RESEARCH ARTICLE

El-FnaVR: An Immersive Virtual Reality Representation of Jemaa El-Fna in Marrakech for Intangible Cultural Heritage Experiences

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ABSTRACT Intangible cultural heritage, a vital part of our collective human legacy, faces the threat of being lost in the tide of modernization. Preserving and promoting these cultural treasures require innovative approaches that transcend traditional boundaries. In this paper, we introduce "El-FnaVR", a groundbreaking virtual reality (VR) application that captures the vibrant essence of Marrakech's renowned UNESCO-listed Jemaa El-Fna square, Morocco. El-FnaVR immerses users in a detailed virtual replica of the square, replete with lifelike animated characters and spatial 3D audio that reproduces the locale's unique atmosphere faithfully capturing the location's distinctive ambiance. This paper delves into the comprehensive five-stage design and development process of the application, highlighting its unique features and demonstrating how it replicates the diverse activities and performances at the square. A user study, conducted with participants, reveals overwhelmingly positive responses, as participants laud the application's immersive nature, ease of use, and social appeal. The study's findings indicate that El-FnaVR successfully evokes the sensation of being present at the Jemaa El-Fna square, and offers valuable insights into the events and traditions that define it. As a significant step towards the preservation and promotion of intangible cultural heritage.

INDEX TERMS Digital cultural heritage, digital tourism, immersion, intangible cultural heritage, user experience, virtual reality, virtual tourism, VR application.

I. INTRODUCTION

Intangible cultural heritage is an essential part of our cultural heritage. It encompasses traditional practices, expressions, knowledge, and skills recognized by communities, groups, and individuals as part of their cultural identity. UNESCO defines it as "the mainspring of cultural diversity and creativity" and recognizes it as an important aspect of cultural heritage. However, intangible cultural heritage is often more vulnerable to extinction than tangible heritage due to its ephemeral nature and dependence on human carriers. Factors

The associate editor coordinating the review of this manuscript and approving it for publication was Xiaogang Jin.

such as modernization, urbanization, and globalization have led to the erosion of many intangible cultural heritage practices and the loss of traditional knowledge [1].

In order to preserve and promote intangible cultural heritage, virtual reality (VR) technology has the potential to play a vital role [2], [3], [4]. VR allows for the creation of immersive experiences that can transport users to different places and times and provide them with a deeper understanding of a culture, for example, [5], [6]. Jemaa El Fna cultural space, a UNESCO-listed[1] square in 2009 and marketplace in Marrakech, Morocco, is an important example

[1]https://ich.unesco.org/en/RL/cultural-space-of-jemaa-el-fna-square-00014

of intangible cultural heritage. This vibrant square is known for its traditional Moroccan games, snake charmers, and other street performers and is an integral part of Moroccan culture. However, visitors are often only able to experience a small part of the square due to the large crowds and the short time they spend in Marrakech. Additionally, many people are unable to visit in person due to various reasons such as distance, cost, mobility issues, and the closure of tourism sites and attractions [7].

The objectives of the research are to: (i) develop a VR application for Jemaa El Fna that provides an immersive and interactive experience of the cultural heritage of the square; (ii) assess the effectiveness of the VR application in providing an immersive cultural experience by conducting a user study; and (iii) contribute to the understanding of the potential of VR technology in intangible cultural heritage tourism and the preservation of cultural heritage, specifically for UNESCO-listed sites.

This paper is structured as follows: we begin by reviewing the existing literature on the application of VR in the preservation and promotion of intangible cultural heritage. Subsequently, we offer a detailed description of the key activities that take place within Jemaa El-Fna. This is followed by an exploration of the design and development process of the El-FnaVR VR application, as well as a comprehensive user study. The subsequent results and discussion sections delve into the insights gleaned from the user study, alongside the potential ramifications of this research. In conclusion, we encapsulate the primary takeaways and offer insights for future investigations in this field.

II. RELATED WORKS

The utilization of VR technology for cultural heritage preservation, both tangible and intangible, has become a topic of growing interest within the research community in the past decade. VR's potential for restoration, analysis, and conservation of cultural landscapes and Intangible Cultural Heritage (ICH) is increasingly being recognized.

For example, VR was used to assess the visual aesthetic effect of restored cultural landscapes in southwest China, finding that the restoration not only reduced visual fatigue but also enhanced the visual aesthetic experience [8]. In the context of ICH preservation, VR has been employed in the learning of traditional crafts, such as Dongyang bamboo weaving, effectively reducing the learning time required for subjects and showcasing its potential as an educational tool for ICH preservation [9].

Further research has investigated the use of VR in ICH High-Definition Digital Mobile Display Technology. One such study focused on Dai ceramics, demonstrating that VR can enhance the virtual visualization of ICH digital display technology by digitally and artistically processing ceramics while maintaining their authenticity [10]. VR platforms have also been developed based on Convolutional Neural Networks (CNNs) for the conservation of ICH, such as the

boat-shaped houses of the Li nationality in Hainan, China, highlighting the advantages of digitizing ICH using artificial intelligence [11].

Other researchers have implemented cloud-based VR systems for preserving traditional art forms, such as Chinese glove puppetry, showcasing its effectiveness and ease of use [12]. An immersive VR learning experience was developed to teach prehistoric intangible cultural heritage to young history students, highlighting VR's potential as a medium for learning and disseminating traditional cultural practices [13]. Additionally, Serious Games have been employed to bring ancient stories to life, such as The Story of the Shipwrecked Sailor, while teaching players about hieroglyphs [14]. An ontology-based system encoded dance and music performances, providing a semantic navigation environment for Indian Classical Dance [15]. A conceptual framework was proposed for the design of virtual environments for cultural learning, emphasizing the importance of information design, information presentation, navigation mechanisms, and environment setting [16].

The preservation of ICH has also been addressed in diverse areas such as archaeology, history, folklore, and performing arts. An immersive VR application was developed for the Museum of Preclassical Civilizations of the Southern Murgia in Ostuni, allowing users to explore the Upper Paleolithic settlement and experience the burial ritual of Ostuni 1 [17]. Research into preserving the heritage of bridge diving at Stari Most in Mostar, Bosnia, used interactive digital storytelling with 360-degree videos in VR [18]. Another study focused on creating a multimedia platform to communicate the tradition of bronze "investment casting" in Pietrasanta, Italy [19]. Research has been conducted into the application of VR systems for the inheritance of intangible cultural heritage in gongs and drums [20]. A unique example of digitizing ICH involves the African oral tradition about the Tokoloshe, cautionary tales passed down through generations [21]. An immersive VR system for exploring the UNESCO-listed Dunhuang Caves was developed [22]. Their user study highlights the importance of spatial context and interactive elements in enhancing users' understanding of cultural heritage within virtual environments. Finally, an interactive VR system was developed to preserve "Huaer," a traditional oral performance that is part of China's national ICH [23].

In our comprehensive analysis of existing VR projects in cultural heritage preservation, as summarized in the provided Table 1, a notable trend emerges: while many projects have successfully incorporated VR technology, they predominantly focus on tangible cultural heritage, leaving a significant gap in the representation of Intangible Cultural Heritage (ICH), especially those recognized by UNESCO. This gap is partly due to the inherent complexity of ICH activities and the high level of interactivity required to faithfully replicate them. Most previous efforts, like the Meta Museum [31], Empty Museum [21], and Wide FOV displays [18], focus mainly on virtual world creation, offering

TABLE 1. Comparative analysis of cultural heritage projects utilizing VR.

Project	Mobility	Interactions in two ways	On-location Storytelling	Gamification	Sense of virtual environments	3D spatial multimedia representation	Guidance	UNESCO inscription	ICH	3D spatial Audio	Customized experience
Meta museum [24]	✗	✓	✗	✗	✗	✗	✓	✗	✗	✗	✓
Empty museum [25]	✓	✓	✗	✗	✗	✗	✗	✗	✗	✓	✗
Wide FOV displays [26]	✗	✗	✓	✗	✗	✓	✓	✗	✗	✗	✗
Cypriot CH [27]	✗	✓	✗	✗	✗	✗	✓	✗	✓	✗	✗
Santa Maria project [28]	✗	✓	✗	✗	✗	✗	✓	✗	✗	✗	✗
World war I [29]	✗	✓	✗	✗	✗	✗	✗	✗	✓	✗	✗
Mobile VR [30]	✗	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗
3DCG [31]	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Tales of the Tokoloshe [21]	✓	✓	✓	✓	✓	✓	✗	✗	✓	✗	✗
HieroQuest [14]	✓	✓	✓	✓	✓	✓	✓	✗	✓	✗	✗
old bridge in Mostar [18]	✓	✗	✓	✗	✓	✓	✓	✗	✓	✗	✗
Dunhuang Cave [22]	✓	✗	✓	✗	✓	✓	✗	✓	✓	✓	✗
V-Museum [32]	✓	✗	✗	✗	✓	✓	✗	✗	✗	✗	✗
Hua'er in VR [23]	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	✗
Re-Live History [13]	✗	✓	✗	✗	✓	✓	✓	✓	✓	✗	✗
Fruition of Ancient Contexts [17]	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✗
Chinese Glove Puppetry [12]	✓	✓	✓	✗	✓	✓	✗	✓	✓	✗	✗
Bamboo Weaving [9]	✓	✓	✓	✓	✓	✓	✗	✗	✓	✗	✗
El-FnaVR	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

✓: The project implemented the technique.
✗: The project did not implement the technique.

limited user mobility and interaction. Projects like Hiero-Quest [14] showadvancements in interactive elements but often fall short of providing comprehensive sensory experiences and deep engagement with ICH. Against this backdrop, El-FnaVR distinguishes itself with its rare use of 3D spatial audio, an essential feature for authentically recreating the atmosphere of Jemaa El-Fna, a UNESCO-inscribed ICH site. Jemaa El-Fna, known for its diverse and intricate activities, serves as an exemplary model of ICH. El-FnaVR captures this essence by offering an immersive experience that transcends visual fidelity, embracing auditory and interactive dimensions. By focusing on two-way interactions, gamification, and user preferences, El-FnaVR not only conserves the dynamic spirit of Jemaa El-Fna but also pioneers a new path in VR for cultural heritage, demonstrating the technology's potential to vividly encapsulate and convey the richness of the world's diverse cultural landscapes.

III. CASE STUDY: JEMAA EL-FNA
A. HISTORICAL BACKGROUND
Jemaa El-Fna, a vibrant square situated in the heart of Marrakech, Morocco as depicted in Figiure 1, has an intricate historical background that embodies the living pulse of Moroccan heritage. The square, whose name roughly translates to "Assembly of the Dead," is nothing short of an emblematic symbol of Morocco's rich history and vibrant cultural life.

Originating in the 11th century under the rule of the Almoravids, Jemaa El-Fna was initially conceived as a meeting point for traders, nomads, and the like. Throughout its existence, it has witnessed significant transformations reflective of Morocco's sociopolitical changes, enhancing its historical significance.

As the city expanded, the square grew into an essential hub of cultural, commercial, and spiritual activities. By day, the Jemaa El-Fna square is populated by snake charmers, fruit vendors, traditional healers, and storytellers; come twilight, it transforms into an enormous open-air restaurant filled with food stalls, accompanied by music and dance performances, embodying the diverse sensory experience that characterizes Moroccan culture.

Moreover, the square has been a crucial site for the oral transmission of stories, historical events, and traditional customs, effectively preserving the intangible cultural heritage of the region. As a testament to its significance, Jemaa El-Fna was recognized as a Masterpiece of the Oral and Intangible Heritage of Humanity by UNESCO in 2009, emphasizing its importance as a living museum of Moroccan tradition and heritage.

The inclusion of digital and VR technologies in the depiction and preservation of the Jemaa El-Fna square presents a unique opportunity to capture its dynamic atmosphere and cultural vibrancy. Such technological advances can offer a novel perspective, enhancing the understanding of the square's historical background while fostering a deeper appreciation of Morocco's rich cultural tapestry.

B. RELEVANT ACTIVITIES
1) HALQA
Within the dynamic milieu of Jemaa El-Fna, the Halqa, or the storytelling circle, represents a distinctive part of Moroccan cultural tradition. The term 'Halqa' is derived from the Arabic word for 'circle' or 'ring,' mirroring the crowd of listeners that envelop the storyteller in the square.

A typical Halqa involves a 'Hlayqi', or a storyteller, narrating enthralling tales filled with heroes, fables, and moral lessons, punctuated with elements of humor, drama, and mystery. This deeply ingrained cultural practice has been passed down through generations, with Hlayqis traditionally learning their craft under the guidance of an older mentor.

However, the Halqa isn't solely about storytelling; it encompasses a broad array of performances and displays. The square often comes alive with the spectacle of snake charmers, as shown in Figure 2a, entrancing spectators as they coax and control their serpents to the rhythm of their pungi flutes. Monkeys dressed in tiny outfits might be seen performing tricks, much to the delight of children and adults alike, as depicted in Figure 2b. These performances and activities form an intrinsic part of the Halqa experience, contributing to the vibrant and dynamic character of Jemaa El-Fna. They serve not only as sources of entertainment but also as living records of Moroccan history, culture, and societal norms.

2) GNAWA
Gnawa, UNESCO-listed[2] in 2019, another integral part of Jemaa El-Fna, is an entrancing form of music and dance native to the Maghreb region. Gnawa has its roots in the sub-Saharan African heritage of Morocco, especially among groups brought to the region through the Trans-Saharan trade.

This unique art form, recognized by UNESCO as an intangible cultural heritage, is characteristically performed by a group known as 'Gnaoua.' The performers, typically dressed in colorful, traditional attire, enthrall the audience with their rhythmic music and expressive dance moves. The performance is characterized by the use of instruments like the 'Guembri' (a three-stringed lute), 'Krakebs' (large iron castanets), and rhythmic clapping.

Gnawa is not merely a form of entertainment. It is deeply spiritual, associated with healing ceremonies that involve trance and spiritual cleansing. The repetitive and hypnotic music is believed to induce a trance state in participants, leading to therapeutic effects.

The Gnawa performances in Jemaa El-Fna are a sight to behold, drawing both locals and tourists into their rhythmic swirl as shown in Figure 2d. The melodic harmony of the guembri, the sharp clatter of the Krakebs, the vibrant colors, and the swirling dancers make it an unforgettable experience.

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[2]https://ich.unesco.org/en/RL/gnawa-01170

FIGURE 1. Jemaa El-Fna, Marrakech, Morocco.

3) TRADITIONAL FOODS

From dusk until late into the night, Jemaa El-Fna transforms into a gigantic open-air restaurant, teeming with pop-up stalls serving an assortment of traditional Moroccan dishes. The experience is a feast for all senses, with the aroma of grilling meats, simmering tagines, and exotic spices wafting through the air, accompanying the vibrant cacophony of the square.

Essential Moroccan dishes such as couscous, Harira (a hearty lentil and tomato soup), and tagines (slow-cooked stews) of all varieties can be found in abundance. Street vendors offer various grilled meats like Kefta (minced lamb), Merguez (spicy sausage), and Brochettes (skewers) cooked over charcoal grills, as depicted in Figure 2f.

In addition, Jemaa El-Fna is an excellent place to sample less common delicacies. Adventurous food enthusiasts can try snails cooked in a spicy broth or sheep's head, considered a delicacy. There's also a large variety of seafood, freshly caught from the nearby Atlantic coast and grilled to perfection.

For those with a sweet tooth, there are countless options, from Pastilla (a sweet-savory pastry filled usually with squab or chicken) to freshly squeezed juices from an assortment of local fruits like oranges (Figure 2e), pomegranates, and dates. The unique charm of Jemaa El-Fna's food stalls is not just about the food itself, but the atmosphere of community and camaraderie it engenders. Shared tables encourage interactions between locals and visitors, leading to engaging conversations and cultural exchange over a communal love for food.

4) HORSE CARRIAGE

As shown in Figure 2c, the horse carriages are an integral part of the bustling atmosphere at Jemaa El-Fna, offering both locals and tourists an alternative way to explore the square and its surroundings. Traditionally adorned and guided by experienced carriage drivers, these horse-drawn vehicles add a touch of historic charm to the modern vibrancy of the square.

IV. El-FnaVR: DESIGN AND IMPLEMENTATION

The development of El-FnaVR unfolds across five distinct stages inspired by [33], summarized in Figure 3, with the first being bifurcated. Stage 1.A focuses on identifying the salient features of Jemaa El-Fna for accurate representation, while Stage 1.B scours relevant literature to pinpoint suitable tools for design and execution. In Stage 2, the earmarked features and characteristics are methodically designed to facilitate an engaging virtual tour. Stage 3 involves creating essential assets such as 3D models and animated characters. This phase undergoes iterative self-reviews to ensure authenticity and accuracy. Upon validation, Stage 4 ensues, centering on prototype development. This involves integrating the validated assets and scripting interactions to enable smooth navigation throughout the virtual environment. The prototype undergoes rigorous self-review until it meets the desired benchmarks. Concluding the process, Stage 5 employs a qualitative evaluation strategy, to gauge the prototype's efficacy.

A. STAGE 1: CONTENT REQUIREMENTS & LITERATURE STUDY

1) STAGE 1.A

It revolves around the characteristics of cultural information and the presentation formats. Here, the essence lies in capturing the richness and diversity of Jemaa El-Fna's cultural elements and transforming them into a digital format that is accurate, immersive, and interactive. By doing so, we can provide an authentic and engaging user experience. From the traditional Gnawa music to the vibrant food stalls and captivating Halqas, we aim to encapsulate all facets of this vibrant square. The presentation formats are carefully chosen to facilitate this immersive experience. The environment is designed using realistic 3D models and animations, complemented with spatial audio to render a 360-degree sensory experience.

2) STAGE 1.B

We delve into the literature to investigate studies that have explored VR technology's application in the preservation and dissemination of intangible cultural heritage. This research provides critical sheds essential light on best practices, challenges, and potential solutions when developing VR applications for cultural heritage. Additionally, it aids in

FIGURE 2. Some Jemaa El-Fna activities and traditional street foods. (a): Halqa of snakes from Jemaa El Fna square. (b): Halqa of monkeys from Jemaa El Fna square. (c): Horse carriage. (d): Gnawa dancers group performing traditional dance and songs. (e): Orange Jus at the left. (f): The grilled meats and Harira at right.

understanding how VR can enhance accessibility, immersion, and interactive learning experiences for users, enabling them to connect with the cultural content on a deeper level. These insights guide us in designing a VR application that not only replicates Jemaa El-Fna in a digital format but also provides an enriching and meaningful cultural experience for users.

B. STAGE 2: DESIGN FEATURES AND CHARACTERISTICS
In the second stage of our development process, we focus on the detailed design of features and characteristics that make our Jemaa El-Fna VR application an authentic representation of the cultural heritage site. This stage is all about bringing the richness and diversity of Jemaa El-Fna into a VR environment

and ensuring the accuracy and immersion of the cultural information presented. This involves careful consideration of the aesthetic aspects, interactive elements, and the overall sensory experience for the user.

1) EL-FnaVR FUNCTIONS
The following functions describe the features that have been designed to achieve these objectives.

- **Function 1** - Aesthetic Design: Environment
  Implements the visual aesthetics of the environment, reflecting the color palette and Islamic design principles of Marrakech. Also, the red color of the buildings, which indicates the city.
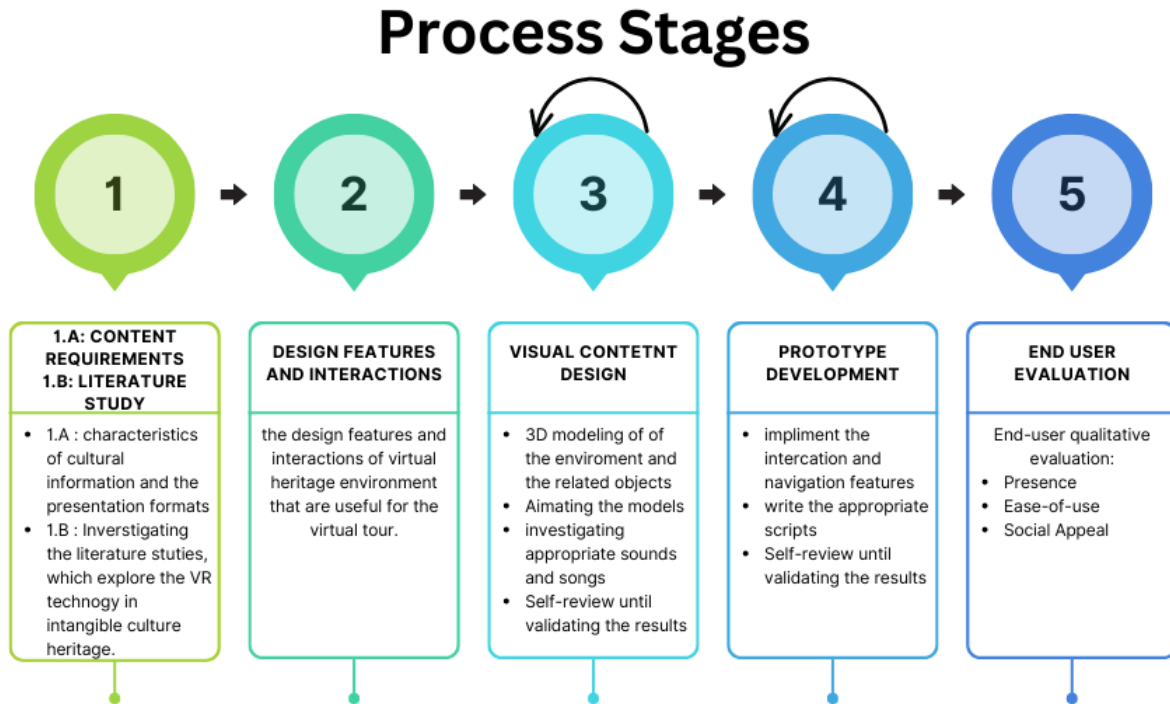
Process Stages

FIGURE 3. Sequential stages of El-FnaVR design and implementation process.

- **Function 2** - Activity Design: Snakes Halqa
  Introduces the Halqa of snakes, where users can interactively pick up animated snakes that slither around the Halqa.
- **Function 3** - Activity Design: Monkies Halqa
  Adds the Halqa of monkeys, where users can observe animated monkeys walking around the Halqa.
- **Function 4** - Activity Design: Gnawa Groups
  Incorporates Gnawa music, enabling users to experience virtual Gnawa groups performing traditional songs and dances.
- **Function 5** - Activity Design: Traditional Foods
  Introduces the aspect of gastronomy with virtual food stalls serving barbeque, Tajine, and couscous.
- **Function 6** - Activity Design: Horse Carriage
  Integrates horse carriages into the environment, which users can interact with and drive.
- **Function 7** - Activity Design: Everyday Activities
  Creates an immersive atmosphere by adding virtual people performing everyday activities like walking, talking, watching Halqa, Gnawa, and food stalls.
- **Function 8** - User Interaction
  Provides users with a range of interactive capabilities, such as navigating the square, observing activities, and picking up objects.
- **Function 9** - Points of Interest
  Implements informative points of interest related to each activity and their locations.
- **Function 10** - Spatial 3D Audio Design

Establishes an immersive 3D soundscape that corresponds with every activity in the environment, from the hissing of snakes to the rhythm of Gnawa music, and even the ambient sound of conversation among virtual people.

- **Function 11** - Preferences
  The system empowers users to personalize their experience by selecting from a variety of hand models. To mitigate the effects of cybersickness, users have the option to switch to a teleportation-based navigation mechanism as an alternative to continuous movement.

2) TOUR AND SPATIAL DESIGN

Crafting an optimal tour scenario is paramount to guide visitors through all activities in an immersive sequence. The vast expanse of Jemaa El-Fna square allows tourists unrestricted movement, with no predetermined path. Most, however, often experience walking to Jemaa El-Fna by horse carriage. As depicted in Figure 4 – which serves as a guideline rather than a strict route – our virtual application simulates this experience, beginning with a horse carriage journey towards the square. Visitors are first introduced to the Halqa of monkeys, offering a glimpse of Maalem's playful interactions with them. Adjacently, the enthralling rhythms of Gnawa music beckon from the Halqa of the Gnawa group. From there, an adventurous stride leads to the Snakes Halqa, as depicted in, where audacious visitors can handle snakes and observe Maalem's deft maneuvers with

them. A quintessential part of the Jemaa El-Fna experience is indulging in traditional street foods and refreshing orange juice, so the tour naturally progresses to stalls offering these delights. To conclude, visitors can immerse themselves in the vibrant atmosphere of three additional Gnawa Halqas, each presenting a unique medley of songs and music.

3) APPLICATION STRUCTURE

The design of the El-FnaVR application is user interaction and navigation-centered. This structure is layered, integrating physical and virtual components to enhance user control and engagement within the virtual environment, as depicted in Figure 5.

The first layer, physical, involves the controllers and sensors of the Oculus Quest headset. These devices enable users to navigate, control, and interact within the virtual environment.

The second layer is represented by a virtual guide. This guide helps users navigate the virtual space by providing points of interest, coins, and storytelling, thus enhancing the localization of each activity within the virtual environment.

The third layer, the most comprehensive, constitutes the entire 3D virtual environment. It encompasses all 3D characters, objects, spatial 3D audio, and effects, immersing users in a rich, detailed representation of the cultural setting.

C. STAGE 3: VISUAL CONTENT DESIGN

In the third stage of development, our focus shifts to the Visual Content Design (Figure 6), which forms the core of the VR experience. This stage ensures that the immersive digital environment accurately represents the authentic spirit and visual richness of Jemaa El-Fna.

The stage involves the following steps:

1) **3D Modeling of the Environment and Related Objects:** This step involves creating a 3D model of Jemaa El-Fna and all associated objects like the Halqa, Gnawa musicians, and local food stalls. This involves detailed architectural modeling of the square and careful sculpting of related elements, using high-quality 3D graphics to accurately represent the physical appearance of the cultural site and its elements. To achieve this goal, AutoDesk MAYA[3] was chosen for 3D modeling and Pixologic ZBrush[4] for the sculpting process.

2) **Animating the Models:** Static models do not capture the vibrant life of Jemaa El-Fna. Therefore, we bring our 3D models to life through animation. Snakes slither, monkeys wander, Gnawa musicians perform, and virtual inhabitants carry out their activities, lending dynamism and realism to the experience. Autodesk Maya was used to animate virtual objects.

3) **Investigating Appropriate Sounds and Songs:** The audio design is a critical element of the immersive

experience. We carefully research and curate a selection of appropriate ambient audios, musical performances, and sound effects, ensuring they are culturally accurate and contribute to the overall authenticity of the environment.

4) **Self-Review and Validation of Results:** Lastly, the team conducts iterative reviews of the designed content, verifying the accuracy and quality of the visual and auditory elements. This step is crucial to ensure that the VR representation remains faithful to the cultural richness and diversity of the real Jemaa El-Fna, providing users with an immersive and authentic experience.

D. STAGE 4: PROTOTYPE IMPLEMENTATION

The fourth stage, Prototype Implementation, delves into the actual construction of our VR application, bringing the design features and visual content to life. This stage is split into two main components.

1) DEVELOPMENT PIPELINE

The VR application is developed using the Unity[5] 3D game engine and the VR Interaction Framework. It is specifically designed to be compatible with the Oculus Quest 2 and later models. A critical aspect of this phase is the implementation of interaction and navigation features, which are essential for user engagement and the overall user experience within the VR environment. This includes coding the necessary scripts that drive these features and constantly reviewing and adjusting until satisfactory results are achieved. Such a systematic approach ensures that the application is not only immersive but also interactive and responsive to user input, providing an enriching virtual experience. The development pipeline is summarized in Figure 7.

2) VIRTUAL SCENARIO

The system scenario was designed to be adaptable, as depicted in Figure 10. The system provides users with the freedom to navigate through the virtual space and jump from one scene to another at their own pace. Such flexibility not only increases the level of user engagement but also enhances their ability to learn and enjoy the tour. To aid navigation, "points of interest" markers have been placed to localize each activity, as demonstrated in Figure 8a. Furthermore, to encourage exploration, 10 coins have been distributed next to each activity or point of interest for users to collect, as shown in Figure 8b. To help reduce any potential anxiety from continuous movement, an alternative teleportation movement mechanism has been implemented [34], as depicted in Figure 9. This allows users to move to different areas quickly, providing them with a seamless and comfortable VR experience.

As outlined in Function 11, El-FnaVR offers users the ability to customize their experience by selecting their

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[3]https://www.autodesk.com/products/maya
[4]https://www.maxon.net/en/zbrush
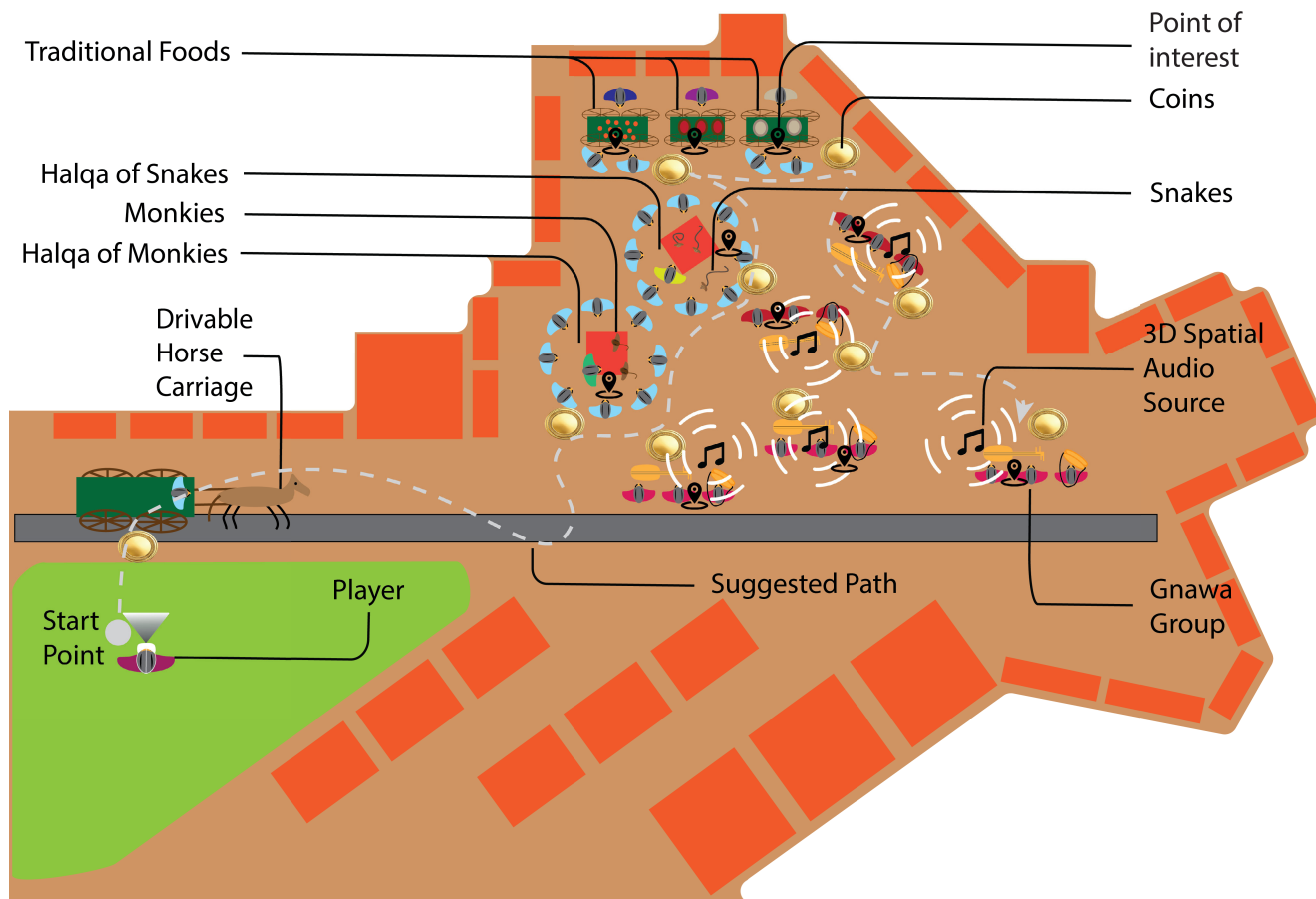
[5]https://unity.com/

FIGURE 4. Mapping and tour design of El-FnaVR.

preferred hand model within the virtual environment. This feature allows for a more personalized and immersive interaction, tailoring the virtual world to individual tastes. Figure 11 demonstrating this functionality.

3) REFINED IMPLEMENTATION AND DEPLOYMENT

Following rigorous self-testing, the ultimate version of El-FnaVR has been fully developed and is now primed for end-user evaluation. The application meticulously replicates the ambiance of Jemaa El-Fna with a high degree of detail, allowing users to interact with a multitude of objects and select their desired tour scenario through points of interest. Figure 12 showcases the most prominent activities implemented in the application.

E. STAGE 5: END USER EVALUATION

The evaluation methodology employed for the El-FnaVR system was grounded in a purposive sampling approach, utilizing semi-structured questionnaires for participant feedback [35]. This approach mirrors successful evaluation strategies from similar studies in the field [36], [37], [38], [39]. The qualitative evaluation was meticulously crafted to address pertinent research questions arising from the system

evaluation. In addition to serving as a direct exploration of the El-FnaVR experience, the questionnaire also acted as a barometer for understanding the pivotal role of guides within the system and identifying areas of improvement to enhance the overall visitor experience.

In our study, participants were primarily drawn from the Higher Institute of Applied Technology in Morocco, providing a technologically adept and diverse respondent group, as outlined in Table 2. We maintained strict ethical standards and ensured quality in our field research by setting an age limit of 18 to 60 years. Our sampling strategy aimed at gender balance resulted in a participant pool comprising 53% males and 47% females. The age of participants predominantly fell within the 18-24 range (79.6%), reflecting a younger demographic. A significant majority were students (81.5%), aligning with our institutional recruitment strategy. Notably, the majority of participants had limited or no prior experience with VR (87.8%), providing a unique perspective on VR engagement among novices in the field.

Upon their arrival, participants unfamiliar with VR received a brief training session focused on system navigation and air-tapping techniques, specifically designed to acquaint them with the Oculus Quest 2. Subsequently, they were briefed on the tour's layout within the room and the key portal
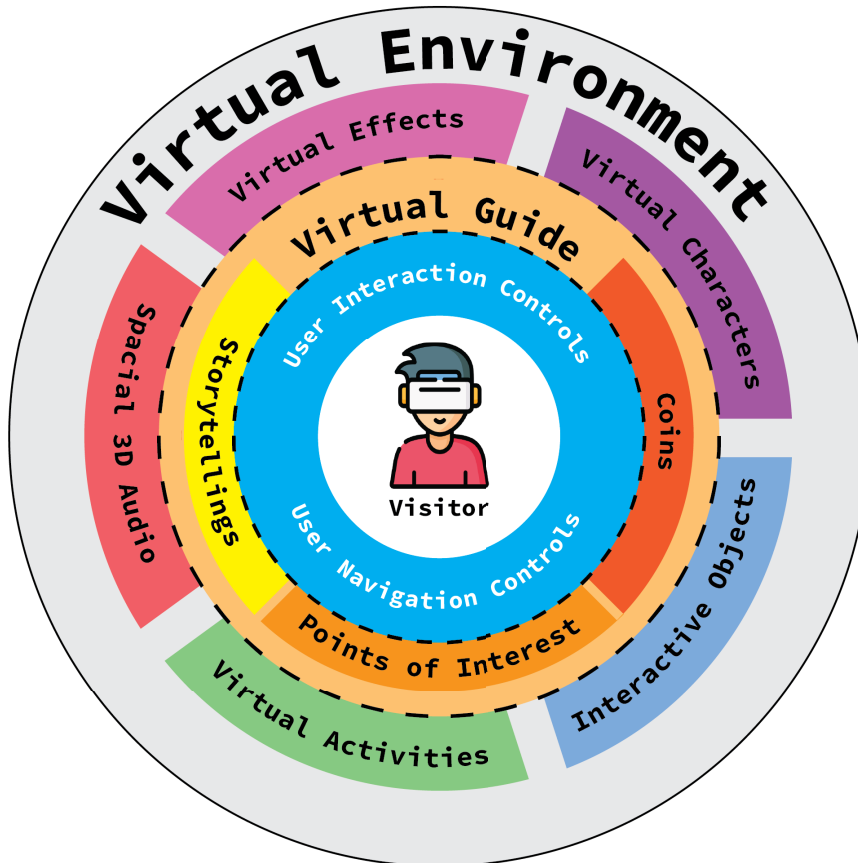
FIGURE 5. The layers-based application structure.

points. Participants were then allowed an unrestricted time frame to evaluate and engage with the El-FnaVR system, ensuring they had a comprehensive experience, as depicted in Figure 13. Following the demonstration, participants completed a questionnaire comprising 20 open-ended questions, arranged in seven separate sections, as outlined in the Appendix. These sections cover key areas such as immersion, authenticity, cyber-sickness, ease of use, and social appeal. This multifaceted approach to evaluation allowed for a holistic understanding of the user experience and provided valuable insights for the future refinement of the El-FnaVR system.

V. RESULTS
The results section of this study presents the findings from the end-user qualitative evaluation of the El-FnaVR application. Participants' responses to the semi-structured questionnaire were systematically analyzed to assess their experiences and perceptions of the application. The evaluation focused on various aspects of the application, including the Sense of Presence, Ease of Use, and Social Appeal. In the following subsections, we present the insights gathered from the participants' feedback, supplemented with direct quotes to illustrate their experiences. The observations and comments shared by the participants provide valuable insights into the

impact and potential of the El-FnaVR application in offering a compelling and informative virtual tour of the Jemaa El-Fna Square in Marrakech.

A. PRESENCE EXPERIENCE
1) IMMERSION AND ENGAGEMENT
The immersion and engagement of users in the El-FnaVR experience were highly positive, as reflected in their responses. Participants overwhelmingly found the application to be "enjoyable and engaging," with many expressing their astonishment with exclamations such as "Wow, it's very beautiful!" This high level of engagement was further evidenced by the fact that most users reported feeling a strong sense of presence at Jemaa El-Fna while using the application. They felt transported to the vibrant square and could easily focus their attention on the stories and information about Jemaa El-Fna throughout the experience. One participant captured the sentiments of many others by remarking, "It feels like I am truly at Jemaa El-Fna. It's like I'm there without leaving the room!"

B. AUTHENTICITY OF THE EXPERIENCE
The authenticity of the virtual tour of Jemaa El-Fna was highly valued by participants. They reported that the application provided a genuine and insightful experience, capturing
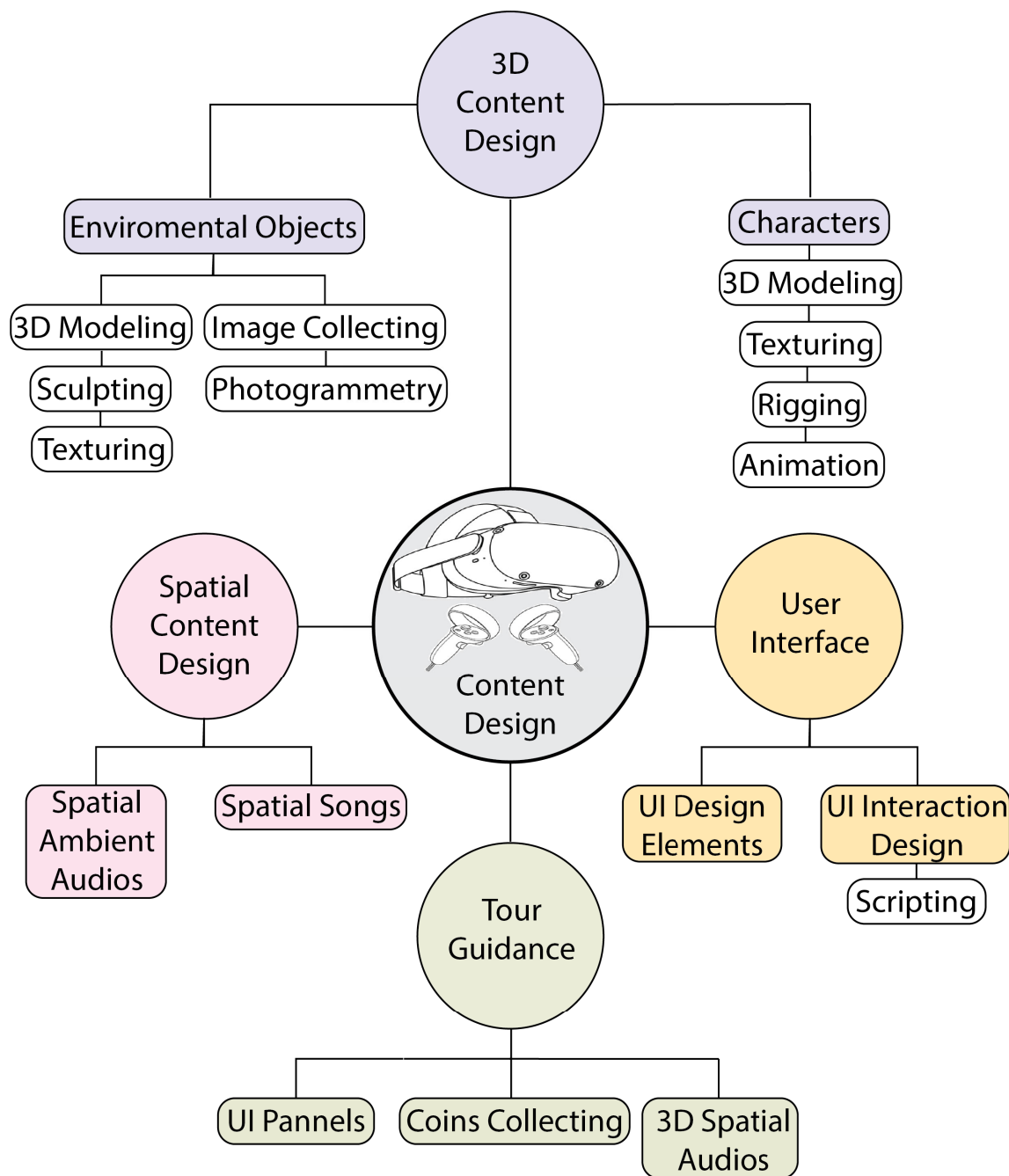
FIGURE 6. Visual content design of El-FnaVR.

the unique atmosphere and cultural richness of Jemaa El-Fna. Many participants commented on the valuable insights they gained into the famous square, with one participant noting, "I never knew so much about Jemaa El-Fna. This application gives me a new perspective." The experience left a lasting impression on participants, with several expressing their desire for additional stages and expanded content. One user shared their enthusiasm by saying, "This was a distinct and memorable experience. I hope you can add more things and stages to this application."

C. NAVIGATION AND USABILITY

The ease of navigation and usability of the El-FnaVR system played an important role in shaping users' experiences. While a few participants initially faced some difficulties in navigating the application, they were able to use it properly after receiving brief explanations. However, it should be noted that two participants chose not to complete the evaluation due to difficulties with navigation. Despite this, the majority of users found the navigation to be "natural and spontaneous" once they became accustomed to it. One
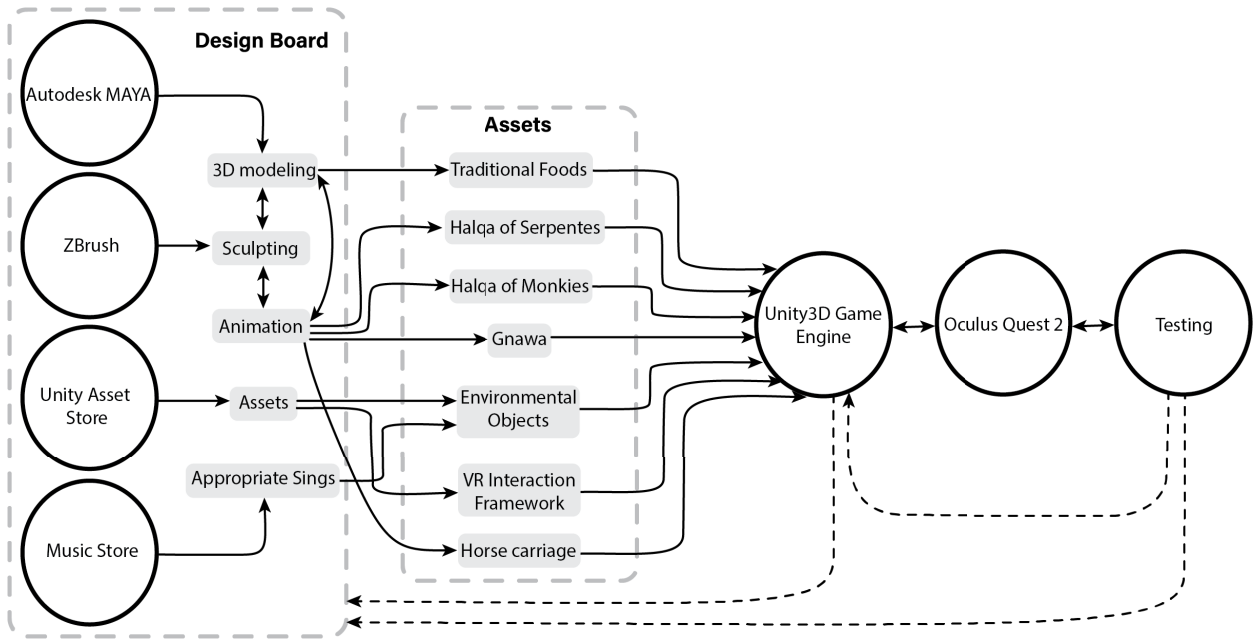
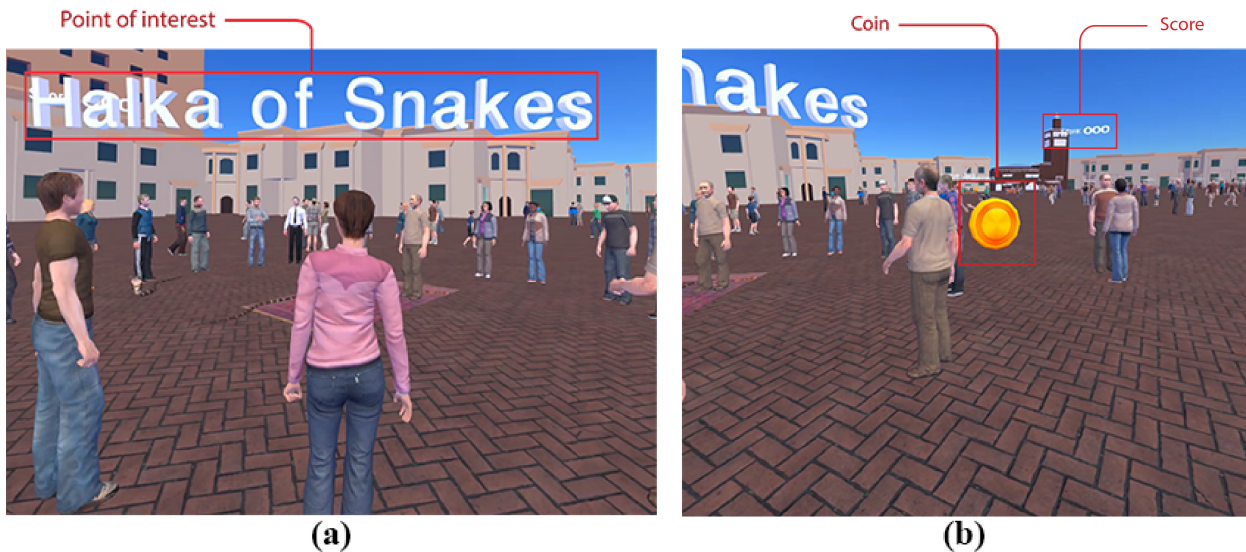**FIGURE 7.** Development pipeline of El-FnaVR.

FIGURE 8. Aid-navigation tools. (a): a point of interest placed beside the Halqa of snakes. (b): collectible coin.

user stated, "At first, I was a bit confused, but once I got the hang of it, it was easy to move around." This feedback emphasizes the importance of providing clear instructions to users and highlights the potential for further refinements in the application's navigation interface to enhance the overall user experience.

D. CYBERSICKNESS

Cybersickness emerged as a topic of discussion among participants in the El-FnaVR experience, although the reports were not widespread. Some users did mention experiencing dizziness and headaches during the virtual tour. For instance, one user remarked, 'I felt a bit dizzy at first when moving around in the application.' Another user added, 'I had a slight headache while exploring the square.' Interestingly, none of the participants reported feeling nauseous. It is worth noting that these effects seemed to diminish significantly when users switched to a teleportation movement mechanism instead of continuous movement. A participant shared, 'Once I switched to the teleportation mode, I felt much better and the dizziness disappeared.' It's also important to note that these effects were more commonly reported among female participants.

E. ANXIETY

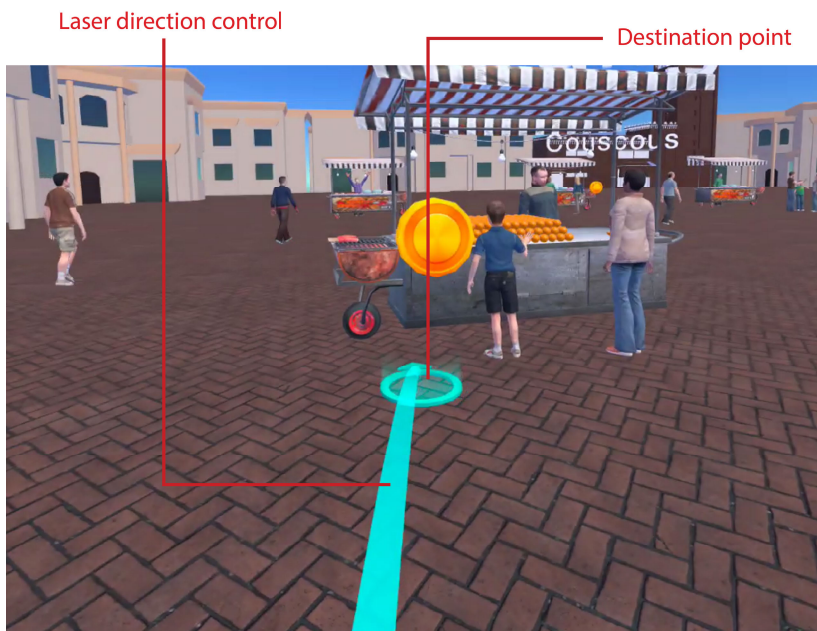The El-FnaVR application elicited a range of emotional responses among participants. While most users enjoyed the

FIGURE 9. Movement using point & teleport locomotion technique principle [34].
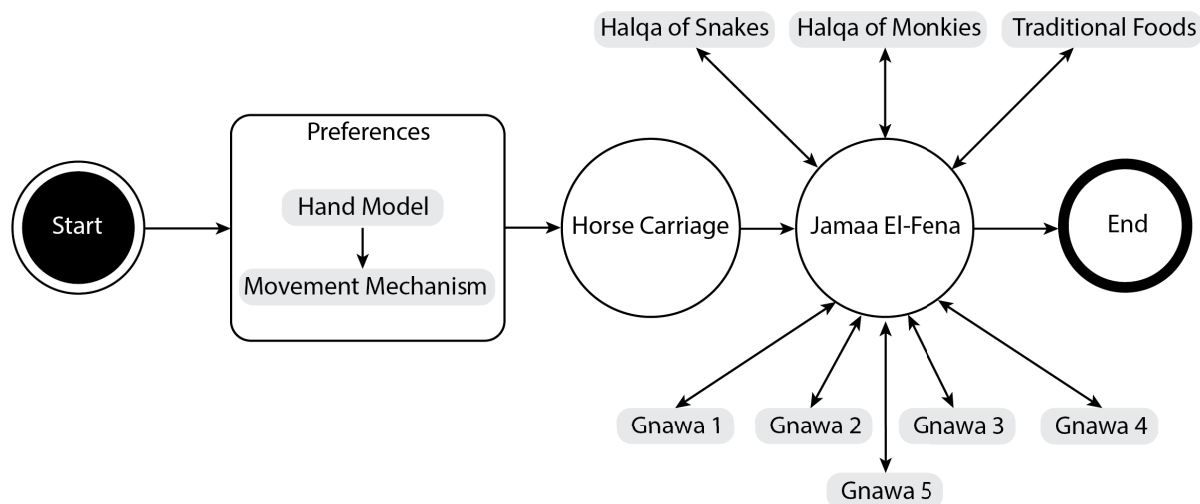

FIGURE 10. El-FnaVR system scenario.

experience, some, particularly females and older individuals (approximately 40 years and above), reported feelings of anxiety and discomfort. This was often linked to the lifelike depictions of walking people and snakes in the virtual environment. For instance, one participant expressed fear of the virtual snakes, saying, "I was so scared of the snakes; I couldn't even look at them." On the other hand, some users reached out to interact with them virtually. The divergent reactions highlight the importance of considering individual sensitivities and preferences in VR design. It was also noted that older users were more prone to discomfort with the VR experience, with some removing the head-mounted display and discontinuing use. Accommodating diverse user needs, including offering customization options and alternative navigation modes, is essential to create an inclusive and comfortable virtual experience.

F. EASE OF USE

1) USER INTERACTION AND INTERFACE
Participants largely found the El-FnaVR application easy to use and interact with. The majority of users felt that the application's interface was "clear and easy to understand." This ease of interaction with the application contributed to the overall positive experience of participants. One user noted, "I'm not tech-savvy, but I could easily use this application and enjoy the tour."

2) NAVIGATION EXPERIENCE
The ability to navigate the virtual tour smoothly and without problems was another aspect that was highly rated by participants. Most users found the application intuitive and straightforward in terms of navigation. "I could move around
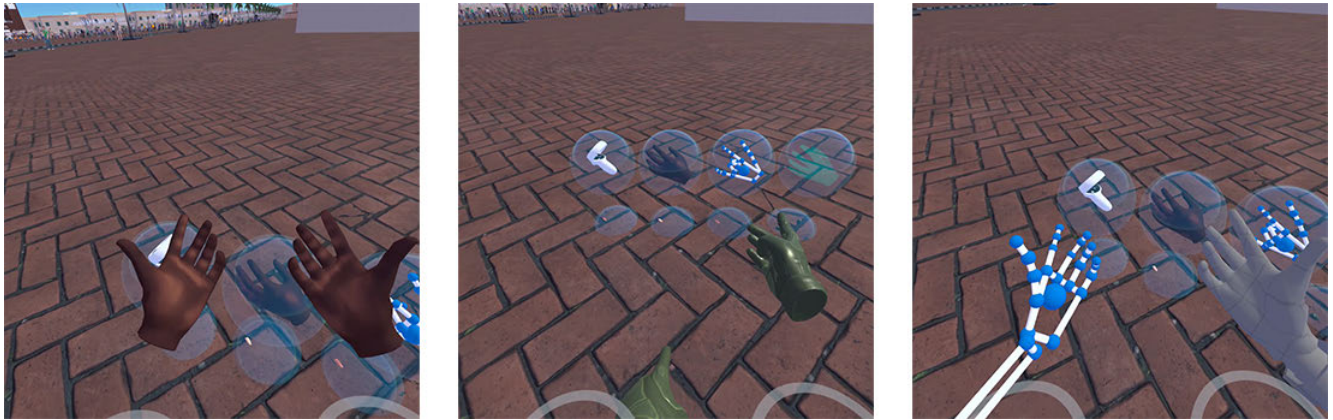
FIGURE 11. Customizing hand model from suggested models.

TABLE 2. Demographic characteristics of the sample.

Dimension	Value	Frequency
Gender	Female	23 (47%)
	Male	26 (53%)
Age	18-24	39 (79.6%)
	25-34	3 (6.1%)
	35-44	3 (6.1%)
	45-54	2 (4.1%)
	55-64	2 (4.1%)
Occupation	Student	40 (81.5%)
	Employed	9 (18.5%)
Education Level	High school graduate	19 (38.8%)
	Some college or associate degree	18 (36.8%)
	Bachelor's degree	8 (16.3%)
	Less than high school	3 (6.1%)
	Master's degree	1 (2%)
Previous Experience with VR	Extensive experience	1 (2%)
	Moderate experience	2 (4.1%)
	Some experience	3 (6.1%)
	Limited experience	23 (47%)
	No experience	20 (40.8%)

easily and explore different parts of the square,'' shared one participant.

3) INDEPENDENCE AND SELF-SUFFICIENCY
A significant feature of the El-FnaVR application was that it allowed users to independently navigate and explore the virtual tour without requiring external help or assistance. Most users could use the application without any additional help. One user commented, ''I don't usually play games or use VR applications, but this was not demanding or complicated at all. I could easily explore the tour on my own.''

4) LEARNING CURVE
Although the majority of participants had a positive experience, there were a few who initially faced difficulties in navigating the application. However, after receiving brief explanations, they were able to navigate and interact with the application efficiently. This indicates a minimal learning curve for new users, which enhances the overall usability of the application. One user noted, ''At first, I was a bit unsure about how to move around, but after a few minutes, I got the hang of it and could explore the tour with ease.''

G. SOCIAL APPEAL
1) RECOMMENDATION
The majority of the participants expressed enthusiasm about the El-FnaVR application, indicating that they would ''recommend this application for exploring Jemaa El-Fna to friends and family.'' The positive experiences of participants during the virtual tour prompted many of them to share their impressions and suggest the application to others. One user enthusiastically shared, ''This is a fantastic application, and I would definitely recommend it to my friends and family to experience Jemaa El-Fna in a new and unique way.''

2) PEER ENJOYMENT
Participants also believed that their peers would enjoy using the El-FnaVR application for a virtual tour of Jemaa El-Fna. They felt that the immersive experience, interactive features, and cultural insights offered by the application would resonate with a broad audience. One user commented, ''My friends who enjoy traveling and exploring new places would definitely love this virtual tour. It offers a different perspective of Jemaa El-Fna.''

3) VALIDATION BY RESPECTED INDIVIDUALS
Participants shared the belief that ''people whose opinions they value'' would appreciate the experience provided by the El-FnaVR application for the virtual tour of Jemaa El-Fna. Many users felt that the quality of the virtual tour would be appreciated by individuals who value cultural experiences and historical insights. A participant remarked, ''I think
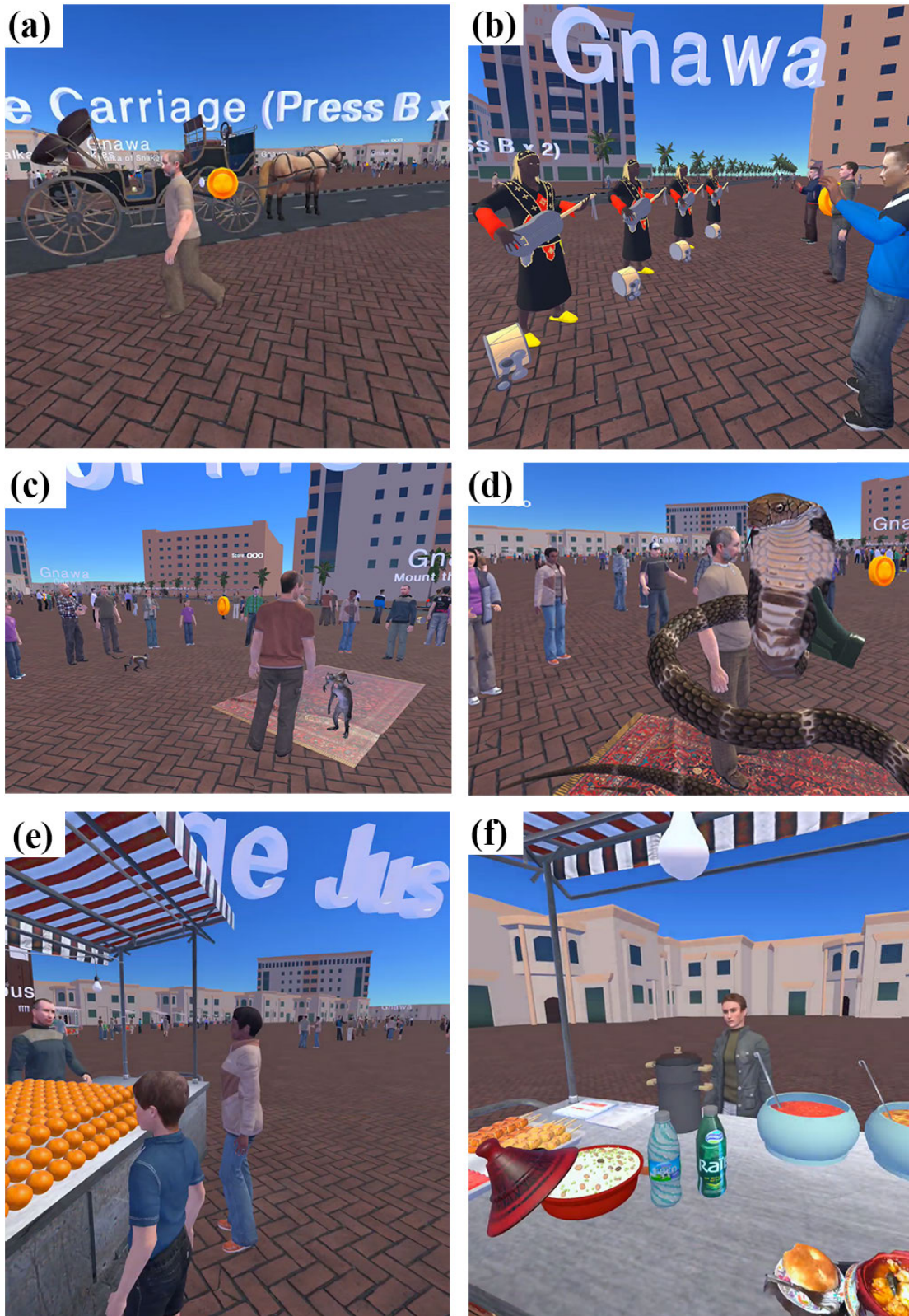
FIGURE 12. Depiction of activities in the El-FnaVR experience. (a) shows the horse carriage, which visitors can virtually ride and steer. (b) features the Gnawa group engaged in song and dance. (c) showcases animated monkeys in various poses. (d) displays the option to handle animated snakes. (e) highlights street-side orange juice vendors. (f) illustrates some traditional street food offerings.

FIGURE 13. Participants during the El-FnaVR experience.

my history teacher would find this application fascinating. It showcases the cultural richness of Jemaa El-Fna so well.''

4) CULTURAL SENSITIVITY

Participants' reactions to the El-FnaVR experience underscore the importance of capturing the cultural richness of a location like Jemaa El-Fna. While many participants found the VR tour to be an authentic representation, echoing sentiments like ''I feel like I am truly at Jemaa El-Fna,'' there were also requests for the inclusion of more activities. As one participant suggested, ''The experience was great, but I think adding more activities or performances from Jemaa El-Fna would make it even better.''

VI. DISCUSSION

The design and implementation of the El-FnaVR application are essential components of its success in promoting and preserving the intangible cultural heritage of Jemaa El-Fna. The structured approach adopted in its development, involving several stages from content requirement definition to prototype development and evaluation, was highly effective in creating an immersive VR experience.

The application's design, focusing on user interaction and navigation, greatly contributed to its positive reception. The multi-layered structure of the application, consisting of physical controllers, a virtual guide, and a 3D virtual environment, provided an intuitive and immersive experience for users [40]. This underscores the importance of a carefully planned and executed design in the development of VR applications for cultural heritage promotion.

Moreover, the inclusion of a virtual guide, equipped with points of interest, coins, and storytelling features, significantly enhanced the user experience by providing context and direction during the virtual tour. This design choice reflects the importance of providing users with guidance and information to help them better understand and appreciate the cultural heritage they are experiencing [41].

However, certain factors, including Cybersickness and anxiety, emerged as potential issues during the evaluation. Notably, some female participants reported experiencing dizziness and headaches, confirming findings from a study by [42]. As suggested by research on VR, cybersickness incidents can vary based on factors like the type of movement mechanism employed and individual differences among users [43]. Additionally, elements such as walking snakes triggered anxiety among some users, highlighting the need for consideration of user sensitivities and preferences when designing VR experiences [44].

The participants' feedback also revealed a desire for a more comprehensive representation of the cultural activities within Jemaa El-Fna. This is an important consideration for further enhancing the cultural sensitivity of the application, by including a broader range of activities that capture the full spectrum of the cultural heritage at Jemaa El-Fna [45].

Participants' feedback further highlighted the importance of a user-centered design approach in developing VR applications. Initial navigation difficulties underscored the need for user-friendly interfaces and user education. Addressing these challenges can further enhance the application's usability and accessibility [46].

VII. LIMITATIONS AND FUTURE WORKS

There are several limitations to this study. First, the headset used for the El-FnaVR application has limitations in supporting a large number of highly triangulated objects, which impacts the level of detail that can be rendered in the virtual environment. Second, modeling all objects in Jemaa El-Fna is a time-consuming and challenging task due to the vast number of objects present. This undertaking requires a dedicated team of modelers to accurately represent the intricacies and nuances of the square. Another limitation is the challenge of encouraging older people to participate in testing the VR application, as they might be less familiar or comfortable with the technology. It is also worth noting that the cultural nuances and richness of Jemaa El-Fna, as with any cultural site, can be challenging to capture fully and authentically in a virtual environment. Lastly, as with any virtual representation, there may be elements of the real-world experience that cannot be fully replicated, such as tactile sensations and smells that contribute to the overall ambiance of the location.

Future work will focus on enhancing the El-FnaVR application by incorporating personalization and recommendation systems to tailor the user experience to individual preferences and provide curated recommendations. We aim to employ Artificial Intelligence techniques to develop intelligent virtual guides that can provide real-time responses and interact more dynamically with users. Another promising direction is to enable shared visits, allowing multiple users to simultaneously explore Jemaa El-Fna virtually and interact with each other, creating a more social and communal experience. Additionally, we plan to expand the application by integrating more activities, capturing a richer and more comprehensive representation of the cultural richness of Jemaa El-Fna. These advancements will serve to further immerse users and provide an increasingly authentic and engaging virtual experience of this iconic cultural site.

VIII. CONCLUSION

The El-FnaVR application showcases the power of VR technology in preserving and promoting intangible cultural heritage. Our structured approach to the design and implementation played a crucial role in creating an engaging and immersive experience of the Jemaa El-Fna Square. The positive feedback received from participants highlights the application's potential to foster a deeper appreciation of cultural heritage sites. On the other hand, the tourism industry has experienced even greater difficulties as a result of the COVID-19 pandemic, with notable socio-economic consequences for stakeholders in the sector. Looking ahead to the post-COVID-19 period, our efforts aimed to address this challenge by offering tourists an engaging and interactive VR experience, which enables them to explore and familiarize themselves with Jemaa El-Fna Square without having to physically relocate, thus fostering the growth of virtual and remote tourism.

The inclusion of a virtual guide, multi-layered structure, and user-centered design all contributed to the application's success. The lessons learned from participants' feedback, such as the importance of intuitive navigation and user education, will be invaluable for further development and improvement of the application.

In conclusion, the El-FnaVR application demonstrates the potential of VR technology to immerse users in cultural heritage experiences and foster global appreciation of our shared cultural treasures. With continued research, development, and user-centered design, VR can play a vital role in preserving and promoting our rich cultural heritage for future generations.

APPENDIX

TABLE 3. User experience questionnaire.

No.	Question
Immersion and Engagement	
1	How enjoyable and engaging did you find the El-FnaVR application?
2	Did you feel a strong sense of presence at Jemaa El-Fna while using the application?
3	How effectively did the application capture your attention and interest throughout the experience?
Authenticity of the Experience	
4	Did the application provide a genuine experience of Jemaa El-Fna?
5	How insightful did you find the virtual tour in terms of learning about Jemaa El-Fna?
Navigation and Usability	
6	Did you face any difficulties in navigating the application?
7	How natural did you find the navigation within the application?
8	Were the navigation controls and instructions clear and easy to follow?
Cybersickness	
9	Did you experience any dizziness or headaches during the virtual tour?
10	How did the teleportation movement mechanism affect your experience compared to continuous movement?
Anxiety	
11	Did the application evoke any feelings of anxiety or discomfort, particularly regarding the lifelike depictions in the virtual environment?
12	How did older participants (around 40 years and above) react to the VR experience?
Ease of Use	
13	How easy was it to use and interact with the El-FnaVR application?
14	Did you find the application's interface clear and understandable?
15	Were you able to navigate the virtual tour smoothly and independently?
16	How steep was the learning curve when first using the application?
Social Appeal	
17	Would you recommend the El-FnaVR application to friends and family?
18	Do you believe your peers would enjoy using the El-FnaVR application?
19	Do you think people whose opinions you value would appreciate the El-FnaVR experience?
20	How well do you think the application captured the cultural richness of Jemaa El-Fna?

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