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A study on the spatial visual elements in extended reality content

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Abstract: With the advancement of digital technology, spatial experiences are undergoing a significant transformation through extended reality (XR). This study investigates how spatial visual elements—including lighting, color transformation, texture, depth, and interactive viewpoints—contribute to user immersion in XR environments. Adopting a case study approach, the research examines The Sphere in Las Vegas, a state-of-the-art example of XR integration in architectural and performance design. Methodologically, this study evaluates The Sphere's LED-paneled exterior and immersive interior environment, analyzing their impact on user perception and engagement. The findings indicate that real-time lighting adjustments, interactive three-dimensional (3D) elements, and dynamic scene transitions substantially enhance audience immersion, as exemplified by the Anyma performance. Furthermore, this research highlights the scalability of XR spatial visuals and their potential applications in diverse fields, including entertainment, education, architecture, and virtual collaboration. In conclusion, as XR technology converges with artificial intelligence (AI) and big data analytics, it is expected to become increasingly adaptive and personalized. This study underscores the necessity of optimizing XR content creation, interactive storytelling, and immersive spatial design strategies. From a practical perspective, industries incorporating XR can significantly enhance user experiences and redefine spatial interaction within both physical and virtual environments.

Keywords: *Anyma, Extended reality, Immersive environments, Spatial visual design, Virtual space.*

1. Introduction

Space is one of the most fundamental elements that organize human life and experience, and it has long been studied across various disciplines, including philosophy, physics, architecture, and art. Traditionally, space has been defined as the sensually perceivable, three-dimensional region of the physical world and understood as an environment governed by physical laws such as gravity. Classical physicists such as Newton viewed space as an independent and absolute concept, with humans occupying specific locations within it. This concept of physical space has played a crucial role in fields such as urban design, architecture, and landscape design. However, with the rapid advancement of digital technologies since the late 20th century, the concept of space has undergone a fundamental transformation [1].

In particular, advances in computer graphics, the Internet, and networking technologies have led to the emergence of a new form of space known as virtual space. Virtual space does not exist in the real world but is constructed within a digital environment, allowing people to experience and explore it through digital media. The concept gained traction in the 1980s with the development of virtual reality (VR) technology, which initially consisted of simple 2D computer graphics environments. Over time, it evolved to incorporate 3D modeling, physical simulation, and haptic technology, providing increasingly sophisticated spatial experiences [2].

The evolution of virtual space has taken an even more intriguing turn with the advent of extended reality (XR) technology. XR technology merges physical and virtual spaces to create new forms of spatial experiences, categorized into virtual reality (VR), augmented reality (AR), and mixed reality

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(MR). VR immerses users in fully digitalized environments, while AR overlays digital information onto the real world, blending physical and virtual elements [3]. MR offers a more advanced integration, enabling users to interact with virtual objects within a physical environment. These technologies expand the concept of space beyond a simple physical environment, transforming it into an interactive and fluid experience.

As augmented reality technologies advance, the meaning of space is becoming increasingly multilayered, opening new possibilities in the arts and entertainment industries. A notable example of this transformation is The Sphere in Las Vegas, USA. The Sphere is the world's largest immersive theater, designed using extended reality technology to offer audiences a groundbreaking spatial experience. Inside, it features an 18K resolution curved LED screen and more than 160,000 surround speakers, creating an unprecedented level of immersion. Additionally, its exterior, composed of 1.2 million LED panels, functions as a massive digital canvas visible across Las Vegas, redefining the intersection of physical architecture and virtual content [4].

A particularly noteworthy example of XR's application in the performing arts is Anyma's performance at The Sphere. Anyma's performances blend XR-based immersive visual art with music, leveraging XR-based visual elements to distinguish them from traditional performances. Rather than relying on conventional lighting effects, Anyma creates an immersive environment where digital avatars and virtual worlds dynamically change in real time. During the performance, the entire stage transforms into a cyberpunk landscape, featuring giant mechanical structures that appear to float in mid-air, demonstrating how XR technology facilitates fluid spatial transitions [5].

These examples illustrate how XR technology can redefine and extend spatial visuals. In XR environments, spatial visuals go beyond mere visual representation to maximize sensory immersion, blur the boundaries between the real and the virtual, and enable novel forms of interaction. The Sphere and Anyma's performances exemplify the effective combination of elements such as dynamic lighting and color manipulation, texture and depth perception, and interactive viewpoints [6].

This study analyzes how spatial visual elements are utilized in extended reality environments, focusing on their practical implementation in The Sphere and Anyma performances. It further explores how XR technology is reshaping the concept of space and anticipates the future evolution of spatial experiences. As technology continues to advance, space will become a more dynamic and participatory environment, with significant social, cultural, and economic implications that extend beyond technological innovation.

2. Changes in the Concept of Physical Space and Virtual Space

Space is a fundamental element of human experience and perception, studied extensively across various disciplines, including philosophy, physics, architecture, and art. Traditionally, space has been defined as the three-dimensional, perceivable region of the physical world, governed by physical laws such as gravity [7]. Classical physicists, such as Newton, viewed space as an absolute and independent entity in which objects occupy specific positions. Physical space can be measured by dimensions such as length, width, and height, shaping sensory experiences through interactions with factors such as light, sound, and temperature. These physical spaces serve as the foundational stage for daily activities and play a crucial role in architecture, urban planning, and landscape design [8].

With the rapid advancement of digital technologies since the late 20th century, the traditional concept of physical space has undergone significant transformation, particularly with the development of computer graphics, the Internet, and network technologies. Virtual space, which does not exist in the real world but is constructed within a digital environment, has become an area that people can experience and explore through digital media. This concept gained momentum in the 1980s with the emergence of virtual reality (VR) technology, which initially comprised simple 2D computer graphics environments but evolved to incorporate 3D modeling, physical simulation, and haptic technology, providing increasingly sophisticated spatial experiences [9].

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Virtual spaces possess several defining characteristics. First, they are non-physical, meaning they are not subject to physical constraints and can transcend natural laws. For instance, virtual environments can feature architectural structures or zero-gravity spaces that defy real-world possibilities. Second, virtual spaces are transformable, allowing users to reshape, edit, or dynamically alter their environments based on context and interaction. Third, they offer network scalability, enabling multiple users to access and interact in shared digital spaces. The metaverse exemplifies this concept, providing an interconnected virtual space where users can engage, collaborate, and exchange information in real time.

The evolution of virtual spaces has become even more compelling with the advent of extended reality (XR) technology. XR seamlessly integrates physical and virtual spaces, offering new forms of spatial experiences. Virtual reality (VR) immerses users in entirely digital environments, while augmented reality (AR) overlays digital information onto the real world, blending physical and virtual elements. Mixed reality (MR) represents a more advanced fusion, enabling users to interact with virtual objects within a physical space. These technologies have redefined space as an interactive and fluid concept, moving beyond static environments to adaptive and participatory experiences [10].

This shift in spatial perception has profound implications for human experiences. Historically, space was perceived as fixed and absolute; however, emerging augmented reality technologies now allow space to be dynamic, responsive, and interactive. For example, traditional exhibition spaces followed a linear, passive viewing experience, but virtual reality has transformed them into interactive environments where visitors can explore and engage with artworks actively. This evolution positions space as an active participant in shaping user experiences and narratives rather than a mere backdrop [11].

Virtual spaces are also reshaping social, economic, and cultural landscapes. The rise of online virtual meetings, remote work, and metaverse-based social networks—particularly since the COVID-19 pandemic—has demonstrated that virtual spaces are no longer just experimental but are deeply integrated into real life. Businesses now leverage virtual spaces for hosting meetings, digital showrooms, and events, while education has embraced remote lectures and virtual laboratories as essential learning environments.

This transformation extends to the arts and media industries as well. Traditionally, media art was exhibited in physical spaces through screens or sculptures. Now, it is evolving into interactive virtual experiences where users actively participate in shaping the environment and narrative. This shift signifies that space is no longer static but is continuously redefined through technological advancements and human interaction [12].

As a result, the concept of space has expanded from its traditional physical understanding to a more complex, multi-layered experience that integrates digital dimensions. The modern perception of space no longer adheres to physical boundaries but is instead shaped by technological innovation, offering immersive and participatory experiences [13]. As augmented reality technology continues to advance, space will become even more fluid and interactive, carrying significant implications for human experience, as well as broader social, cultural, and economic transformations.

3. Spatial Characteristics of Extended Reality (XR) Content

Extended reality (XR) content integrates physical and virtual spaces to create novel and immersive experiences. The creation of such content requires more than merely placing digital objects—it necessitates a deep understanding of spatial characteristics and their effective utilization. In an augmented reality (AR) environment, spatial elements play a crucial role in determining content immersion and shaping the user experience [14]. This chapter analyzes the key spatial components essential for developing VR content, explores spatial design principles for user experience (UX) and interactivity, and examines immersive production techniques and storytelling strategies [15].

The spatial elements in an augmented reality environment significantly contribute to crafting a realistic sensory experience and providing a seamless and convincing setting for the user. Visual components such as lighting, color, and texture are fundamental to achieving an immersive XR space.

Lighting is a critical factor in establishing the ambiance of a space and directing the user's visual focus. In the real world, lighting reflects various aspects such as time of day, weather, and emotions, and it can serve a similar purpose in virtual environments. For instance, in VR-based media art exhibitions, adjusting the intensity and color of light can enhance emotional engagement. In AR content, blending real-world lighting with virtual lighting is essential to achieving seamless realism. Real-time light transformation technology further enhances immersion by dynamically adjusting lighting based on the user's position and movement [16].

Color is another crucial element that influences visual perception and helps convey emotions or moods. Cool tones (such as blues and purples) can evoke a futuristic or mysterious atmosphere, while warm tones (such as reds and oranges) can emphasize dynamism and emotion. In AR content, color not only enhances aesthetics but also serves as an intuitive guide for user interaction. Effective use of color gradients and contrasts enhances visual clarity and contributes to the perception of depth in virtual spaces.

Texture defines the surface characteristics of virtual objects and plays a vital role in determining the realism of a space. The application of realistic textures allows users to perceive the virtual environment as more authentic, thereby increasing visual immersion. For example, the distinction between rough stone walls and smooth glass surfaces conveys different tactile experiences, helping users intuitively grasp the physical properties of the space. High-resolution physically based rendering (PBR) technology enables precise surface textures, while light reflection and shadow effects further enhance the realism of virtual environments [17].

To maximize user interaction, spatial elements in augmented reality content must be designed with interactivity in mind. Interactivity is a core component of UX design, requiring an approach that encourages users to actively explore and manipulate their environment within virtual spaces. A well-designed interactive space enhances engagement and ensures a more immersive and dynamic XR experience.

Table 1.
Interacting in an Extended Reality Space

Category	Description	Example
Direct Manipulation	Users directly move or manipulate virtual objects using their hands	Providing an experience where users touch or arrange virtual sculptures in VR-based media art exhibitions
Indirect Interaction	The system detects the user's position or movement and reacts automatically	In AR content, the environment changes or new elements appear when the user reaches a certain location
Eye and Voice Interaction	The system recognizes user's gaze movement or voice commands to trigger content responses	In MR environments, the space reacts when the user looks at a specific object or gives a voice command
Navigation in Space	The connection between real-world movement and virtual environment navigation	Teleportation movement in VR; natural movement based on real-world terrain in AR

Examining Table 1, spatial interaction can be categorized into three primary types.

First, direct manipulation allows users to move or manipulate virtual objects using their hands. This approach is particularly effective in VR environments, where combining it with haptic feedback enhances realism by providing a tactile experience. For instance, in VR-based media art exhibitions, users can engage more deeply by touching or placing virtual sculptures, making the content more immersive.

Second, indirect interaction occurs when a system recognizes a user's location or behavior and responds automatically. This type of interaction is commonly used in AR content, where environmental changes or new elements appear as users reach specific points. This technique enables users to experience new content progressively as they navigate a space, enhancing engagement and discovery.

Third, eye and voice interaction involve content responding to a user's eye movements or voice commands. This approach is particularly useful in scenarios where hands-free interaction is necessary or where intuitive control is required. For example, in a mixed reality (MR) environment, objects can respond instantly when a user looks at them or issues a voice command, creating a seamless and interactive experience.

Navigation within virtual and augmented spaces is another critical factor in optimizing user experience. The transition between real-world and virtual movement should be designed to feel natural and intuitive. For instance, teleportation is commonly employed in VR environments to allow users to move efficiently, while AR environments typically favor movement aligned with real-world terrain for a more seamless experience.

Additionally, directing techniques and storytelling strategies play a crucial role in maximizing spatial immersion within augmented reality content. Virtual environments should be designed not just as visual experiences but as dynamic spaces where users feel fully integrated into the narrative. Achieving this level of immersion requires the implementation of advanced production techniques that reinforce the user's engagement and presence within the digital space.

Table 2.
Immersive Presentation Techniques and Storytelling Strategies

Category	Description	Example
Environmental Storytelling	Designing spaces to convey narratives intrinsically	In AR-based historical content, virtual videos appear when users reach a specific location
Interactive Narrative	Users can choose and progress through the story on their own	In VR-based immersive theater, the storyline changes depending on user actions
Spatial Time Manipulation	XR environments allow non-traditional time expressions	In VR content, a user's actions change the environment to reflect the past or future

As shown in Table 2, three main types of immersive production techniques enhance augmented reality content.

First, environmental storytelling utilizes space itself to convey a narrative. In this technique, the environment plays an active role in shaping the user's experience. For instance, AR-based historical content can be designed so that when a user approaches a particular location, virtual footage of its historical significance appears. This approach immerses the user in the story, making them an active participant rather than a passive observer.

Second, interactive narrative techniques enable users to shape and direct the story, increasing engagement and immersion. Extended reality content incorporating user-driven choices enhances the depth of interaction. For example, VR-based immersive theater can be designed so that specific user actions influence the storyline's direction, creating a personalized and dynamic experience.

Third, spatial time manipulation allows for the representation of time in ways that differ from real-world constraints, offering unique experiences. In VR content, for instance, users can trigger actions that shift the environment into the past or future, enabling a seamless transition between different temporal dimensions.

The creation of extended reality content requires the precise design of spatial elements such as lighting, color, and texture, alongside interactive features that maximize user engagement. Additionally, employing immersive production techniques and storytelling strategies is essential to crafting compelling experiences. By integrating these elements effectively, XR content can transcend visual representation to deliver deep sensory and narrative immersion, leaving a lasting impression and emotional impact on users.

4. Spatial Visual Elements Based on Cases of Extended Reality (XR) Content

In an extended reality (XR) environment, spatial visuals play a crucial role in maximizing user immersion and seamlessly blending reality with virtuality [18]. XR spatial visuals extend beyond simple graphical elements, encompassing a harmonious combination of various visual components that shape the immersive space. These elements enhance realism, improve user experience (UX), and reinforce the narrative structure of the content. To explore this concept, we analyze the application of spatial visuals in XR environments, with a focus on The Sphere in Las Vegas and Anyma's recent performance there.

The Sphere in Las Vegas exemplifies the potential of XR spatial visuals. Its exterior is enveloped with approximately 1.2 million programmable LED lights, enabling the dynamic display of a wide range of visual content [19]. The Sphere's exterior walls transform in real-time, showcasing visuals such as the Earth, the moon, human pupils, and even a giant basketball, functioning as an iconic landmark within the cityscape. This fusion of real-world architecture with virtual content illustrates how XR environments can integrate digital visuals into physical structures, turning them into expansive digital canvases.

Inside The Sphere, the immersive experience is even more pronounced. The venue houses the world's largest 18K resolution curved LED screen, which surrounds the audience, creating an all-encompassing visual spectacle. Unlike traditional rectangular screens, the curved display extends to the ceiling, erasing visual boundaries and utilizing the entire space as a unified digital interface. This spatial immersion is a cornerstone of the XR experience, as The Sphere employs ultra-high-resolution displays and innovative design to dissolve the distinction between reality and virtuality.

One of the most notable performances within this groundbreaking environment is Anyma's recent show. Anyma effectively leverages The Sphere's technological capabilities to push the boundaries of XR-based visual storytelling. By integrating dynamic lighting, real-time 3D visuals, and spatial depth, Anyma's performance exemplifies how XR spatial visuals can heighten sensory immersion and transform live experiences into multidimensional artistic expressions.

Figure 1.
Anyma the end of genesys residency, Sphere, Las vegas, 2024

Anima, shown in Figure 1, is a performance project that seamlessly integrates XR-based immersive visual art with music, utilizing XR-driven visual elements to distinguish itself from conventional performances [15]. Anima's performance at The Sphere goes beyond mere lighting effects, creating a fully immersive environment where digital avatars and virtual worlds evolve dynamically in real time. Throughout the performance, the stage transforms into a cyberpunk world, with massive mechanical structures appearing mid-air, demonstrating the fluid transformation of space enabled by XR technology.

A crucial aspect of these visuals is Dynamic Lighting & Color Manipulation. Leveraging The Sphere's expansive curved LED screens, Anima's performance incorporated rhythmic color transitions and streams of light extending through the environment. For instance, certain sections of the show were enveloped in dark tones, only for neon colors to explode onto the stage during the Beat Drop, dramatically altering the atmosphere. This manipulation of visual perception is a fundamental XR technique designed to elicit emotional responses from the audience, and it was specifically optimized for The Sphere's unique venue.

Furthermore, the impact of these visual elements can be significantly enhanced through the integration of texture and depth perception. By meticulously designing spatial visuals, Anima's performance achieved an unprecedented level of immersion, reinforcing the transformative capabilities of XR in live entertainment.

Figure 2.
Analyzing Animas performance scenes

In the Anima performance scene depicted in Figure 2, advanced 3D object rendering and layering techniques were employed instead of simple flat graphics. This approach, commonly used in VR environments, applies different perspectives to enhance the three-dimensional appearance of virtual spaces. For instance, a massive virtual statue was positioned at the center of the stage, enveloped by a dynamic digital data stream that moved around it. This technique imbues virtual objects with a tactile realism, allowing the audience to perceive them as an integrated part of the physical experience.

In an extended reality environment, spatial visual elements are also closely connected to the concept of Interactive Viewpoint, which alters the visual experience based on the user's position. In the performances of The Sphere and Anima, this method was strategically implemented to ensure that visuals changed dynamically depending on the audience's seating position. This technique mirrors the Eye Tracking functionality in VR content, which displays specific objects only when viewed from a particular angle or point in time. For example, while the front section of the theater displayed a large mechanical structure in motion, the side sections emphasized a vast Particle Effect enveloping the entire space. This approach allows each audience member to experience a unique and personalized visual journey, a critical aspect of XR environments.

The cases of The Sphere and Anima demonstrate that spatial visual elements in XR environments go beyond mere graphic representation; they involve a strategic design process that enhances cognitive engagement and sensory immersion. When elements such as lighting, color, texture, three-dimensionality, and interactive viewpoints are cohesively integrated, XR environments transcend their virtual nature and become sensorially rich extensions of reality.

In conclusion, the performances of The Sphere and Anima exemplify the transformative potential of spatial visual elements in extended reality environments. Through immersive displays, dynamic color manipulation, and interactive visual effects, XR spaces are evolving beyond static virtual realms into vivid, interactive environments that engage and respond to audiences in real time. These advancements offer significant insights for XR content creators, providing a blueprint for the future of XR-based performances and media art.

5. Conclusion

This study analyzed the role of spatial visual elements in extended reality (XR) environments and examined their practical implementation through the cases of The Sphere and Anyma. The findings reveal that XR technology dissolves the boundaries between physical and virtual spaces, offering a novel spatial experience that maximizes user immersion. By integrating various visual elements such as lighting, color, texture, three-dimensionality, and interactive viewpoints, XR environments transcend mere visual representations to create deep sensory, emotional, and narrative engagement.

The Sphere serves as a prime example of an XR-based immersive space, redefining audience experiences by blending physical structures with virtual content. Externally, its massive LED-panel digital canvas achieves seamless visual harmony with the surrounding urban landscape. Internally, it fosters an immersive environment through the integration of a curved LED screen and an advanced sound system, effectively erasing the distinction between reality and virtuality. These features highlight how spatial visual elements in XR environments extend beyond serving as passive backgrounds, instead actively shaping user perception and cognitive engagement.

Anima's performance further demonstrated the potential of XR-based immersive production techniques in performing arts. By leveraging The Sphere's unique spatial characteristics, Anima dynamically transformed colors and lighting while integrating virtual objects and digital avatars. This case confirms that, within an XR environment, space functions as an interactive element that engages the audience beyond the traditional concept of a static stage.

The continued advancement of XR technology is further redefining the fluidity of spatial concepts, unlocking new possibilities beyond art and entertainment. In education, XR environments facilitate immersive learning experiences. In architecture and urban planning, virtual simulations powered by XR technology allow for preemptive design optimization. Additionally, remote collaboration and metaverse-based virtual spaces introduce new paradigms for work environments, demonstrating that spatial visual elements in XR have significant social and economic implications beyond aesthetics.

The results of this study offer critical insights for XR content creators in designing spatial visual elements. To maximize immersion, interactive components that respond dynamically to user movement and behavior should be prioritized over static visual effects. Additionally, spatial design should evoke emotional responses and gradually blur the distinction between physical and virtual environments to facilitate seamless narrative integration.

As XR technology continues to evolve, spatial visual elements will become more sophisticated and personalized. The integration of artificial intelligence (AI) and big data analytics will enable customized spatial experiences, further strengthening the interconnection between virtual and physical spaces. This suggests that future XR environments will evolve into comprehensive experiential spaces, extending beyond visual immersion to engage the user's senses, emotions, and social interactions.

In conclusion, this study explored the implementation and impact of spatial visual elements in XR environments and their role in enhancing immersive experiences. The cases of The Sphere and Anima exemplify how XR technology is redefining spatial perception, providing a valuable foundation for future XR content creation and spatial design. Moving forward, further research should systematically assess the influence of spatial visual elements on user experience and explore their broader applications across various industries.

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