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An Analysis On 3D Modelling Technique in Virtual Reality for Hajj and Umrah Simulation

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ABSTRACT

This study investigates the use of 3D modelling techniques in virtual reality (VR) simulations for Hajj and Umrah education. It focuses on how these techniques support realism, user interaction, and system performance. The research uses qualitative content analysis to study five VR platforms: HAJJI VR, Pilgrim VR, Labbaik VR, HAJJ, and Muslim 3D. The aim is to understand how 3D modelling is applied in VR religious learning and to identify which techniques are most used. The main problem addressed is the challenge of balancing high-quality visuals with the limited processing power of VR devices, which can reduce the effectiveness of the learning experience. The findings show that basic techniques like polygonal modelling, texturing, and real-time rendering are widely used, while more advanced methods—such as parametric modelling, physically based simulation, and mixed reality—are not applied. Techniques like procedural modelling and Level of Detail (LOD) are used only in some platforms, likely due to technical limitations. This paper recommends that future development should include AI tools to help optimise models and improve performance. It also suggests exploring scalable techniques like procedural modelling to improve realism without overloading system resources. These suggestions are based on observed gaps in current Virtual Reality systems and aim to improve the quality of religious learning through immersive simulations.

Keywords: *3D Modelling Technique, Virtual Reality, Hajj and Umrah, Immersive Education*

1 INTRODUCTION

Over the past few decades, Virtual Reality (VR) has been extensively applied across various fields, including entertainment, education and training, manufacturing, and medical and rehabilitation sectors. Through the use of these technologies, users can be transported into virtual environments, with virtual characters and objects integrated into their real-world surroundings, resulting in immersive and realistic experiences according to (Rana,2019). The technique of creating digital representations of three-dimensional objects or surroundings is at the heart of 3D modelling. Artists and designers utilise

specialised tools to shape and define the geometry, surfaces, and textures of virtual assets, thereby bringing their creative visions to life. Enriched with a better understanding of geometric shapes, size, scaling and surrounding environment as studied by (Bhalla, 2022), 3D data modelling techniques have taken over 2D coordinates and image representation methods without any discretisation.

In the context of Hajj and Umrah education, VR simulations support education through an innovative training platform that instructs pilgrims on ritual procedures inside the sacred sites. The success of educational technologies is due to realistic and interactive virtual space construction in their 3D systems. Developing specialised VR 3D modelling solutions leads to improved technical performance while functioning as essential support for educational projects with cultural and spiritual importance. These technologies use 3D modelling techniques to create detailed and realistic models of the important sites and rituals of the pilgrimage

2 RESEARCH OBJECTIVES

The objective of this research is to study the technique used on 3D Modelling in Virtual Reality for Hajj and Umrah.

3 PROBLEM STATEMENT

Increasingly computationally intensive, detailed and optimised 3D models and rendering algorithms that can produce immersive content without sacrificing performance are needed to enable immersive environments in the rapid development of virtual reality (VR) technology. The processing and visual fidelity limitations of VR devices are frequently not adequately balanced in current 3D modelling, leading to limitations of user experiences (Rana, 2022).

No matter what kind of application to be applied by the VR, the visualisation effect is critical to enhance the engagement of participants and thus increases the education and training effectiveness. Nevertheless, increasing the visual realism in VR is not an easy task because it is not only due to artist's sense of the design engineers but also due to the drawback between the realistic VR environment (Tang & Ho, 2020).

4 LITERATURE REVIEW

The discussion of this paper is outlined in the literature review. It looks at a few fundamental 3D modelling techniques for virtual reality. Research by Bakri et al, (2019) underscores the significance of 3D modelling in education, noting its effectiveness in helping students visualise and comprehend complex phenomena. The researchers explaining intricate processes in areas like physics, engineering, medicine, and architecture is often insufficiently supported by basic teaching tools like 2D drawings or written texts. On the other hand, 3D modelling provides geographically correct representations of objects and interactivity which helps students integrate more deeply with the topic.

Using specialised software, 3D modelling is the process of creating a digital or mathematical representation of a three-dimensional item or surface. This method is essential for developing virtual worlds for simulation-based training, animation, gaming, augmented reality, and virtual reality (Saeed & Nwajana, 2023). One of the modelling techniques consists of several approaches. Each approach has its own features and applications.

Some techniques offer specific advantages depending on the intended application, the level of detail required, and computational constraints. In VR and AR contexts, especially for educational and simulations like Hajj and Umrah, a combination of polygonal and photogrammetric modelling is often employed to balance performance and realism (Dinein & Kalid, 2022).

5 METHODOLOGY

The qualitative method in this study is to investigate and assess the implementation of 3D Modelling Technique in (VR) design related explicitly to Hajj and Umrah education. The research will use content analysis to analyse the existing literature and documented contents of selected VR applications platform to draw insights. The discussion will be framed in the representation in the study of ”3D Modelling and Rendering for Virtual and Augmented Reality Application” (Rana, 2019), which outlines a summary of the modelling methods used in immersive environments.

Using a clear methodical purpose, there are five different learning platforms using VR, specifically HAJJI VR, Pilgrim VR, Labbaik VR, Hajj, and Muslim 3D VR, to explore the occurrence, meaning and variety of 3D modelling technique they employed in their development. This method supports the larger purpose of the research, which is to identify the current state of 3D Modelling technique in VR-based Hajj and Umrah education and for the overarching goal of informing the design of immersive educational tools.

6 RESEARCH DESIGN

This study adopts a qualitative method using content analysis from 3D Modelling and Rendering for Virtual and Augmented Reality Applications (Rana, 2019) on 3D Modelling Technique to examine the role and effectiveness in developing immersive virtual reality (VR) environments, particularly for educational purposes such as simulating Hajj and Umrah rituals. A sample of five existing Hajj and Umrah VR simulation was selected for data analysis. The selection of the VR simulation was based on their use of 3D Modelling Technique in their VR simulation, as illustrated in Figure 1.

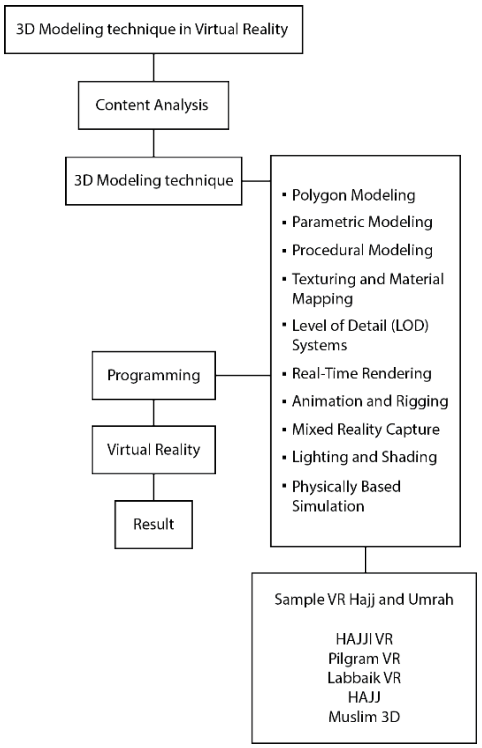

Figure 1 Framework of study

6.1 3D Modelling Techniques

Table 1 Comparative Structure of Existing Techniques from article 3D modelling and rendering for Virtual and Augmented Reality Article Application (Rana, 2019)

Technique Name	Description	Application
Polygonal Modelling	This technique builds 3D models using interconnected polygons (triangles or quadrilaterals). Artists manipulate vertices, edges, and faces to shape detailed objects—ideal for games, animation, and design.	Object modelling in VR/AR applications
Parametric Modelling	Constructs objects using mathematical equations and adjustable parameters, enabling precise and customisable design modifications. This approach is widely used in engineering, architecture, and procedural generation.	Procedural generation and interactive design in VR/AR applications
Procedural Modelling	Algorithmically generates 3D assets using defined rules and parameters, enabling automated, scalable content creation.	Large-scale environment generation in VR/AR applications
Texturing and Material Mapping	Applies material properties and surface details to 3D objects using techniques such as UV mapping, bump mapping, and normal mapping to achieve photorealistic rendering.	Surface detailing and realistic rendering in VR/AR applications
Lighting and Shading	Simulate realistic illumination through global lighting calculations and optimised rendering techniques.	Creating immersive environments with realistic lighting in VR/AR
Level of Detail (LOD) Systems	Optimisation dynamically simplifies 3D models based on camera distance to improve rendering performance. This technique reduces geometric complexity for distant objects while maintaining visual fidelity for nearby elements, achieving optimal resource allocation.	Rendering large and complex scenes with interactive frame rates
Animation and Rigging	Rigging builds bone systems and deformation controls for 3D models, enabling animatable characters through joint hierarchies, weight painting, and constraint systems.	Character animation and object manipulation in VR/AR applications
Real-Time Rendering	Techniques maintain smooth frame rates by combining efficient algorithms (like culling and LOD), optimised data structures, and parallel processing to balance performance and visual quality. Essential for games, VR, and interactive applications.	Rendering realistic graphics in real time VR/AR experiences
Mixed Reality Capture	Blends virtual content with real-world environments through live video integration, enabling real-time interaction with digital objects.	Augmented reality applications with
Physically Based Simulation	Virtual physics engines simulate realistic object interactions, including collisions, cloth movement, and fluid flow in digital environments.	Realistic physics-based interactions in VR/AR environments

6.2 Sample of Hajj and Umrah (VR) Simulation

The five identified VR platforms—HAJJI VR, Pilgrim VR, Labbaik VR, HAJJ, and Muslim 3D—were selected based on their direct educational relevance to Hajj and Umrah or the immersive simulations of Islamic rituals that they develop for viewing. They are based on various developers, countries, and release dates, all of which provide a comprehensive foundation for content analysis. This sample provides a broad impression and understanding of present-day 3D modelling in VR learning environments in the religious domain.

Table 2 Selection Sample of Hajj and Umrah VR simulation Learning.

HAJJ VR	Salam Softwork Studio (Francophone country)	Updated on 2nd July 2022
Pilgrim VR	Siraj Studios (Shenandoah University)	Released on 31th May 2024
Labbaik MV	Labbaik VR Ltd (UK- London)	Update on 9th June 2022
HAJJ	Light Art VR (Bridgeview, Illinois, USA)	Released on 9th January 2023
Muslim 3D	BIGITEC GmbH (Bonn, Germany)	Released on 20th February 2020

7 DATA ANALYSIS

Table 3 Analysis of Modelling Technique use in VR simulation

	Modelling Technique	**Virtual Reality Learning Platform**				
		HAJJI VR	**Pilgrim VR**	**Labbaik VR**	**HAJJ**	**Muslim 3D**
1	Polygon modelling	✓	✓	✓	✓	✓
2	Parametric modelling	-	-	-	-	-
3	Procedural modelling	-	✓	-	-	-
4	Texturing and Material Mapping	✓	✓	✓	✓	✓
5	Level of Detail (LOD) Systems	✓	✓	-	✓	-
6	Real-Time Rendering	✓	✓	✓	✓	✓
7	Animation and Rigging	✓	-	-	✓	✓
8	Mixed Reality Capture	-	-	-	-	-
9	Lighting and Shading	✓	✓	✓	✓	✓
10	Physically Based Simulation	-	-	-	-	-

8 FINDINGS

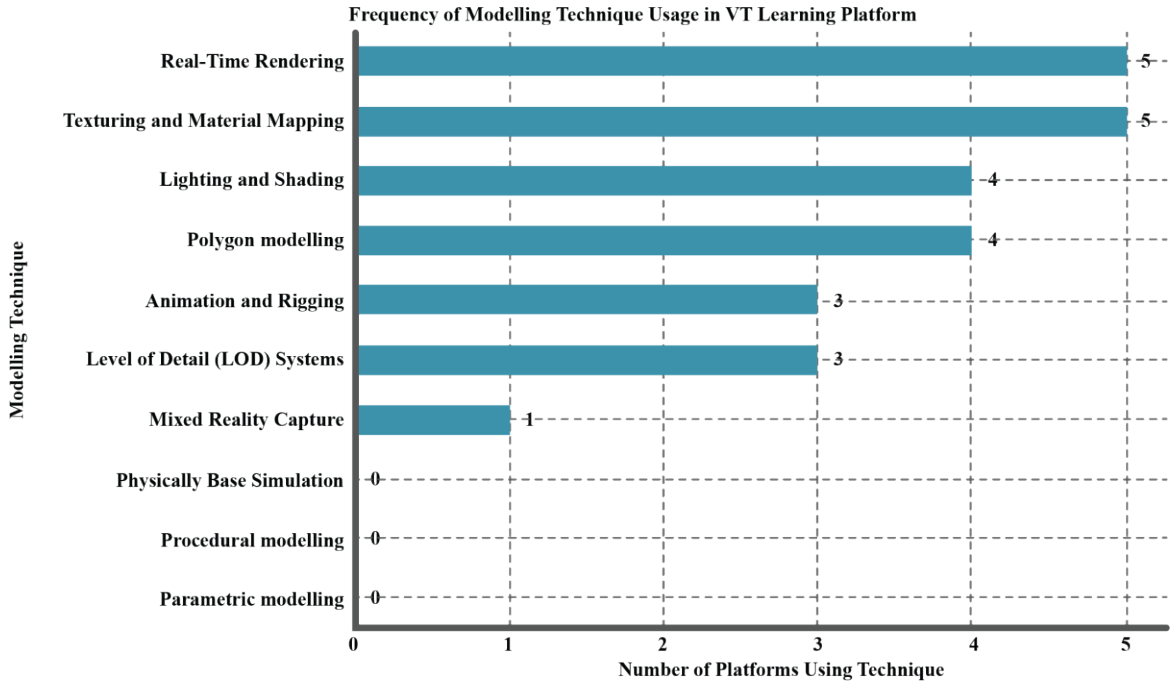

Figure 2 Analysis of Modelling Technique use in VR simulation.

The study of the modelling techniques employed by the Five Virtual Reality (VR) Learning platforms HAJJI VR, Pilgrim VR, Labbaik VR, HAJJ, and Muslim 3D revealed a trending utilisation of basic and performance-based modelling techniques used to improve realism, interaction, and computational efficiency.

8.1 Polygon Modelling

Polygon modelling is the most universally accepted modelling technique, used by all five platforms (100%). Polygon modelling creates a basic structure in most 3D modelling because it allows for the control of geometric integrity, and it is the most efficient way of building structure. Its universal adoption provides a baseline standard for building environments and characters in VR applications, which tends to be most challenging due to balancing performance and visual fidelity.

8.2 Parametric Modelling

None of the systems include parametric modelling. The only reason I could think of is that parametric methods are mainly used in CAD and architectural visualisation but not as much in real-time VR applications. In these applications, the focus is on flexibility and optimising performance over precision modelling.

8.3 Procedural Modelling

Procedural modelling, which can be found in Pilgrim VR and Muslim 3D environments, is used to generate complex environments programmatically. The application of procedural modelling in the Muslim 3D suggests the possibility of a need to generate content on the scale (potentially procedural terrain, crowds or cities), which is advantageous in educational simulations that attempt to represent large geographic areas or architectural structures.

8.4 Texturing and Material Mapping

Texturing and material mapping are utilised by HAJJI VR, Pilgrim VR, and Labbaik VR in recognition of the necessity of photorealistic environments. These techniques are fundamental for developing perceived immersion through details of surface representations, specifically cloth textures, architectural finishes, and skin. These are especially pertinent to religious environments representing deeply symbolic and historical fidelity.

8.5 Level of Detail (LOD) Systems

LOD systems are applied in both HAJJI VR and Pilgrim VR. The use of LOD systems indicates a deliberate optimisation strategy to reduce model complexity based on distance from the camera allowing for better rendering effectiveness, which is a critical consideration when simulating a multi-user or expansive environment, such as a pilgrimage site.

8.6 Real-Time Rendering

Real-time rendering is used on all platforms, with the exception of HAJJ (Light Art), which only reinforces the fact that it is a key element in providing responsive and immersive VR experiences. Real-time rendering allows for instant visual feedback and supports interactivity, which is an essential feature of training and education applications which will enable users to navigate and take actions in dynamic settings.

8.7 Animation and Rigging

Animation and rigging are featured inside HAJJI VR and Muslim 3D. They allow characters and objects to move around in a dynamic manner. These 2D processes are helpful for simulating physical human-based actions such as praying, walking, and historical role-playing. Their selective use is an indicator of scope, where some systems emphasise static exploration as opposed to interactive roleplay.

8.8 Mixed Reality Capture

No platforms claimed to utilise mixed reality capture. Mixed reality capture is typically employed for engagements in a professional broadcast context or augmented reality-integrated training scenarios, but it isn't currently typical for Hajj-related immersive simulations. This could be due to a variety of reasons including resources, complexity, or because the user supports limited hardware.

8.9 Lighting and Shading

The presence of lighting and shading elements in HAJJI VR and Muslim 3D demonstrates their focus on atmospheric realism. Realistic lighting builds mood, depth perception, and spatial orientation, essential in rendering sacred and architecturally significant spaces.

8.10 Physically Base Simulation

All platforms reviewed do not feature physically based simulation into their platform. They may use PBR (physically based rendering) but are likely to exclude the physical-based simulations underlying those renderings (for fluid, cloth, crowd behaviour, etc.) because of computational cost or necessity in a controlled educational environment of training and education applications which will enable users to navigate and take actions in dynamic settings.

9 CONCLUSION

This study evaluated 3D modelling in VR simulative representations of Hajj and Umrah education by focusing on five different VR platforms. From the data gathered, polygonal modelling, texturing/material mapping, and real-time rendering are recognised as standard techniques, and these techniques operate individually yet collectively fundamental for creating immersive experiences. Key findings also indicated the total absence of parametric modelling and physically based simulations, likely due to technological constraints, such as procedural modelling and Level of. Detail systems were used, but selectively and in accordance with the Level of detail; a balancing act was used for functionality.

The research highlighted the way modelling technique choices must be examined based on educational and technical demands. The central techniques will provide a form of stability, but there are many features of advanced techniques (i.e., procedural generation techniques) that may increase the scalable type of projects. Future work could also be related to the use of AI to optimise models and materials to create better experiences in terms of realism while complying with the technical limitations of VR. In summary, this study demonstrates approaches to use while developing effective VR-based technologies focused solely on Hajj and Umrah education while underscoring the importance of optimised three-dimensional modelling for creating meaningful experiences.

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AUTHOR CONTRIBUTION

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

CONFLICT OF INTEREST

The author declares no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

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