Academic Education Publishing House

Philosophy and Social Science Vol. 3 No. 7, 2026

Design of Virtual and Physical Symbiotic Spaces for Immersive Stages Driven by Multimedia Imagery

Siyu Li

Department of Digital Media Arts, Xi'an Eurasia University, Xi'an, Shaanxi, China

Abstract: This study examines how multimedia imagery restructures immersive stage space and, within the context of digital performance, explains the generative logic of virtual–physical symbiosis in immersive stages. On the basis of the theatrical functions of imagery, four design types are identified: scene substitution, atmospheric rendering, narrative extension, and interactive symbiosis. Comparative analyses are conducted using representative Chinese and international productions, including Encore Pingyao, Cirque du Soleil's KÀ, and teamLab's digital-art environments. In response to recurrent problems in the integration of virtual and physical elements, the study proposes four core strategies: spatial adaptation, virtual–physical balance, dynamic-rhythm coordination, and all-encompassing immersion. The study seeks to improve the design system for immersive visual stage space and to provide theoretical support and practical pathways for spatial innovation and multimedia scenography in contemporary stage art.

Keywords: Multimedia Imagery; Immersive Stage; Virtual–Physical Symbiosis; Spatial Restructuring; Scenographic Design

1. Introduction

1.1 Research Background and Current Conditions

Real-time rendering, dynamic projection mapping, intelligent sensing, and extended-reality imagery continue to transform theatrical production. The implementation of projects such as Encore Pingyao and Music of Dunhuang in China, together with KÀ and teamLab's Future World internationally, demonstrates the feasibility of using multimedia imagery to reshape stage space. Conventional proscenium stages depend on physical scenery and mechanical structures for scene changes. Such changes are labor-intensive and offer limited means of representing multilayered time and space, psychological landscapes, and imagined worlds. Conventional one-way spectatorship also places audiences primarily in a passive role. Recent productions such as Dreamlike Datong and Moon over Wuyi employ walk-through, enveloping environments, suggesting that immersive, composite performance fields are becoming an important direction in the performing-arts market.

By means of panoramic LED systems, architectural projection, and real-time rendering, multimedia imagery integrates virtual images with physical architecture, moving machinery, and performers' trajectories. In Encore Pingyao, reconstructed historical courtyards provide the physical setting, while images projected onto gauze screens extend the narrative of Shanxi merchants [1]. KÀ uses tracking-based projection to accommodate a rotating mechanical stage, allowing virtual terrain to change with performers' movements. teamLab employs distributed sensing to create two-way interaction among audiences, performers, and images. These works exemplify three approaches—narrative extension, scenic transformation, and interaction—and show how digital imagery can broaden narrative boundaries and weaken physical divisions.

Nevertheless, significant shortcomings remain in both scholarship and practice. Existing studies frequently concentrate on equipment, rendering engines, and other implementation technologies, while systematic frameworks centered on visual narration and the hierarchy of virtual and physical space remain underdeveloped [2]. In practice, some cultural-tourism productions overuse particle effects and glasses-free 3D imagery. Excessive brightness may overpower performers; virtual perspective may be misaligned with physical scenery; and image rhythm may be disconnected from dramatic action. In smaller immersive productions, confused virtual–physical hierarchies can further

weaken humanistic expression. Addressing these problems, this study investigates the mechanisms through which imagery restructures symbiotic stage space and develops an operational design method for digital scenography.

1.2 Review of Chinese and International Research

Research on immersive digital stages in China has developed alongside the cultural-tourism performance sector since the beginning of the twenty-first century. Its main lines of inquiry concern technological implementation, visual expression, and spatial restructuring. Drawing on projected-image projects in traditional opera and outdoor performance, Liao Dawei discusses how digital media extend the expressive boundaries of physical scenery [1]. Sun Maozhong subsequently takes walk-through immersive theaters as analytical objects and uses "virtual–physical symbiosis" as a central concept to clarify the coupling of physical venues, digital imagery, and audience movement [2]. Later studies extend this discussion to perception, engineering practice, and intelligent performance. Zhang Geping and Li Ming analyze XR-based Chinese opera from the perspective of visual psychology, explaining how light, color, and composition shape immersion [3]. Wang Lijun summarizes geometric calibration and image alignment for irregular projection surfaces [4], while Yan Ming examines multidimensional visual-space reconstruction and changing narrative structures in intelligent-media performance [5]. Chinese scholarship has therefore developed a relatively clear chain linking technology, spatial form, and audience perception. However, detailed questions—including image-based narration, virtual–physical lighting ratios, and the coordination of dynamic imagery with performance rhythm—require further investigation.

Foreign related research started earlier, mainly focusing on digital media ontology, theater space transformation and the perception mechanism of immersive experience. Manovich pointed out that real-time generation and interactivity are the core features of new media and are also an important basis for distinguishing digital images from static scenes [6]. Dixon believes that digital media eliminates the fixed boundaries of the framed stage and transforms the stage into a dynamic media environment composed of performers, virtual images and audiences [7]. The research in the field of immersive aesthetics and interactive environment has further expanded this theoretical framework. Through the investigation of the image installation, Grau summarized the three immersive experience mechanisms of visual encirclement, spatial continuity and emotional resonance [8]. Crawford discusses the color and brightness balance between projected images and natural landscapes in outdoor performances [9]; Nguyen analyzes the technical logic of the interconnection of body movements, spatial tracking and real-time image generation [10].

A comparison of existing relevant research in China and abroad reveals significant differences in their research focuses. Overseas studies tend to center on media theory and the aesthetics of immersion, while domestic research leans more toward the practical implementation of stage engineering and real-world cultural tourism projects. However, neither type of research has yet established a comprehensive, integrated design system — one that uses multimedia imagery as the core driving force for creating virtual and real spaces, while also accommodating live stage performances. This existing gap in research is precisely the core innovative focus of this paper.

1.3 Research Contributions and Methods

This study promoted the relevant discussion in three ways. First of all, it regards the narrative function of multimedia images as a key variable for spatial reconstruction, rather than simply dealing with the theme from a technical or aesthetic perspective. Secondly, it introduces "virtual and physical symbiosis" as an analytical framework and builds a model consisting of four parts: physical stage, virtual image, live performance and audience experience. Third, by comparing four completely different case studies - Pingyao Reenactment, KÀ, teamLab Future World and Dunhuang Celebration - this study distilled the designs that can be promoted. Strategy. Therefore, this research method combines theoretical analysis with the actual conditions of stage production.

Three research methods are used in this study. The literature review examines academic research on digital stage design, immersive drama and new media art to clarify the development trajectory and limitations of existing research. The comparative case study

examines four representative projects with different technologies and narrative structures, focusing on their spatial logic and the use of images. Finally, by combining inductive reasoning and deductive reasoning, this study comprehensively summarizes the advantages and limitations of each case, and formulates a coherent design strategy for the "virtual-physical symbiosis" of immersive theaters.

2. Mechanisms of Immersive Stage-Space Restructuring Driven by Multimedia Imagery

2.1 Restructuring Spatial Boundaries

The front stage establishes strict physical boundaries through the stage opening, flanks and fixed scenery. The performance area, the backstage space and the audience seats are clearly separated, and the visual scale is limited by the building structure. This limitation exists in traditional plays, small musicals, and some early large outdoor performances, making it difficult to create an open and cohesive environment in a closed venue. Multimedia imaging technology - combined with projection mapping, panoramic LED layout and controlled lighting effects - minimizes the visual presence of walls, metal structures and stage frames. Therefore, the facade, the circular background, the floor, and even the aisle next to the audience seat can become the surface of the projected image, creating a continuous and immersive visual space.

KÀ of Circe du Soleil uses high-precision tracking technology to project images onto mechanically tiltable performance platforms. The combination of perspective extension, depth of field and visual repetition creates scenes such as cliffs, forests, oceans and caves, which visually seem to go beyond the dimension of the physical platform. The mechanical device mainly serves as a support for performance, and the virtual image extends the depth of perception beyond it. This relationship creates the effect of a physically compact performance space leding to a vast virtual world, showing how images can exceed the visual scale restrictions imposed by traditional stage boundaries.

2.2 Restructuring Narrative

Traditional stage stories mainly rely on dialogue, physical action and physical scenery. Although this form is very effective in presenting visible actions, it is not enough to directly imagine subconscious experiences, distant history, fantasy worlds and abstract cultural metaphors. Multimedia images can provide relatively independent narrative functions, including supplementary interpretation, emotional metaphor, time transition and atmosphere creation. 3D modeling, particle and fluid simulation, and abstract lighting and shadow effects enable creators to visualize spaces and states that are difficult to construct using physical sets.

In the XR Kunqu opera production Peony Pavilion: Love in a Dream, holographic images are projected on the gauze screen, bringing Du Lin Niang's dream world to life. In the future world of teamLab, flowing light and symbols convey concepts related to nature. Both of these works transform psychological processes, classic images and narrative omissions into visible spatial events. Therefore, the stage narrative goes beyond a single linear structure and becomes a multi-layered system, in which live performance and virtual images complement each other, expanding the expression and emotional scope of dramatic storytelling.

2.3 Restructuring the Performer–Audience Relationship

The traditional mirror frame stage has established a standardized one-way communication structure: the performers complete the performance on the fixed stage, and the audience sits in the audience to receive the performance content passively. The visual and spatial boundaries between the stage and the audience limit the audience's participation in the performance situation and the atmosphere of the scene. When multimedia images are combined with technologies such as infrared tracking, motion capture and real-time rendering, real body movements can establish a two-way interaction with virtual images, thus bridging the distance between performers and the audience.

In the interactive dance environment built by teamLab, the sensors are embedded in the ground and walls. The dancer's movements and the visitor's path and stay behavior can trigger the generation of visual elements such as flowers, streams and meteors in real time. Therefore, the physical activity of the audience can directly change the visual composition of the environment. At this time, the stage is no longer a fixed display interface of preset content, but a responsive media field that continues to evolve

with the behavior of participants. The audience has also changed from onlookers to co-creators of live atmosphere and visual space, thus reconstructing the one-way relationship between traditional performance and acceptance.

3. Comparative Case Analysis

3.1 "See You Again in Pingyao": Virtual

"Seeing Pingyao Again" is a representative work of Chinese immersive cultural tourism performance. The play abandons the traditional mirror-framed stage and promotes the plot through the audience's spatial movement and cross-field fragmented narrative. Inspired by the architectural style of the Qing Dynasty, the theater design builds a maze-like space with staggered discharges and winding paths, and is divided into four main performance areas: post stations, streets, ancestral halls and city walls. There are no fixed seats in the theater, and the audience keeps moving with the development of the plot, thus forming a continuously changing and intimate viewing experience. Architectural projection, translucent gauze curtain and projection images penetrating the stage smoke are intertwined with each other, forming a multi-layer nested virtual and real space. Brick and stone structures, wood carvings and architectural details form the foundation of physical space, and dynamic images inject vitality into the historical narrative.

In paragraphs such as escorting the deceased back to their hometown and offering sacrifices to ancestors, the projection images showing population migration and commercial activities are superimposed with the physical texture of streets and courtyards, promoting the collision between historical time and space and contemporary time and space. From the functional level, the work embodies the visual concept of "narrative extension" image: visual technology has always served the core theme of "Jin Shang's loyalty", and has not evolved into an independent visual spectacle detached from the narrative. Its limitations are also enlightening. Most of the visual materials in the work are in the form of pre-production, and the performance system does not widely use real-time sensing technology. Therefore, it is difficult for the audience's behavior to have a substantial impact on the visual content, and the synchronous coordination between visual prompts and actors' actions is still insufficient in terms of flexibility.

3.2 Sun Circus "KÀ": Virtual and Real

"KÀ" is a representative case of realizing the integration of virtual and real on the dynamic stage. Its core performance platform covers an area of about 25 feet x 50 feet, which can rotate, tilt and lift. The retractable bolts set on the platform can support actors to complete acrobatic movements such as climbing. As the performance platform continues to change the spatial posture, the performance must ensure an accurate correspondence between the direction of the physical stage, the perspective relationship of the image and the position of the actor. The work combines infrared tracking, multi-channel projection and platform three-dimensional calibration technology, and updates the image perspective in real time according to the tilt angle, rotation amplitude and spatial position data of the platform, so as to improve the image alignment accuracy during stage movement.

When the platform is in a horizontal state, the projection forms an open landscape such as a plain or water surface; when the platform gradually rises to a vertical state, it is transformed into a cliff, sand or vegetation wall. The actors' walking, trampling and climbing movements can also be coordinated with image events such as water ripples and falling stones. As a result, the metal mechanical platform is transformed into a natural landform at the visual level. This case reflects the characteristics of "scene replacement" images: the projection makes up for the neutral characteristics of the mechanical support structure in landscape performance, and establishes a coordinated relationship between the physical structure, virtual image and live performance. This practice provides a reference-valued engineering experience for the dynamic stage that needs to continuously update the visual alposition relationship.

3.3 TeamLab "Future World": Global Interactive Symbiosis

Future World dispels the traditional boundary between the stage and the audience by building an enclosed digital environment without fixed performance areas and independent seats. The wall, floor and inclined interface are all covered by laser projection, and the setting of distributed infrared sensors and depth sensors effectively reduces the visual and interactive blind spots. Thus, a continuous media space is formed, so

that visitors, performers and digital images coexist in the same domain.

The project replaces the traditional "edit first, play later" workflow with real-time graphics processing and behavior-driven generation. The movement trajectory, action intensity and stay time of visitors and performers can be converted into system input parameters to generate particle images of flowers, streams, stars, etc. in real time. Physical movement can accelerate or change the evolutionary direction of the visual field, while rest may slow down image changes. This model embodies the characteristics of "interactive symbiosis" images: the solid wall and the ground are used as image carriers, and the virtual content is generated in real time according to physical behavior. Both cannot exist completely independently. Material space and computational images evolve together in the process of interaction, showing the development potential of an intelligent and responsive stage environment.

3.4 "Dunhuang Ceremony": Cultural

Relying on the natural environment of the sand dunes of Mingsha Mountain and the Gobi landscape, Dunhuang Grand Ceremony has built a large-scale outdoor performance space. The work combines natural landforms, architectural installations and landscape three-dimensional projection to reproduce the historical world carried by Dunhuang culture. Its narrative content revolves around Silk Road trade, mural art, flying image and cross-cultural communication, and through multi-channel laser projection and layered lighting system, the irregular landscape surface is geometrically calibrated to transform static mural images into continuous visual narratives.

Deserts and mountains provide a spatial basis for the performance with both material attributes and cultural connotations, while dynamic images transform historical symbols into temporal visual forms. Images such as flying sky, caravans and murals show mythical scenes that the natural landscape itself cannot create independently. However, outdoor performances also face problems such as environmental light, irregular geometric structure, and image deformation caused by changes in temperature and humidity. Therefore, automatic brightness adjustment and multi-projector color balance have become key technologies to ensure visual effects. The project provides practical reference for geometric calibration and ambient light management in large-scale outdoor immersive performance.

3.5 Common Problems in Current Practice

Comparing the above four cases, it can be found that there are three common problems in the current practice. First, it is easy to have a primary and secondary imbalance between image and performance. In some cultural and tourism performing arts and small theater works, particle animation and naked-eye 3D effects are overused, and the brightness of the image and the intensity of movement form a visual competition for the actor's performance, causing the narrative focus to turn to technical display. Second, the accuracy of space adaptation is insufficient. Dynamic mechanical structures, irregular indoor venues and outdoor natural landscapes may cause problems such as perspective error, edge blur and color inconsistency between multiple projectors, making the stitching traces between virtual images and physical space too obvious. Third, the rhythm of the image lacks flexibility. It is difficult for performances that rely heavily on pre-recorded media to adjust the image transition, color and movement rhythm in time according to the time change of the live performance, thus destroying the continuity of the immersive experience.

4. Design Strategies for Virtual–Physical Symbiosis in Immersive Stages

4.1 Accurate Space Adaptation

Geometric adaptation is the basis for realizing visual integration. Before the video production begins, the creative team should measure the complete performance environment, including the spatial size, the curvature of the irregular surface, the difference between different audience points, the projection distance and the lens parameters, etc., and establish a unified three-dimensional coordinate system based on the measurement results. Subsequently, geometric correction, multi-point perspective calibration and multi-channel edge fusion can be carried out with Blender, MadMapper and other software. By unifying the relationship between the disappearing point, field of view range and proportion in physical space and virtual space, we can effectively reduce the problems of image stretching, picture breakage and uneven brightness.

For the dynamic stage used by KÀ, the real-time three-dimensional tracking system can continuously collect the tilt, rotation and displacement data of the platform, and update the virtual camera and projection parameters based on these data, so as to reduce image drift, local deformation and light breakage during mechanical movement. Therefore, spatial adaptation should not be regarded as a one-time calibration work, but should be understood as a dynamic process that continues to accompany the stage movement.

4.2 Controlling Virtual–Physical Hierarchy

Immersive visual design should follow a core creative principle: live actors are always at the focus of the narrative, the physical structure is responsible for establishing a spatial framework, and the projection image plays an auxiliary and atmospheric role. Building a three-level visual hierarchy helps to alleviate the common problems of image shielding actors' performances in the current industry.

The first level is the core performance area. The actor's activity area can use a fixed front area light with a color temperature of 2800K-3200K, and the saturation of the surrounding projected image can be controlled at 30%-40%. Guide the audience to focus their visual attention on the actors through high-contrast directional lighting. For example, "See You in Pingyao" adopts a similar method in the clan sacrifice scene to ensure the central position of the actors in the narrative. The second level is the transition buffer zone. A translucent phantom gauze curtain with a light transmittance of about 45% can be used, and combined with local prop projection mapping, a natural transition can be established between physical materials and virtual images. The third level is the spatial extension area. The top canopy, ground screen and side wall projection are mainly used to create a long-term view and environmental atmosphere to avoid competing with the core performance area for the audience's attention.

By adjusting the light and dark contrast gradient, color saturation level and dynamic picture intensity, the relative visual weight between the three levels can be controlled. The visual dominant carrier should also be dynamically transformed with the development of the plot to ensure that digital images always serve the core theme of live performance and drama narrative.

4.3 Coordinating Dynamic Rhythm

The dynamic image parameters should be synchronized with the emotional curve of the script, the BPM beat of the music and the physical movement speed of the actor, so as to achieve the unity of the audio-visual rhythm. Soothing and lyrical plot paragraphs can use low-speed particle animation of 15-25 frames per second, and with soft, low-saturation cold tones; in the climax passages with strong contradictions and conflicts, high-speed dynamic images of 45-60 frames per second can be used, and with high-contrast and high-saturation lighting colors.

A unified overall lighting standard should also be established for the performance: the color temperature difference between the physical stage light and the virtual image light source should be controlled within ±200K, and the deviation of the light projection angle should not exceed 15°. This standard can reduce the sense of suspension and "sense of keying" caused by improper calibration, and enhance the visual consistency between virtual images and physical space.

"Dunhuang Ceremony" connects the central performance control system with the physical lighting console and image rendering server, and adjusts the stage lighting and mountain projection screen synchronously according to the real-time lighting conditions of the natural landscape. Unified lighting control logic can avoid conflicts between virtual light sources and physical light sources, and establish a continuous and unified emotional expression chain in the whole performance space.

4.4 Build a Global Immersive Experience

Immersive stage design should break through the traditional single-wall and single-channel projection layout, and establish a four-dimensional full-coverage visual system composed of top canopy, vertical facade, stage ground and lateral ring screen, so as to eliminate the visual blind spot in 360° space as much as possible. The multi-channel rendering server can synchronously output surround projection content, and support different regions to independently play differentiated images according to narrative needs. Low-level diffuse ambient light can weaken the rigid boundary between the stage and the audience, transforming the audience from viewers outside the scene to participants inside the scene.

In this spatial framework, the infrared depth sensing array and the Unreal Engine 5 real-time rendering module can be introduced, and drawing on the interactive design logic of teamLab, the position coordinates and movement speed of the audience can be transformed into input parameters generated by real-time vision, thus establishing a two-way feedback machine between human behavior and projection media. System. The creative process can transform the static pre-recorded visual space into an intelligently evolved immersive environment, and improve the overall sensory immersion of the audience through the expansion of the spatial range, the enrichment of the audio-visual hierarchy, and the real-time interaction between the human body and the image.

5. Conclusion and Outlook

5.1 Research Conclusion

In the digital age, multimedia images have become the core medium for reshaping the virtual and real symbiosis space of the immersive stage. It promotes the transformation of the traditional theater structure by changing the spatial boundaries, narrative organization, and the relationship between performance and viewing. Through the analysis of "Seeing Pingyao Again", the Sun Circus "KÀ", teamLab "Future World" and "Dunhuang Grand Ceremony", this study summarizes four functional modes: narrative extension, scene substitution, interactive symbiosis and cultural atmosphere construction. These cases reveal the coupling between virtual images and architectural space, dynamic machinery, live performers and natural landscapes under different production conditions.

Comparative analysis shows that there are still problems such as imbalance between image and performance, insufficient accuracy of geometric adaptation, and disconnection between image rhythm and dramatic action in current practice. In this regard, this study puts forward four design strategies: precise spatial adaptation, virtual-real hierarchical control, dynamic rhythm coordination and global immersion construction. Spatial adaptation reduces the breakage of perspective relationships through field measurement, geometric calibration and real-time tracking; hierarchical control maintains the narrative main position of actors with the help of lighting, color and movement intensity; rhythm coordination makes image movement and lighting changes consistent with the drama plot and music structure; global immersion is through multi-directional image coverage. Cover and real-time sensing technology to establish two-way interaction between participants and the spatial environment. The above strategies can provide theoretical and practical references for mechanical stage theaters, outdoor cultural tourism and performing arts and interactive digital art environments.

5.2 Research Limitations and Future Direction

This research mainly focuses on the design logic and technical realization of the stage visual space. It has not yet quantitatively evaluated the immersive experience of the audience, nor has it explored the generative artificial intelligence image system in depth. These contents need to be further improved by follow-up research. In the future, there may be three major development trends in this field.

Video production will further move towards real-time, reducing dependence on a large number of pre-recorded content, so that the visual environment can respond to the improvisation of actors and changes in on-site conditions in a timely manner. The interactive system will be more intelligent, connecting the audience's behavior, actor's action and environmental sound through multi-modal technology, so that different sessions and different participants can have a differentiated scene experience. With the further integration of XR display, spatial projection and outdoor natural landscape, the boundary between virtual space and physical space will gradually blur, and immersive performance will break through the space limitations of traditional theater architecture.

In the future, stage creation will gradually surpass the traditional model of "physical set plus pre-recorded images". Digital media will no longer only assume decorative functions, but will become an important part of the dynamic system composed of physical space, performers and audiences. The four strategies proposed in this study help to balance the relationship between technological spectacles and humanistic narratives, reduce the excessive display of technological effects, and promote the coordinated development of artistic expression,

spatial aesthetics and intelligent systems in immersive performance.

References

[1] Liao, D. W. (2020). The application of digital media art in contemporary stage design. Art Panorama, 3, 112–118.

[2] Sun, M. Z. (2021). Virtual–physical symbiosis: Strategies for reconstructing immersive theater space in the digital era. Theatre Arts, 4, 89–97.

[3] Zhang, G. P., & Li, M. (2022). Spatial visual construction and psychological perception mechanisms in immersive multimedia performance. Zhuangshi, 2, 45–49.

[4] Wang, L. J. (2021). Immersive stage visual-design practice based on projection mapping. Journal of Beijing Film Academy, 8, 101–107.

[5] Yan, M. (2023). Reconstruction of multidimensional visual space and narrative transformation in intelligent-media performance. Literature & Art Studies, 1, 130–138.

[6] Manovich, L. (2001). The language of new media. MIT Press, 71,162.

[7] Dixon, S. (2007). Digital performance: A history of new media in theater, dance, performance art, and installation. MIT Press, 335-337.

[8] Grau, O. (2003). Virtual art: From illusion to immersion. MIT Press, 13-15.

[9] Crawford, M. (2019). Outdoor immersive projection: Light balance between natural landscape and virtual image. Journal of Digital Media & Culture, 6(2), 34–47.

[10] Nguyen, T. (2022). Interactive sensing system for real-time human–stage visual symbiosis. Computational Theatre Review, 11(1), 18–31.