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The Components of 3D Virtual Environment Design in Immersive Virtual Reality for Cultural Heritage Preservation

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ABSTRACT

This study examines the use of 3D virtual environment design components in immersive Virtual Reality (VR) applications for cultural heritage preservation. As intangible cultural heritage faces challenges from modernisation and declining public interest, particularly among younger generations, immersive VR offers an opportunity to present cultural narratives in engaging and interactive ways. This research aims to identify the key components of 3D environment design used in cultural heritage VR and analyse their implementation across existing projects. A qualitative content analysis approach was applied, using a structured 5-point rating scale to evaluate seven (7) immersive VR heritage projects. The evaluation framework included components such as terrain, structures, props, lighting, atmosphere, storytelling, interactivity, and sound design. The results show that storytelling and architectural structures scored highest in consistency and cultural impact, while props and object interaction were less effectively utilised. This suggests that while many VR heritage applications succeed in visual and narrative immersion, they often lack depth in interactivity and functional realism. The study concludes that 3D design frameworks, when carefully implemented, can significantly enhance user engagement and cultural authenticity in immersive heritage experiences. These findings provide design insights for VR developers and cultural institutions aiming to create more meaningful, interactive, and preservation-focused virtual environments.

Keywords: *3D Virtual Environment, Immersive Virtual Reality, Cultural Heritage Preservation*

1 INTRODUCTION

As digital technologies evolve, VR has emerged as a powerful tool to convey cultural narratives and environments through immersive experiences (Addison, 2000; Champion, 2016). These experiences rely heavily on 3D design elements such as terrain, lighting, atmosphere, storytelling, interactivity, and sound design to create a sense of presence and emotional connection. This study analyses the key components of 3D virtual environment design in fully immersive Virtual Reality (VR) applications for cultural heritage preservation. In Malaysia, 3D design has already been applied in digital tourism projects to support cultural storytelling and improve audience engagement through immersive visuals (Noor Hishamuddin et al., 2024). Recent research also demonstrates how VR supports immersive learning through 3D modelling, interaction, and emotional engagement in education, indicating its

broader potential for meaningful user experiences (Yi et al., 2024). While numerous cultural heritage projects have adopted VR to preserve and promote cultural content, many lack consistent design frameworks, leading to varied quality and cultural effectiveness (Petrelli et al., 2013; Champion, 2016). This study aims to identify the components of 3D virtual environment design used in immersive VR and analyse their use in selected cultural heritage VR experiences. Immersive VR cultural heritage projects will be analysed using criteria adapted from Catanese et al. (2011), focusing on how the selected components contribute to user experience and cultural representation. This study is justified as one of the few that systematically examines 3D virtual environment design elements for cultural heritage and explores how these elements can be adapted to different cultural contexts effectively. This research addresses that gap by identifying the essential components used in immersive 3D virtual environments and analysing how they are implemented in existing cultural heritage VR projects.

1.1 Research Objective

The objective of the study was to identify the components of 3D virtual environment design used in immersive virtual reality environments and to analyse samples of cultural heritage preservation in immersive virtual reality.

1.2 Problem Statement

Intangible cultural heritage, including traditional performances and oral histories, is at risk of fading due to the shift in modern lifestyles away from cultural roots (Champion, 2016). Existing preservation methods often struggle to sustain public interest, particularly among younger audiences.

2 LITERATURE REVIEW

The literature review provides a comprehensive understanding of the subject. It is based on the components adapted from Catanese et al. (2011), including terrain, lighting, storytelling, atmosphere, interactivity, and sound design. The analysis aims to observe how these elements are integrated and how they affect user experience.

2.1 Cultural Heritage

Cultural heritage encompasses both tangible and intangible elements of human history, including architecture, objects, rituals, language, and oral traditions (UNESCO, 2003). Intangible heritage, such as storytelling and traditional practices, is especially at risk due to modernisation and generational disconnect (Champion, 2016). Digital preservation through immersive technologies offers an innovative way to make cultural heritage accessible and engaging to broader audiences, especially the younger generation (Addison, 2000). The integration of cultural content into virtual environments allows users to experience and interact with heritage more dynamically, fostering better cultural appreciation (Petrelli et al., 2013).

2.2 Immersive Virtual Reality

Virtual Reality (VR) is a computer-generated simulation that enables users to interact with three-dimensional environments in real time (Slater & Wilbur, 1997). Immersive VR, which typically uses head-mounted displays (HMDs), enhances user presence by stimulating multiple senses, thus creating an illusion of being physically present in a non-physical world. Recent studies suggest that immersive VR applications are effective tools in education and cultural preservation because they support experiential learning and memory retention (Minocha et al., 2017). In cultural heritage contexts, immersive VR enables users to explore heritage sites or narratives with high emotional and cognitive impact (Bruno et al., 2010).

2.3 What is 3D Virtual Environment Design?

A 3D virtual environment is a digitally constructed space that replicates real or imagined environments through three-dimensional models and simulations. These environments are composed of multiple design elements such as terrain, lighting, atmosphere, structures, and interactive objects (Catanese et al., 2011). Effective 3D environment design plays a critical role in VR experiences, shaping how users perceive realism, engagement, and usability (Jerald, 2015). In the context of heritage, designing culturally accurate and emotionally resonant environments enhances both educational and preservation outcomes (Bekele et al., 2018).

2.4 Components of 3D Virtual Environment Design

To evaluate immersive VR heritage experiences, several 3D design components must be considered. These include terrain, structures, props, lighting, atmosphere, storytelling, interactivity, and sound. These elements are adapted from the model proposed by Catanese et al. (2011) and widely used in virtual environment design research.

2.4.1 Terrain

Terrain refers to the digital representation of physical landforms, such as mountains, roads, and ground textures. In heritage VR, terrain sets the geographical and cultural context, influencing immersion and authenticity (Wang et al., 2019).

2.4.2 Structures

Structures are architectural elements that define space within the virtual environment. Their historical accuracy, material textures, and spatial layout contribute to cultural realism and user orientation (Addison, 2000).

2.4.3 Props

Props are interactive or static objects that carry cultural significance, such as tools, artefacts, or furniture. They help users understand the lived experience of a specific culture (Bruno et al., 2010).

2.4.4 Lighting

Lighting affects mood, depth perception, and time simulation. It enhances storytelling and atmosphere by mimicking real-world lighting conditions (Bekele et al., 2018).

2.4.5 Atmosphere

Atmosphere includes environmental effects like fog, weather, and ambient colour, which set the emotional tone and historical context of the experience (Jerald, 2015).

2.4.6 Storytelling

Storytelling refers to the narrative structure embedded within the VR environment, guiding users through a cultural or historical journey. Interactive storytelling enhances user engagement and learning (Champion, 2016).

2.4.7 Interactivity

Interactivity allows users to manipulate objects or navigate the environment. It is crucial for user

engagement and enables deeper exploration of the heritage content (Slater & Wilbur, 1997).

2.4.8 Sound Design

Sound design includes ambient audio, cultural music, and narration, all of which support immersion and emotional resonance (Minocha et al., 2017). Proper use of sound can enhance user presence and help deliver cultural narratives effectively.

3 RESEARCH DESIGN

This research uses a qualitative content analysis approach to examine the components of 3D virtual environment design in immersive VR cultural heritage projects. According to Krippendorff (1980), content analysis is a systematic research method for making replicable and valid inferences from data to their context. Seven (7) immersive VR cultural heritage projects will be selected and analysed based on components adapted from Catanese et al. (2011), including terrain, lighting, storytelling, atmosphere, interactivity, and sound design. The analysis aims to observe how these elements are integrated and how they affect user experience.

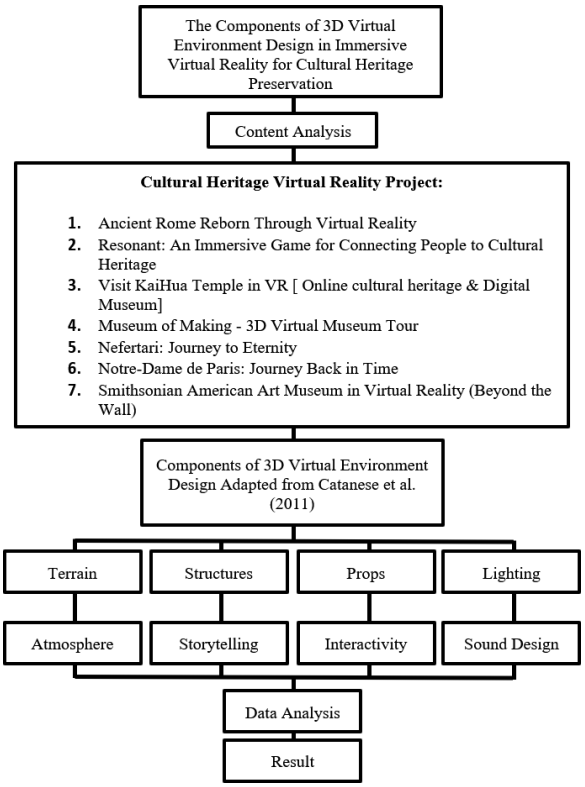
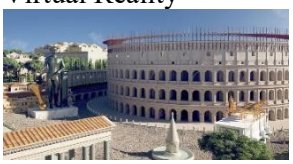


Figure 1 Framework of Study

3.1 SELECTION OF SAMPLES

The following table presents seven selected VR projects that serve as primary samples for this study. These projects were chosen based on their relevance to cultural heritage preservation, immersive 3D environment design, and public accessibility.

Table 1 Selection Sample of Virtual Reality Project Related to Cultural Heritage Preservation

VR Project	Label	Publisher	'ublishedDate	Justification
1. Ancient Rome Reborn Through Virtual Reality 	VRP1	Flyover Zone Productions.	Published in November 2023	High-quality reconstruction of Ancient Rome, good for historical learning and heritage appreciation.
2. Resonant: An ImmersiveGame for Connecting People to Cultural Heritage 	VRP2	CyArk	Published in October 2020	Interactive storytelling connects users emotionally to cultural heritage.
3. Visit KaiHua Temple inVR 	VRP3	Harvard's CAMLab	Showcased in April 2025	Digitally preserves the temple; allows global access to Chinese heritage.
4. Museum of Making – 3DVirtual Museum Tour 	VRP4	Produced by V21 Artspace.	Published inJune 2021	Shows industrial heritage with engaging 3D designand interactive experience.
5. Nefertari: Journey toEternity 	VRP5	Experius VR	Published on June 28, 2018	Highly rated (92% positive on Steam), detailed visuals and educational content on Ancient Egypt.
6. Notre-Dame de Paris:Journey Back in Time 	VRP6	Ubisoft	Published on September 10, 2020	Rebuilds the historic Cathedral in VR is useful for education and real-life restoration.
7. Smithsonian American Art Museum in Virtual Reality 	VRP7	Smithsonian American Art Museum	Published on August 7, 2019	Well-received (76% positive on Steam); offers interactive access to American artand culture.

4 DATA ANALYSIS

To evaluate Components of 3D Virtual Environment Design in selected cultural heritage VR projects,this study uses a structured 5-point rating scale Adapted from the Likert scale (Likert, 1932):
1 = Very Poor (missing or extremely weak)
2 = Poor (present but minimal or low quality)3 = Average (meets basic expectations)
4 = Good (well-presented and meaningful)
5 = Excellent (highly immersive, detailed, and impactful)

Table 2 Analysis of Components of 3D Virtual Environment Design

Components of 3D Virtual Environment Design		VR Project						
		VRP1	VRP2	VRP3	VRP4	VRP5	VRP6	VRP7
Terrain	Topography (SC1)	5	3	4	4	5	5	3
	Cultural Relevance (SC2)	5	4	5	4	5	5	4
Structures	Architectural Style (SC1)	5	4	4	3	5	5	4
	Material Authenticity (SC2)	4	4	4	3	5	5	4
Props	Cultural Significance (SC1)	4	5	4	3	4	5	4
	Functionality (SC2)	3	4	3	3	4	4	4
Lighting	Lighting Type (SC1)	4	4	3	3	5	5	4
	Mood Setting (SC2)	4	5	4	3	5	5	4
Atmosphere	Environmental Effects (SC1)	3	4	4	3	5	5	4
	nal Ambience(SC2)	4	5	4	3	5	5	4
Storytelling	tive Method(SC1)	4	5	4	3	4	5	4
	ral Content(SC2)	5	5	5	4	5	5	4
Interactivity	tion Freedom(SC1)	4	5	4	4	4	4	4
	t Interaction(SC2)	3	5	3	3	4	4	4
Sound Design	ient Sound(SC1)	4	5	4	3	5	5	4
	Cultural Audio (SC2)	4	5	4	3	5	5	4

5 RESULTS

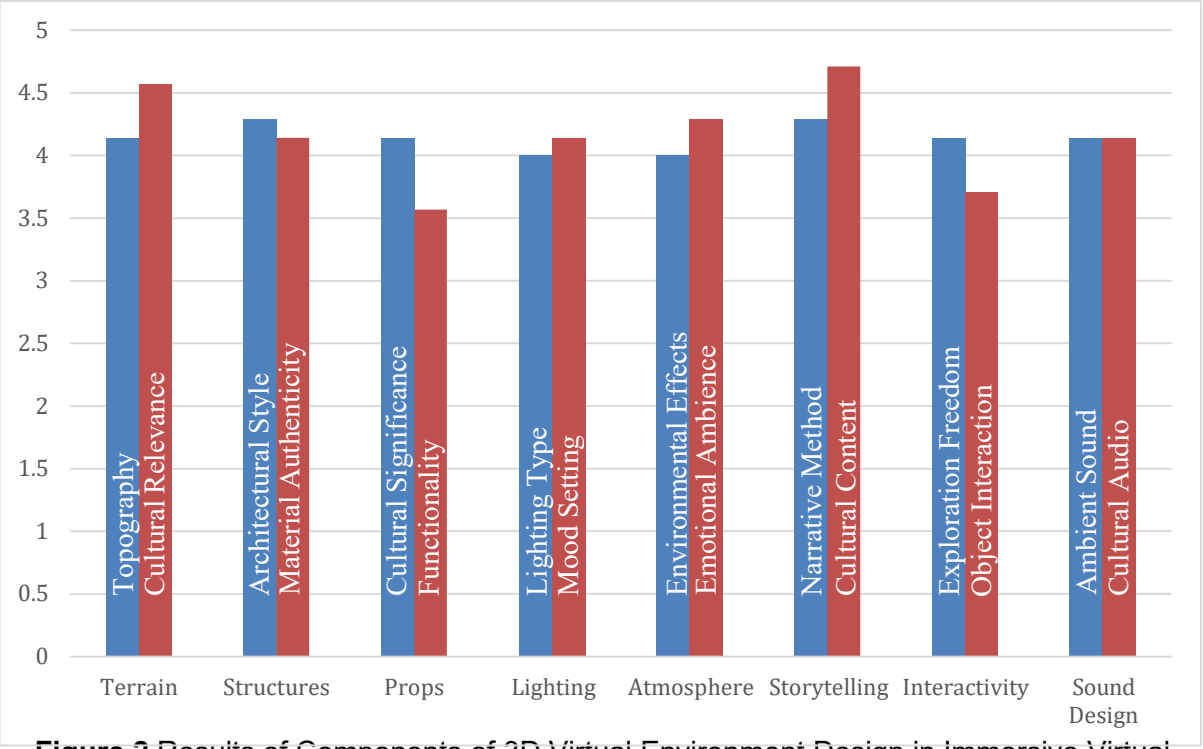


Figure 2 Results of Components of 3D Virtual Environment Design in Immersive Virtual Reality forCultural Heritage Preservation

6 FINDINGS

The results reveal that immersive VR projects for cultural heritage preservation prioritise certain design components more than others, reflecting deliberate academic and cultural intentions. The highest scoring component was Storytelling, where the narrative method (4.29) and cultural content (4.71) demonstrated consistent strength across all seven VR projects. This indicates that developers place great importance on constructing meaningful and educational experiences through strong cultural narratives.

Other highly rated components include Structures, with Architectural Style (4.29) and Material Authenticity (4.14) indicating efforts to maintain visual and historical accuracy in virtual reconstructions. Sound Design**,** Terrain, and Atmosphere also received high average ratings (ranging from 4.14 to 4.57), highlighting the importance of environmental immersion**,** cultural ambience, and emotional tone.

Meanwhile, Props and Interactivity components recorded slightly lower averages. In particular, Functionality (3.57) and Object Interaction (3.71) scored the lowest among all subcomponents. This suggests that while props are often present for visual context, their interactive potential is not fully utilised. Similarly, interaction design appears limited to basic exploration rather than deep engagement, pointing to an area of improvement for future VR cultural heritage applications.

Overall, the results suggest that immersive VR environments are largely effective at delivering visually and narratively rich heritage experiences, though greater interactivity and functional detail could further enhance user immersion and cultural understanding.

7 CONCLUSION

In conclusion, the analysis highlights the critical role of design components in shaping immersive VR experiences for cultural heritage preservation. The components of storytelling, architecture, and cultural context were found to be the most consistently integrated and impactful across the selected projects. This suggests that successful VR heritage environments rely not only on visual realism but also on storytelling and cultural depth.

While most projects demonstrated excellence in atmosphere, narrative structure, and educational content, the findings also reveal gaps in object interaction and prop functionality. These findings imply that future VR designers should focus on enhancing interactivity and making virtual elements more responsive and purposeful. By addressing these areas, VR projects can evolve into more holistic platforms that balance authenticity, engagement, and learning.

The study confirms that the framework of 3D virtual environment design, as adapted from Catanese et al, (2011), provides a robust foundation for evaluating and guiding the development of culturally meaningful VR experiences. As immersive VR continues to gain prominence in education and preservation, strategic use of these components will be key to ensuring that heritage is not only preserved visually but also felt, understood, and appreciated.

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AUTHOR CONTRIBUTIONS

All authors played equal contributions towards the production of this paper.

CONFLICT OF INTEREST

There is no potential conflict of interest with respect to the research, authorship, and publication of this article.

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