The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-9-2025
30th CIPA Symposium “Heritage Conservation from Bits:
From Digital Documentation to Data-driven Heritage Conservation”, 25–29 August 2025, Seoul, Republic of Korea

Embodied Reconstruction of Digital Museum Applications: A New Paradigm for Cultural Communication Based on Perceptual Extension and Immersive Interaction

Fangfang Wang[1], Juan Du[1,*]

[1]Dunhuang Academy, Dunhuang, Gansu, China - (ffwangdh, dujuan0312) @126.com

Keywords: Immersive Experience, Embodied Cognition, Museum Experience.

Abstract

The audience constitutes the central subject of digital applications in museums, with their experience fundamentally grounded in the physical, embodied self. From the standpoint of embodied cognition, perception and experience arise through dynamic interactions between the body and its surrounding environment. The integration of digital technologies is not only transforming the paradigm of cultural transmission within museums but also reshaping the logic of interaction between audiences and cultural heritage through embodied integration, sensory augmentation, and environmental synthesis. Embodied cognition theory offers a critical theoretical framework for understanding this shift: by conceptualizing the body as a medium of cognition and emphasizing the coupling between cognition and environment, it elucidates how digital technologies facilitate deeper engagement between audiences and curatorial content via scenographic enhancement, narrative innovation, and technological embodiment. Consequently, digital applications transcend conventional sensory limitations, extending the perceptual capacities of the body to engender immersive experiential states. This "embodied presence" is characterized by a heightened synchrony between bodily experience and environmental stimuli, reconfiguring the museum as an embodied media space. Within this space, the museum's function evolves beyond that of a conduit for information dissemination to become a technologically augmented platform in which the audience's body serves as a primary medium for cultural interpretation. This process fosters an immersive mode of engagement wherein cognitive and affective dimensions coalesce, facilitating a dynamic integration of audience subjectivity, technological environments, and cultural meaning.

1. Introduction

1.1 Technocentrism and Audience Estrangement

Museums serve multiple functions, including cultural inheritance and preservation, social education and enlightenment, as well as cultural interaction and presentation. They are not only bridges between history and reality but also crucial windows through which people engage with the past and understand the future. A high-quality museum experience is vital for sparking public awareness and emotional resonance with cultural heritage. However, due to limitations in technology, design thinking, and exhibition spaces, traditional museums often remain exhibit-centered, with low audience engagement and poor interactivity. As a result, the audience struggles to become fully immersed and experience both physical and mental enjoyment.

With the continuous advancement of digital technologies, modern museums are utilizing applications such as VR, AR, and holographic projection to present the diverse values embedded in cultural relics in a more transcendent, interactive, and multidimensional manner. Digital applications in museums aim to transform static cultural display spaces into dynamic emotional connection mediums through technological means. The core goal is not only to present exhibits but also to inspire the full engagement of the audience, enabling them to reach a state of embodied immersion, thus achieving a dual enhancement of both cultural communication and audience experience.

While some museum digital applications claim to offer "immersive experiences" the frequent intervention of technology often fails to meet the perceptual needs of the audience. Instead, it shifts the focus of the exhibition from the transmission of cultural meaning to the display of the technology itself. Advanced digital technologies may create dazzling visual effects, yet they fail to establish a deep emotional connection between the audience and the exhibits. The audience's psychological state and sensory needs are ignored, leading to feelings of estrangement and fatigue in the face of information overload and technological intricacies.

1.2 Digital Applications and Immersive Experience

The active psychological state in which the audience is fully engaged, highly focused, filters out "noise," and reaches a state of pleasure and satisfaction is defined as the "Flow" experience by renowned American psychologist Mihaly Csikszentmihalyi (Nakamura and Csikszentmihalyi, 2002). As a cultural media space, museums aim to foster the generation of flow experiences for the audience through the immersive experiences provided by digital applications.

The flow experience focuses on the audience's cognitive state and psychological experience, emphasizing the concentration and enjoyment during an activity; digital applications, on the other hand, focus on constructing immersive exhibition environments, aiming to enhance the audience's sense of immersion. In terms of the mechanisms that shape the sense of immersion, the interactive relationship between the body, perception, and the external environment is crucial. The generation of immersive experience depends on the participation of the body, with cognition formed through bodily experiences and activities, while the interaction between the body and the external environment profoundly impacts the formation of perceptual experiences. Whether it is the flow experience or the immersive experience, their core lies in the

dynamic interaction between the body and the environment, leading to multisensory integration and emotional resonance, which aligns closely with the theory of embodied cognition.

1.3 Digital Applications and Embodied Cognition

Embodied cognition theory emphasizes the interconnection between the body, environment, and cognition: 1. The body participates in cognition, influencing mental processes such as thinking, judgment, attitudes, and emotions; 2. Perception of the objective world depends on the interaction between the body and the world, with bodily movements shaping representations of the objective world; 3. Abstract meanings are based on the body's sensory-motor systems; 4. Different bodily tendencies lead to distinct thinking and cognitive modes (Ye, 2014). Merleau-Ponty views the body as an intermediary connecting the external world with the internal world, with meaning emerging through bodily experience (Merleau-Ponty et al., 2013).

From the perspective of embodied cognition, digital applications center on human perception and enable the audience to construct their understanding and experience of cultural meanings through multisensory participation in the interaction between the body, exhibits, and the environment. This embodiment allows digital applications to transcend traditional information transmission methods, becoming a participatory process that integrates both body and mind, thus truly realizing a viewer-centered exhibition design concept. When museum digital applications begin with the body and perception, immersing people in the experience, the value and significance of the museum emerge through the bodily experiences of the audience.

2. Research Methodology

This study adopts a methodological approach that integrates theoretical analysis with case study research. It begins by systematically reviewing and analyzing foundational theories closely related to the research topic, including embodied cognition theory, immersion theory, the theory of the tourist gaze, and scenography theory. Through an in-depth examination of the internal logic and interrelations among these theoretical frameworks, the study establishes a conceptual foundation for understanding the embodied reconfiguration of digital applications in museums.

Building upon this theoretical groundwork, the research constructs a logical pathway and analytical framework for the embodied transformation of digital museum experiences, and accordingly proposes concrete strategies and approaches for implementing embodied design in digital contexts.

To assess the feasibility and practical effectiveness of the proposed theoretical paradigm, the study employs a case study methodology. It focuses on three representative digital cultural projects led by the Dunhuang Academy of China: the Digital Library Cave, Traveling in Dunhuang, and the Flying Apsaras-themed digital experience line. These cases are examined to evaluate and validate the theoretical model. By combining theoretical exploration with empirical analysis, the study seeks to offer meaningful insights into the embodied reconfiguration of digital museum applications and to explore its broader implications for cultural communication in the digital age.

3. Theoretical Approach: Everything Begins with the Body

3.1 Experience Originates from the Body

The museum experience is neither a simple stimulus-response connection nor merely a "purely mental product" as suggested by traditional cognitive science. Instead, it emerges from the dynamic interaction between the body, environment, and cognition. This experience involves higher-order cognitive processing, including concept formation and rational reasoning, all of which are profoundly influenced by the body and its modes of activity. Through its unique structure, sensory system, and motor capabilities, the body continuously interacts with the external environment. The sensations and feedback generated in this process construct our rich and complex experiential world.

Audiences perceive the environment through their bodily senses, and their perception and experience are constantly shaped by the real-time interplay, interaction, and feedback between the self and the world. At this moment, the external environment where the body is situated, the internal experiences it possesses, and the particular body schema[(1)] through which it engages with the museum space all significantly influence the perception and generation of experience. As John Urry noted, the "tourist gaze" is an embodied social practice involving multiple senses (Urry and Larsen, 2011). Similarly, the museum experience is constructed through multisensory engagement.

The design philosophy of digital applications in museums has shifted from "What can the museum display?" to "What can the audience perceive?" This shift aims to activate the dynamic interaction between the audience's body schema and the environment, ultimately fostering deeper immersion and cultural resonance.

3.2 The Body Immersed in the Environment

For a long time, vision has dominated the museum experience, with exhibits and their meanings presented through static, two-dimensional formats such as images, texts, and videos. However, these exhibits originally existed within specific cultural spaces and historical contexts. Once relocated to museums, they become detached from their original contextual environments. This reliance on a single visual mode of presentation makes it difficult to reconstruct historical contexts, temporal-spatial settings, and emotional atmospheres that engage the audience. Moreover, merely "seeing" is insufficient to fully activate and engage the audience's multisensory experience.

Scene Theory (Terry Nichols Clark) provides new insights into the cultural value of museum spaces. This theory emphasizes that a scene is not merely a physical space but also a carrier of culture and values. The combination of neighborhoods, architecture, facilities, crowds, and human activities within a geographic space conveys profound cultural significance. This perspective offers valuable guidance for museum space design: by constructing multidimensional scenes, museums can more effectively convey cultural meanings and enhance audience engagement.

In the era of digital intelligence, digital technologies enable the fusion and layering of history and reality. Every element of an artifact, along with the environments it has historically

[(1)] Body Schema: The unconscious framework of spatial awareness, movement, and environmental interaction.

inhabited—whether mountains and rivers, forests and oceans, urban streets, or rural fields — can be reconstructed and perceived through digital twin technology. This significantly enhances the audience's museum experience, allowing them to engage in profound historical dialogues within immersive environments.

3.3 Meaning Revealed Through the Body

Embodied cognition theory posits that perception and experience are inseparable from the body, and experience itself serves to guide action. Even when placed in the same external environment, different bodies perceive and experience the world differently.

In Mihaly Csikszentmihalyi's eight-channel model of flow theory, the degree of match between the challenge level of a task and an individual's skill level is the key to achieving flow. Higher levels of engagement, skill acquisition, and a sense of control correspond to a deeper state of flow. In other words, museums must provide audiences with the pleasure of challenge, which may involve acquiring new knowledge, mastering new interactive devices, or experiencing aesthetic and cultural enrichment. At the same time, audiences who possess richer knowledge, experiences, and media literacy are more likely to achieve an immersive experience in the museum setting.

In the evolution of tourist gaze theory, visitors often pre-consume information about their destination before physically entering the scene, forming an anticipated gaze—a process involving imagination, expectations, and prior experiences (Chen et al., 2024). This pre-experience, which includes knowledge, experience, and technical skills, plays a crucial role in shaping the museum visit. Therefore, effective museum communication that fosters a strong pre-experience is essential for enhancing visitor interest and engagement, achieving high-quality immersion, and promoting cultural transmission and education.

4. Practical Pathways: Scenographic Enhancement, Narrative Innovation, and Technological Embodiment

4.1 Scenographic Enhancement

As a cultural space, museums possess all the core elements of scene construction. From the perspective of scene theory, a museum scene is a carefully constructed environment or situation, which is formed by a combination of rich visual, auditory, and tactile sensory elements, as well as narrative components such as plots, characters, and tasks. This immersive experience relies not only on the physical and digital aspects of the scene but also on the dynamic interaction between the audience and the scene, i.e., the deep participation of the body in perception, movement, and emotion.

Based on centuries of descriptions of key aesthetic features, Clark's team developed a basic framework for scene construction (Clark and Li, 2017), which includes three main dimensions: authenticity, legitimacy, and dramatic quality, as well as 15 sub-dimensions such as localism, ethnicity, nationalism, community, rationality, traditionalism, leadership, utilitarianism, egalitarianism, self-expression, goodwill, transgression, individuality, fashion, and ritual. How to use digital technology to create a perfect immersive scene has become an important topic in the design of museum digital applications.

Under the dimension of authenticity, museums use high-precision scanning, digital modeling, and VR technology to accurately restore the original form of cultural relics and historical environments, providing audiences with a full view of real history. In terms of legitimacy, museums utilize big data analysis and AI technology to deeply interpret and scientifically classify cultural heritage, ensuring the accuracy and authority of exhibition content, and preventing historical distortion. Within the dimension of dramatic quality, technologies such as AR, holographic projection, and interactive screens turn static cultural relics into dynamic narratives, allowing the audience to transcend the limitations of time and space. Through interactions like touch, rotation, and zooming, these technologies stimulate multisensory experiences.

In the "A Journey to Dunhuang (An Immersive Digital Exhibition: Cave 285 of the Mogao Grottoes in Dunhuang)," technology plays a role akin to that of a skilled weaver: within the authenticity dimension, high-precision 3D modeling and VR technology recreate the cave structure and mural details of the Mogao Caves, enabling the audience to view murals up close and even "fly" to the top of the cave to experience light and shadow changes. In the legitimacy dimension, the exhibition strictly adheres to cultural heritage protection principles to avoid excessive entertainment or historical distortion. In the dramatic dimension, AR and VR technologies turn static murals into dynamic narrative scenes, allowing the audience to interact with characters like Thunder God and Apsaras and even participate in the storylines of the murals.

Figure 1. In-Depth Experience Scenario Diagram of A Journey to Dunhuang

Analyzing the deep structure of the "A Journey to Dunhuang" exhibition through the basic framework of scene theory reveals that all its dimensional indicators are closely integrated with technology. However, technology is not the focus or center of this exhibition. Rather, the scenes and content made possible by technology serve the enhancement of cultural communication and audience experience.

Figure 2. The Structure of A Journey to Dunhuang Scenes

4.2 Narrative Innovation

In the communication practices of museums, over-reliance on traditional narrative logic often results in a rigid role assignment between the communicator and the audience. The audience are typically limited to the role of "observers," passively following linear narrative paths, which restricts their ability to deeply immerse themselves in narrative imagination, interactive participation, and emotional resonance. This limits their ability to truly engage with the rich connotations and profound emotions of cultural heritage.

In the era of digital intelligence, the narrative medium in museums has expanded from traditional text and images to a combination of video, audio, and extended reality (XR), exhibiting features of multimodality, interactivity, and scenography. The display of cultural relics has shifted from being static to dynamic, and exhibition spaces have moved beyond physical limitations to develop into scenarios that blend the virtual and the real.

Through interactive design and personalized tours, museums evoke the audience's willingness to engage, prompting deeper participation in the narrative. This makes it possible for the layers of history and reality, virtuality and actuality, and interaction and narration to deeply intertwine, offering the audience a more three-dimensional and diverse exhibition experience. This design logic, known as "gamification," aims to "turn non-game things into games," i.e., to use game elements and techniques in non-game contexts, creating pleasurable experiences and encouraging active participation (Werbach and Hunter, 2012), distinct from the "banal entertainment" of culture.

The Dunhuang Academy's Digital Library Cave project is an innovative practice in which game technology is deeply integrated into museum experiences. It reflects game elements and mechanisms throughout the scene construction, visual presentation, and interactive design. The project uses high-definition digital scanning, 3D reconstruction, game engine physical rendering, dynamic lighting, and cloud gaming technology to achieve millimeter-level precision replication of the Mogao Caves 16 and 17 (The Library Cave) and their cultural relics. In terms of visual presentation, it adopts modern fine brush techniques akin to traditional Chinese painting, integrating Dunhuang mural elements with game visual art, thus uniting historical authenticity with artistic creativity. In terms of interaction design, it subverts the traditional passive viewing model of museums by using role-playing, task challenges, and interactive puzzle-solving, making the audience active participants in the narrative process.

They traverse time and space to experience various historical periods, such as the Late Tang, Northern Song, and Qing dynasties, even becoming key figures in the historical development of the Library Cave audience "personally" experience the excavation, closure, rediscovery, and dispersion history of the Library Cave, while the embedded thoughts on cultural heritage protection and patriotism are conveyed in an engaging, vivid, and captivating manner.

Figure 3. The Digital Library Cave

It is particularly noteworthy that the Digital Library Cave project cleverly uses a narrative nesting strategy to overcome challenges such as the long historical span, numerous figures, and complex storylines of the Library Cave. Narrative nesting typically refers to the embedding of smaller stories or sub-narratives within a larger narrative framework, where these smaller stories intertwine and complement the main narrative to form a complete story. The narrative nesting in the Digital Library Cave project is an exquisite multi-layered design that integrates information about the Library Cave's historical events, biographies, cultural relic introductions, and more, presenting the complex historical background, rich character relationships, and dramatic storylines of the Library Cave.

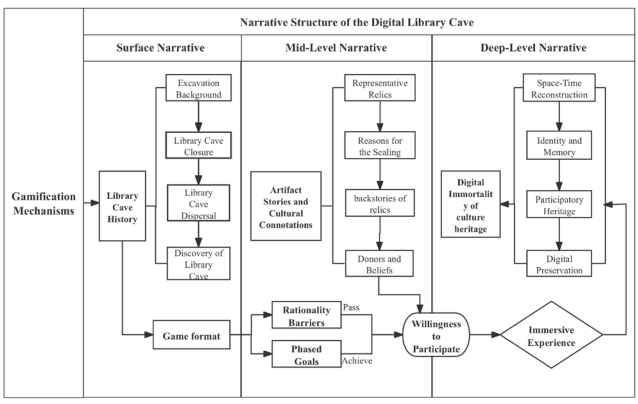

Figure 4. The narrative structure of the Digital Library Cave

The nested types in the Digital Library Cave are diverse and well-executed. Historical events, cultural stories, visitor paths, and narratives are cleverly embedded, presenting the historical background, discovery process, relic dispersion, and protection of the Library Cave through story-driven forms within the high-precision restoration of the Mogao Caves 16 and 17. The main narrative focuses on the history of the Library Cave's relics, while secondary narratives are embedded, covering the social backgrounds, cultural shifts, and other aspects of different historical periods like the Late Tang, Northern Song, and Qing dynasties. In restoring historical scenes, the project embeds the historical background, production techniques, and cultural value of various relics, connecting the magnificent history of Dunhuang culture. Finally, there is the embedding of games and narratives.

Upon entering the Digital Library Cave experience, participants are first introduced to the surface-level narrative, which unfolds through character selection and role-playing. This layer guides users through key historical episodes, including the excavation of the cave, the sealing of the ten-thousand-volume corpus, its rediscovery, and the subsequent global dispersal of its cultural artifacts. Beyond this introductory layer, the intermediate narrative focuses on the historical contexts and cultural significances embedded in the relics of the Library Cave. At the deepest level, the narrative framework situates these elements within the expansive cultural matrix of Dunhuang, encompassing its historical evolution, geographical setting, religious practices, and artistic heritage.

The Digital Library Cave brings the audience into a world full of mystery and legend, where they can complete tasks, unlock levels, and gradually understand the history of the Library Cave and the stories behind its relics. The narrative in the game is not one-directional storytelling but is closely linked to the audience's actions and decisions. The audience's choices can influence the game's direction and the story's outcome, allowing them to participate more deeply in the narrative and experience the weight of history and the charm of culture.

4.3 Technological Embodiment

Technology extends human senses and constructs a unique bodily perception. Marshall McLuhan pointed out that the media are essentially technological extensions of the human sensory system, constantly expanding the dimensions of human cognition by adjusting sensory ratios and reconstructing perceptual modes (Mcluhan, 1994). Just as writing and print media can be seen as extensions of visual abilities, radio becomes an extension of the auditory system. Don Idhe viewed technology as a mediator between humans and the world, proposing the theory of "body-technology-world" as a form of technological embodiment. When technological tools (such as glasses or wheelchairs) form a stable embodied relationship with users, they no longer function merely as external auxiliary devices but gradually integrate into the user's sensory system through ongoing bodily practices, becoming an organic part of their body schema.

Applying this theoretical framework to the field of museum studies, we find that in the context of cultural communication, technological embodiment manifests as a bidirectional construction process. On the one hand, VR/AR devices and interactive display systems serve as mediators of perception, extending the sensory capabilities of the audience and allowing them to transcend physical limitations in order to access multidimensional cultural information. On the other hand, through continuous interactive practices, these technological devices gradually internalize into the cognitive system of the audience, becoming an integral part of their "museum-experiencing body."

This embodied technological interaction not only transforms the traditional knowledge dissemination model in museums but also reconfigures the cognitive relationship between the audience and cultural heritage. The Dunhuang Academy's A Journey to Dunhuang utilizes VR technology, allowing the audience to enter the virtual historical scenes of Mogao Grottoes or restoration sites through headsets, enabling them to experience the historical context and cultural significance of the artifacts firsthand. The Flying Apsaras themed tour route uses AR technology, allowing the audience to overlay virtual digital content onto the real Mogao Grottoes, experiencing virtual flying apsaras scenes, panoramic virtual caves, and apsaras from different dynasties. The British Museum employs MR technology, enabling the audience to "dialogue" with ancient Egyptian pharaohs via HoloLens and engage in virtual archaeological excavation activities. The Shanghai Science and Technology Museum utilizes Kinect motion-sensing technology, allowing the audience to control virtual scenes through body movements, participating in virtual artifact restoration or ancient rituals.

The significance of digital applications in museums is thus revealed: they are not merely supplementary technical additions nor isolated technological spectacles; rather, they represent a profound technological mediation mechanism that embodies a human-centered philosophy. The core pursuit of this mechanism is to create an ideal embodied experience, aiming for the "transparency" of technology, meaning that the audience can naturally use technological tools in an unconscious state, fully immersing themselves in the rich cultural contexts created by the museum. When technology seamlessly integrates into the personal experience of the visitor to the point where they almost forget its existence, they can deeply immerse themselves in the carefully constructed atmosphere of the museum, thereby gaining a more authentic and profound cognitive and emotional experience.

5. Discussion

However, realizing the ideal state of "technology retreating, culture standing out" is constrained by multiple complex factors. On the technological level, the perception accuracy of hardware devices, real-time interaction performance supported by algorithms, and the fidelity of digital twins have not yet reached the ideal state. In the development of museums themselves, there is a global imbalance in economic foundations, policy support, technological strength, and cultural resource allocation. Significant differences exist between audience groups in terms of technological acceptance, cultural backgrounds, and knowledge levels. Some wearable devices, due to poor design (e.g., being too bulky, complicated to operate, or uncomfortable to wear), cause technical difficulties, reducing audience enthusiasm and satisfaction. As museum tourism continues to heat up, problems such as overcrowded exhibition halls, noisy environments, increased safety risks, and deteriorating air quality severely impact the visitor experience.

Therefore, museums, in advancing digital applications, must consider multiple factors, including technology, culture, audience needs, and the external environment, to ensure a harmonious coexistence of technology and culture while safeguarding the visitor experience.

6. Conclusion

As a specialized process that deeply explores and optimizes digital media to enhance audience immersion, the theoretical framework distinctly demonstrates the logical convergence and mutual reinforcement between embodied cognition theory and immersion theory. In the practice of museum digital applications, embodied cognition theory emphasizes the central role of physical experience in understanding and perceiving exhibition content. It posits that cognitive processes are inextricably intertwined with bodily states and experiences, framing the body as an active participant in cognition and highlighting its agency in information reception and meaning construction. On the other hand, immersion theory focuses on the state of complete mental absorption during activities—a state characterized not only by heightened psychological engagement and profound emotional resonance but also by significantly enhanced personal fulfillment, serving as a key indicator of deep audience participation and enriched exhibition experiences.

These two theories form a complementary theoretical foundation in the field of museum digital applications, providing both a solid academic basis for design philosophy and clear guidance for practical implementation.

Building upon this theoretical framework, museum digital applications achieve deep integration between technology and the human body through diversified strategies such as scene enhancement, narrative innovation, and technological embodiment. Scene enhancement creates lifelike virtual environments, transporting visitors into the authentic contexts of historical events or artistic creation. Narrative innovation employs interactive, non-linear storytelling techniques to spark curiosity and exploration, encouraging active interpretation of exhibition content. Technological embodiment utilizes wearable devices and motion-sensing interactions to establish direct correlations between visitors' physical movements and digital content, thereby enhancing the immediacy and interactivity of the experience. The combined application of these strategies delivers a more immersive, profound, and meaningful museum experience.

While museum digital applications excel in improving visitor experience and satisfaction, their contributions to collection management efficiency, expanded dissemination channels, educational functionality, and the promotion of cultural heritage exchange are equally noteworthy. However, this paper primarily focuses on an in-depth exploration of how embodied approaches enhance visitor engagement and experience. The introduction of the embodied concept into research on the impact of digital applications stems from a profound recognition that physical experience is an indispensable component of holistic visitor engagement. It reminds us that only when technology is seamlessly integrated and effectively activates visitors' bodily perception can digital applications fully realize their potential within the unique context of museums, achieving a harmonious synthesis of technology and humanity, rationality and sensibility.

References

Chen, C., Song, C., and Li, X.: The Deconstruction and Re-cognition of Tourist Gaze, Tourism Tribune, 39, 16-27, 10.19765/j.cnki.1002-5006.2024.08.007, 2024.

Clark, T. N. and Li, L.: The concept and analysis of scene theory: Insights from multi-country studies for China, Dongyue Tribune, 38, 16-24, 10.15981/j.cnki.dongyueluncong.2017.01.002, 2017.

McLuhan, M.: Understanding media: The extensions of man, MIT press1994.

Merleau-Ponty, M., Landes, D., Carman, T., and Lefort, C.: Phenomenology of perception, Routledge2013.

Nakamura, J. and Csikszentmihalyi, M.: The concept of flow, Handbook of positive psychology, 89, 105, 2002.

Urry, J. and Larsen, J.: The tourist gaze 3.0, 2011.

Werbach, K. and Hunter, D.: For the Win: How Game Thinking can Revolutionize your Business, Wharton Digital Press2012.

Ye, H.: Theoretical Analysis of the Meaning of Embodiment, Acta Psychologica Sinica, 46, 1032-1042, 2014.