of the matrix of correlation coefficients between indicators: The correlation coefficients reflect the interrelationships between indicators, as shown in Table 13. The correlation coefficients between the jth and kth indicators are calculated r_{ik}:

$$r_{ik} = \frac{\sum_{i=1}^{m}\left(Z_{ij} - \bar{Z}_j\right) \times \left(Z_{ik} - \bar{Z}_k\right)}{\sqrt{\sum_{i=1}^{m}\left(\left(Z_{ij} - \bar{Z}_j\right)\right)^2 \times \sum_{i=1}^{m}\left(\left(Z_{ik} - \bar{Z}_k\right)\right)^2}}$$

Table 13. Correlation coefficient matrix

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11
B1	1.000	0.866	0.872	0.872	0.957	0.849	0.846	0.940	0.859	0.793	0.904
B2	0.866	1.000	0.977	0.968	0.950	0.984	0.985	0.906	0.972	0.955	0.984
B3	0.872	0.977	1.000	0.965	0.936	0.997	0.968	0.907	0.934	0.908	0.992
B4	0.872	0.968	0.965	1.000	0.925	0.968	0.994	0.871	0.977	0.972	0.987
B5	0.957	0.950	0.936	0.925	1.000	0.933	0.921	0.988	0.907	0.871	0.958
B6	0.849	0.984	0.997	0.968	0.933	1.000	0.977	0.902	0.940	0.923	0.990
B7	0.846	0.985	0.968	0.994	0.921	0.977	1.000	0.864	0.985	0.983	0.985
B8	0.940	0.906	0.907	0.871	0.988	0.902	0.864	1.000	0.833	0.794	0.922
B9	0.859	0.972	0.934	0.977	0.907	0.940	0.985	0.833	1.000	0.988	0.961
B10	0.793	0.955	0.908	0.972	0.871	0.923	0.983	0.794	0.988	1.000	0.940
B11	0.904	0.984	0.992	0.987	0.958	0.990	0.985	0.922	0.961	0.940	1.000

Calculate the information content, C_j is the information content of indicator j and r_{ik} is the absolute correlation coefficient between indicator j and indicator k (Wang, Ha & Qiao, 2020).

$$C_j = D_j \times \left(1 - \frac{1}{m-1} \times \sum_{k=1, k\neq j}^{m} r_{jk}\right)$$

Calculate the weight of each indicator: according to the amount of information Cj determine the weight w_{CRITIC} of each indicator: at this time, the weight w_{CRITIC} indicates the importance of each indicator in the design of the immersive experience of the Oceanarium under the perspective of embodied cognition, as shown in Table 14.

$$w_{CRITIC} = \frac{C_j}{\sum_{j=1}^{n} C_j}$$

Table 14. Objective weighting of user experience metrics

	SIGMA	SUM	C_j	w_{CRITIC}
B1	0.398	1.242	0.494316	0.175

B2	0.35	0.452	0.1582	0.056
B3	0.365	0.544	0.19856	0.070
B4	0.398	0.501	0.199398	0.071
B5	0.375	0.655	0.245625	0.087
B6	0.366	0.537	0.196542	0.070
B7	0.379	0.492	0.186468	0.066
B8	0.396	1.073	0.424908	0.150
B9	0.366	0.644	0.235704	0.083
B10	0.395	0.873	0.344835	0.122
B11	0.371	0.378	0.140238	0.050

Calculation of combined weights

In this study, the subjective and objective weights of each indicator have been obtained by AHP and CRITIC methods respectively. In order to ensure the scientificity and comprehensiveness of the evaluation system, the subjective and objective weights are considered on this basis to obtain the final comprehensive weight of each indicator. The comprehensive weights not only reflect the experts' judgment of the importance of the indicators, but also objectively present the data distribution characteristics of each indicator, further enhancing the rationality of the evaluation.

The calculation of the comprehensive weight adopts the weighted average method, i.e., equal weights are assigned between the subjective weights of AHP and the objective weights of CRITIC, i.e., α=0.5, β=0.5, so as to fully reflect the balance of subjective and objective factors, and the formula for calculating the comprehensive weight w_S is as follows, and the final results are shown in Table 15.

$$w_s = \alpha \times w_{AHP} + \beta \times w_{CRITIC}$$

Table 15. Combined subjective and objective weighting of user experience metrics

	w_{AHP}	w_{CRITIC}	w_S	Sorting
B1	0.182	0.175	0.179	1
B2	0.147	0.056	0.102	3
B3	0.120	0.070	0.095	4
B4	0.091	0.071	0.081	6
B5	0.053	0.087	0.070	7
B6	0.043	0.070	0.057	9
B7	0.040	0.066	0.053	10
B8	0.027	0.150	0.089	5
B9	0.120	0.083	0.102	3
B10	0.096	0.122	0.109	2
B11	0.081	0.050	0.066	8

The comprehensive weighting results show that 'Sensory Experience (B1)' and 'Technological Immersion (B10)' have high weights in the overall evaluation, indicating that these indicators play an important role in the design of immersive experiences in the Oceanarium. In addition, the relatively high weights of 'Spatial Perception (B2)', 'Environmental Ambience (B9)' and 'Motion Perception (B3)' also indicate their significant influence on the quality of experience. The lower weights of 'Social Interaction (B6)' and 'Interactive Experience (B7)' indicate their relative inferiority in the comprehensive evaluation system.

Discussion and Analysis

In the comprehensive weighting analysis of this study, the importance ranking of different experience indicators is derived through AHP and CRITIC methods, revealing the optimization direction of immersive experience design. The results of this study show that sensory experience has significant importance in the immersive experience design of the Oceanarium, and its weight is significantly higher than that of other factors, indicating its core role in enhancing user immersion. Through the detailed shaping of visual, auditory and other sensory dimensions, users can more deeply feel the real atmosphere of the ocean world, and then achieve the effect of deep immersion experience (Cadet & Chainay, 2020). It has also been shown that multi-sensory interactions can effectively enhance the richness and engagement of an immersive experience, where high quality interactions of the visual and auditory senses are crucial. Visual and auditory senses are especially critical in immersive experiences, and the high fidelity of these senses is the basis for deep user immersion. For example, high-resolution display technology can make the visual effect more vivid and detailed, coupled with the enhancement of 3D surround sound, users can feel as if they were in the depths of the ocean (Hättich & Schweizer, 2020). Taking famous oceanariums such as S.E.A. Aquarium and Georgia Aquarium as examples, they adopt advanced high-definition projection and stereo sound systems to bring visitors a near-realistic ocean experience, so that users can truly feel the enveloping effect of the soundstage while viewing the dynamic marine life. In addition to visual and auditory enhancements, the integration of multi-sensory experiences is also a key trend. Advances in modern VR and AR technologies have created higher technical standards for multi-sensory interaction, allowing for the introduction of tactile and olfactory interaction dimensions on top of visual and auditory enhancement, thus greatly enhancing the user's sense of immersion (Feld, 2021). Therefore, future immersive design should not only focus on the optimization of a single sense, but also on how to achieve multi-sensory synergy. The high weight of technological immersion reflects users' strong demand for advanced technologies such as virtual reality (VR) and augmented reality (AR). It has been pointed out that immersive technologies such as VR and AR can not only significantly enhance the depth of user immersion, but also increase the fun and realism of the experience through vivid interaction (Fan, Jiang & Deng, 2022). In the case of the S.E.A. Aquarium and the Nausicaá National Maritime Center, AR/VR technology has become a key element of the user experience, not only providing a realistic visual and tactile experience, but also enabling the user to experience the diversity of the oceans in a somewhat 'immersive' way (Siedler, Glatt & Weber, 2021). Future immersive designs can go a step further by providing users with a more multidimensional interactive experience through mobile AR devices and haptic feedback systems. For example, while wearing a mobile AR device, the user can also experience the flow of sea water or the touch of marine life simulated by a haptic feedback device, which will effectively increase the technological content of the experience (Nahavandi, Alizadehsani & Khosravi, 2022). Such technological integration not only enhances the depth of the immersive experience, but also attracts a larger group of users who are sensitive to new technologies and willing to explore.

Storyline plays an important emotional bonding role in immersive experiences, and its high weight ranking demonstrates the influence of plot in establishing users' psychological connections. It has been shown that contextualized narratives can guide users' emotional ups and downs and stimulate their emotional resonance for the theme (Hwang & Lee). In several successful cases, oceanariums have used contextualized story lines to not only add interest to the viewing experience, but also to convey important messages about marine conservation. For example, the Nausicaá National

Maritime Center guides users to gain a deeper understanding of marine ecology and awareness of conservation through the interaction and backstory of virtual marine creatures. Future oceanarium designs could further adopt the strategy of "emotional experience routes", whereby entertaining storylines are woven throughout the visit (Wu, Teng & Hu, 2024). This type of narrative experience not only enhances the user's sense of participation, but also cultivates their environmental awareness more effectively. Users can develop a deeper psychological empathy for marine ecology in such a continuous emotional experience. The importance of environmental ambience and spatial perception in the immersive experience is also supported by the data. The weighting analysis shows that the creation of environmental ambience and the optimization of spatial perception are crucial in shaping realistic and layered spatial experiences. The study showed that dynamic light and shadow effects and ambient sound contribute to the depth and layering of the environment (Kaplan - Rakowski, Cockerham D & Ferdig, 2024). In S.E.A. Aquarium, the "deep sea adventure" scene is constructed through dynamic lighting and 3D surround sound, which makes users feel immersed and effectively enhances the realism of the immersive experience. Therefore, it is recommended to introduce dynamic lighting, controllable sound effects and other elements into the future design to build an immersive space with a sense of "wrapping". In addition, through a reasonable spatial layout and tour route design, users can be guided to move smoothly in the venue to avoid a sense of congestion, and improve the comfort and immersion of the tour (Liu J, Prouzeau A & Ens B, 2022).

The results of the comprehensive weighting analysis clearly reflect the priority and optimization direction of each element of immersive experience. Core factors such as emotional contextualized narrative have a high influence on the immersive experience of the Oceanarium. These key elements should be further enhanced in the future design to promote the deep-level optimization of the immersive experience by means of technological innovation, emotional triggering and personalized design, so as to satisfy the users' needs for real, sensory-rich and emotionally resonant immersive experience.

Conclude

Based on the theory of embodied cognition, this study systematically explores the key influencing factors in the immersive experience design of an oceanarium, and quantitatively analyzes the relative importance of different design elements through the combination of AHP and CRITIC methods. The results of the study show that sensory experience, technological immersion and contextual narrative have significant influence in user immersion experience, and these factors can effectively enhance users' sense of immersion, emotional engagement and scene memory. In addition, emotional response and environmental atmosphere also play an important role in constructing immersive experiences, providing a bridge of emotional resonance for viewers. This study not only verifies the applicability of embodied cognition theory in immersive experience design, but also expands the theoretical framework of immersive experience and provides a multi-dimensional research perspective for the field. In terms of practice, the research results provide data support and optimization direction for future immersive experience design in oceanariums and other cultural venues, specifically including key strategies such as multi-sensory design, application of advanced technology, and contextual narrative integration. By enhancing the immersiveness, interactivity, and personalization of the experience, this study provides practical guidance for improving the emotional connection and educational effect of the audience. Despite the progress made by this study in the field of immersive experience design, several limitations remain. First, the study's data sample size was relatively limited, covering only six oceanariums, and the sample range was insufficient to fully reflect the diversity of oceanarium experiences around the world. Therefore, future research should expand the sample size to cover oceanariums with different geographic and cultural backgrounds to enhance the generalizability of the findings. Future research should first validate the results of this study in a wider range of oceanarium environments to ensure the applicability of the conclusions on a larger scale. Second, the potential of emerging technologies (e.g., artificial intelligence-driven emotion recognition, multi-sensory interaction with augmented reality and virtual reality) in immersive experiences could be further explored to enhance the design of technological immersion.

Author Contributions

Qi Yuzhe conceptualized the idea, designed the project, and drafted the manuscript. Zhang Jing assisted with statistical analysis and manuscript editing. Liu Yaping contributed to the study design and assisted in drafting the manuscript. All authors read and approved the final manuscript.

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