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Enhancing Museum Engagement Through Virtual Reality A Case Study of the Egyptian Museum in Cairo

Henar A. Kalefa[1], Mohamed A. Mohamed Hassan[1*], Mohamed H. Sabet[1]

1 Department of Architecture, Faculty of Engineering, October 6 University, 6th of October City, 12585, Giza, Egypt.

* Corresponding author's email: mohamed.ahmed.eng@o6u.edu.eg

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Abstract – This study explores the transformative role of Virtual Reality (VR) in enhancing museum experiences, with a focus on a 360-degree VR video project created for the Egyptian Museum in Cairo. Situated northeast of Tahrir Square, the Egyptian Museum is one of the largest and most significant cultural institutions in the world. The research examines how VR can recreate the museum environment, making cultural heritage accessible and engaging for a global audience. By analyzing the effectiveness of VR technology in creating immersive and educational experiences, the paper highlights its potential to overcome spatial, temporal, and physical barriers often associated with traditional museum visits. The findings demonstrate that VR not only enriches visitor engagement but also fosters a deeper appreciation for history and culture, aligning with modern pedagogical and technological advancements.

Keywords: Virtual Reality (VR), Egyptian Museum, Cultural Heritage, Museum Experience, Digital Architecture, Immersive Learning, 360-Degree Video, Museum Accessibility.

I. INTRODUCTION

Museums play a pivotal role in preserving cultural heritage and providing educational experiences, yet they often face challenges such as limited accessibility, logistical constraints, and difficulties in maintaining audience engagement in the digital age[1]. The Egyptian Museum in Cairo, situated northeast of Tahrir Square, is one of the world's largest and most significant museums, housing a vast collection of ancient artifacts. However, like many traditional museums, it faces limitations in reaching broader audiences and creating immersive visitor experiences [1].

Virtual Reality (VR) technology has emerged as a transformative solution in the museum sector, enabling the creation of immersive, interactive environments that transcend physical and spatial barriers [2]. By simulating realistic and engaging experiences, VR offers museums the opportunity to attract diverse audiences, enhance learning outcomes, and adapt to the demands of the digital era[2].This study examines the integration of VR into museum practices through a 360-degree VR video project showcasing the Egyptian Museum. This project provides a guided virtual pathway through the museum, allowing users to explore its rich collection from remote locations. By leveraging this technology, the research seeks to demonstrate VR's potential to transform museum experiences, making them more accessible and engaging for global audiences [2].

The research addresses key questions, including:

1. How can VR enhance visitor engagement and educational experiences in museums?
2. What role does VR play in overcoming traditional museum barriers such as accessibility and spatial constraints?
3. How can museums effectively implement VR to broaden their audience base and preserve cultural heritage?

By exploring these aspects, this paper contributes to the discourse on digital heritage and technological innovation in the cultural sector, emphasizing VR's role in shaping the future of museum experiences [1].as shown in Fig 1.

Figure 1: Application statistics screen provided by CC.
Source: https://iopscience.iop.org/article/10.1088/1757-899X/710/1/012015

II. RELATED WORKS

The use of Virtual Reality (VR) in educational and cultural contexts has been widely explored, showcasing its transformative potential. Several studies highlight VR's ability to enhance learning outcomes, foster engagement, and overcome traditional barriers such as geographical and physical limitations [2].

One notable study investigated the impact of virtual museums on cognitive achievement and student attitudes, comparing VR experiences with traditional teaching methods. Results showed a significant improvement in students' academic performance and positive shifts in attitudes towards museum visits when using VR technologies [3]. Similarly, research by Fokides et al. demonstrated that students who engaged with virtual museum environments exhibited higher levels of knowledge retention and enjoyment compared to conventional educational approaches [4]. as shown in Fig 2.

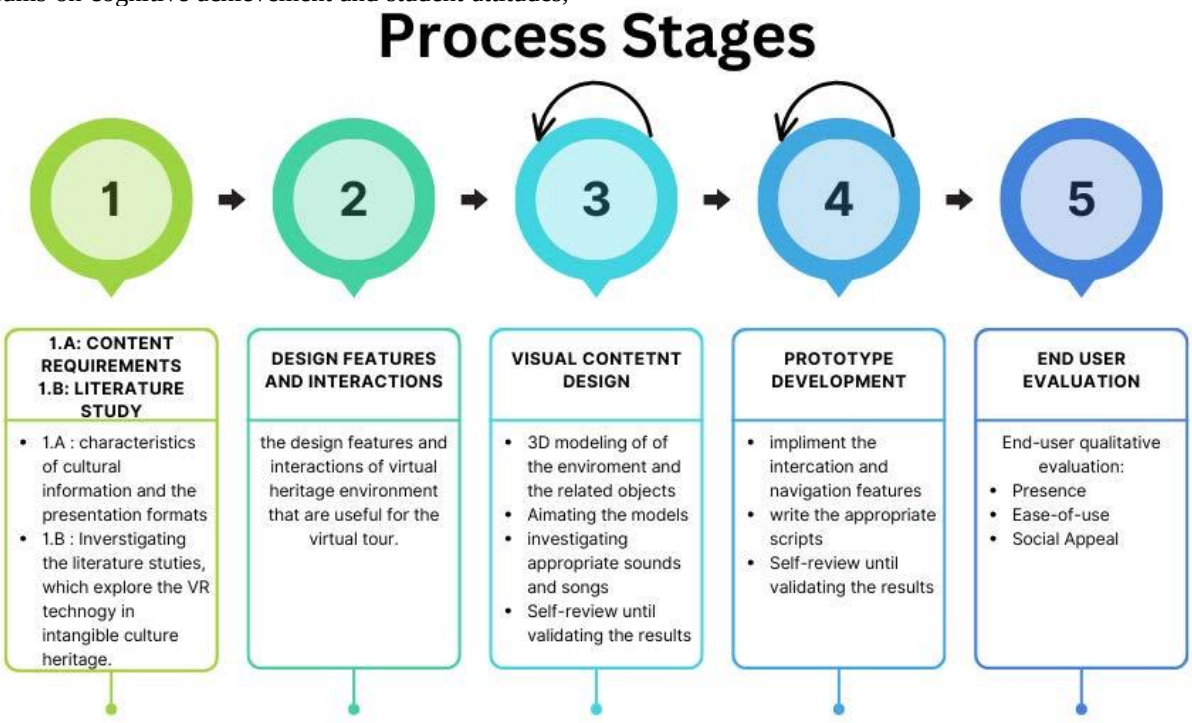


Figure 2: Process Stages for Evaluation by IEEE Xplore
Source: https://ieeexplore.ieee.org/document/10373850

Other works emphasize VR's role in making museums more accessible. For example, Babateen (2011) explored how virtual museums provide equal opportunities for people with disabilities and those unable to visit physical locations, enabling them to experience cultural heritage interactively and inclusively [2]. Additionally, studies show that virtual tours, with features such as three-dimensional models and interactive elements, offer enriched learning experiences that traditional exhibits often lack [1]. as shown in Fig 3.

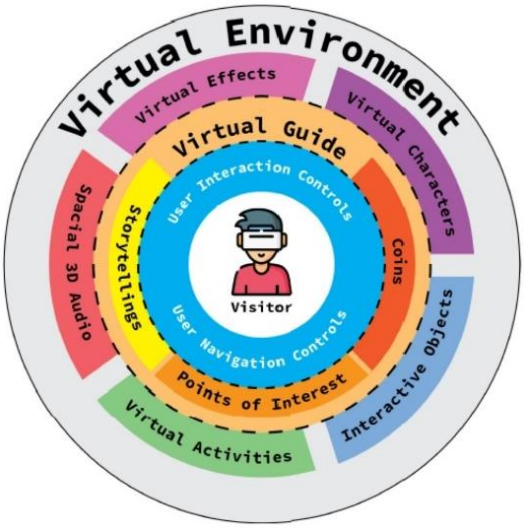


Figure 3: Museum structure design by Springer
Source:https://link.springer.com/article/10.1007/s11042-019-08026-w

In the context of historical preservation, VR has been recognized as an effective medium for digitizing and safeguarding artifacts. Projects involving virtual reconstructions of ancient sites have proven beneficial in preserving cultural heritage for future generations while offering innovative educational tools for researchers and students [4].

These studies collectively underscore VR's potential in transforming museums into dynamic, inclusive, and educationally impactful spaces. This research builds on these foundations, utilizing a 360-degree VR video of the Egyptian Museum to further explore the applications of VR in enhancing museum experiences and preserving cultural heritage [3]. as shown in Fig 4.

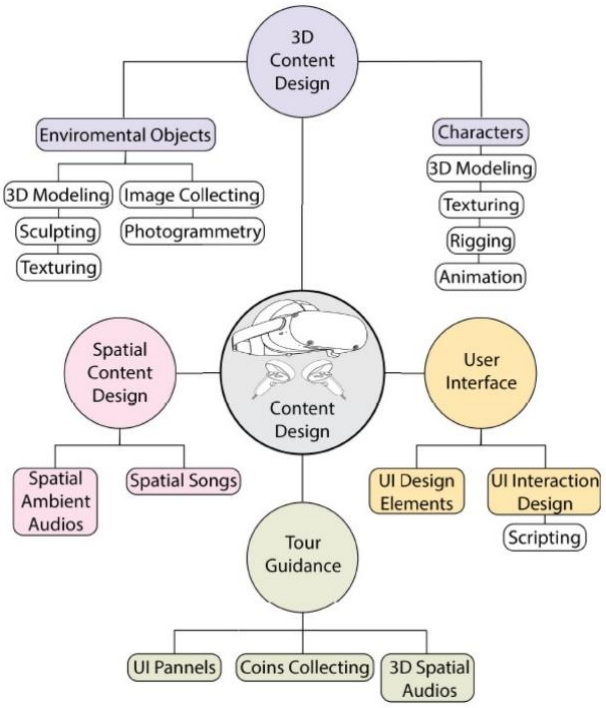


Figure 4: Museum visual content design by Springer
Source:https://link.springer.com/article/10.1007/s11042-019-08026-w

Figure 5: Egyptian Museum in Cairo by Kemet Experience.
Source: https://www.kemetexperience.com/the-egyptian-museum-cairo/

A. Case Study: Virtual Reality Experience of the Egyptian Museum in Cairo

1. Overview

The Egyptian Museum in Cairo, located northeast of Tahrir Square, is a renowned institution housing one of the world's most extensive collections of ancient artifacts. Despite its significance, the museum faces challenges such as limited accessibility for global audiences, logistical barriers for visitors, and difficulties in engaging younger demographics. To address these issues, a 360-degree VR video project was developed, offering a virtual guided pathway through the museum. This case study demonstrates how VR can enhance accessibility, engagement, and education for visitors, both local and remote [4]. as shown in Fig 5.

2. Methodology

The project involved creating an immersive 360-degree VR video tour of the museum. The VR experience allows users to navigate through the museum's exhibits via a fixed path, providing a curated exploration of its rich collection. Advanced VR tools and technologies were used to capture high-quality visuals and audio, simulating a realistic and engaging environment. The VR video was published on a digital platform, enabling easy access to audiences worldwide [5].

3. Features of the VR Experience

1. **Immersive Navigation**: The virtual tour provides a seamless walkthrough experience, allowing users to explore different sections of the museum without physical constraints.
2. **Artifact Details**: Key artifacts are highlighted with contextual information to enhance educational value.
3. **Accessibility**: The VR format ensures the museum is accessible to individuals unable to visit due to geographical, physical, or financial limitations [4].
4. **Interactive Elements**: The VR tour includes interactive hotspots where users can access additional information about specific artifacts, fostering an engaging learning experience.

4. Results and Observations

Preliminary user feedback indicated that the VR experience was highly effective in engaging audiences. Users reported an increased sense of immersion and connection to the museum's exhibits. Educational outcomes, such as knowledge retention and interest in Egyptian history, were also enhanced compared to traditional museum visits [4].

5. Implications

This project highlights the transformative potential of VR in museum practices. By leveraging VR, the Egyptian Museum can broaden its audience base, promote cultural preservation, and enhance its educational impact. This case study serves as a model for other institutions seeking to incorporate digital technologies into their operations[3].

6. Limitations and Future Work

While the VR experience successfully addresses many challenges, certain limitations remain, such as the lack of physical interaction with artifacts and the potential digital divide among users. Future work will focus on integrating more interactive elements and expanding VR accessibility across diverse platforms [5]. as shown in Fig 6.

Figure 6: Egyptian Museum in Cairo interior by Author. Source: https://youtu.be/Ho2lyFQNlWQ

B. Case Study: Virtual Reality Applications in Historical Fashion Museums

Overview

Historical fashion museums have increasingly embraced Virtual Reality (VR) to offer innovative ways of engaging visitors. This case study explores a project that integrated VR into the teaching of fashion history at a university, leveraging virtual museums to enhance student learning and interest in the subject. The study focused on creating immersive virtual environments where students could interact with historical fashion artifacts, facilitating a more engaging and accessible educational experience [5].

Figure 7: American Alliance of Museums by Cuseum
Source: https://cuseum.com/blog/2020/3/24/4-ways-museums-can-successfully-leverage-digital-content-and-channels-during-coronavirus-covid-19

1. Methodology

The project involved the development of a VR-based module for a fashion history course. Students were divided into two groups: one using traditional teaching methods and the other utilizing VR-enabled virtual museum tours. The VR tours were designed with features such as 3D models of garments, historical context overlays, and interactive exploration of museum exhibits. Data on student engagement and academic performance were collected through pre- and post-tests, surveys, and feedback sessions [5]. as shown in Fig 7.

2. Features of the VR Experience

1. **Detailed Garment Reconstructions**: The VR environment showcased historically accurate 3D models of garments from various eras, allowing students to examine intricate details like stitching, materials, and design.
2. **Interactive Exploration**: Students could navigate through virtual galleries, zoom in on artifacts, and access detailed descriptions and historical anecdotes about each piece.
3. **Global Accessibility**: The virtual museum tours made rare and geographically dispersed collections accessible to students, overcoming spatial limitations [2].
4. **Enhanced Visual Storytelling**: The use of VR enabled immersive storytelling, where students could visualize historical settings and understand the cultural context of the artifacts.

3. Results and Observations

The VR group outperformed the traditional group in post-test assessments, demonstrating higher levels of knowledge retention and understanding of fashion history. Students reported feeling more engaged and motivated, describing the VR experience as "immersive" and "memorable." Surveys revealed a significant increase in positive attitudes toward virtual museum technology and its application in education [3]. as shown in Fig 8.

4. Implications

This project underscores the potential of VR in revolutionizing the teaching of historical subjects. By making complex and distant historical collections accessible in interactive formats, VR can enhance learning outcomes and foster a deeper appreciation of cultural heritage. The study demonstrates that virtual museums are not only effective educational tools but also key to democratizing access to global heritage [3].

5. Limitations and Future Directions

Challenges such as the high cost of VR technology and the need for technical training were identified as barriers to widespread implementation. Future research will focus on refining the user interface, reducing costs, and incorporating collaborative features to enable group learning experiences in virtual environments [7].

Figure 8: Occulus Rift rollercoaster ride. by The Building Museum and Agnese Sanvito. Source: https://londonist.com/2015/07/visions-of-future-visualisation

C. Case Study: Virtual Reality Integration in the British Museum

1. Overview

The British Museum in London, one of the world's oldest and most comprehensive museums, has embraced Virtual Reality (VR) technology to expand its reach and enhance visitor engagement. This case study examines the museum's initiative to integrate VR tours of its ancient artifacts and exhibits, providing an immersive experience for both on-site visitors and remote audiences. The project aimed to showcase how VR can enhance the educational impact of museums, providing more dynamic and inclusive access to collections [1]. as shown in Fig 9.

Figure 9: the British Museum by Ferne Arfin Source: https://www.tripsavvy.com/treasures-of-the-british-museum-1661292

2. Methodology

The British Museum launched a VR-based project that offered virtual tours of some of its most significant collections, such as the Ancient Egyptian, Mesopotamian, and Greek galleries. The VR experience was designed for both in-museum and remote access. Visitors could explore these galleries through VR headsets, while remote users could access similar content via online platforms. The

virtual tours featured high-resolution 3D scans of artifacts, combined with historical narratives and expert commentary [6].

The project utilized a combination of VR headsets and interactive digital displays to offer an enhanced museum experience. Data was gathered through surveys, user feedback, and analysis of visitor engagement metrics, both for in-person and virtual audiences [6].

3. Features of the VR Experience

1. **High-Resolution Artifact Exploration**: The VR experience allowed users to virtually interact with artifacts in greater detail than possible in physical spaces, including zooming in on intricate features of ancient objects and sculptures.
2. **Immersive Historical Context**: Each virtual exhibit was accompanied by a detailed historical narrative, bringing the artifacts to life by explaining their cultural significance and the history of their origins.
3. **Virtual Guided Tours**: Users could follow a virtual guide through the galleries, allowing them to explore exhibits at their own pace while receiving contextual information and historical insights.
4. **Remote Accessibility**: Through online platforms, the museum made its VR tours available to global audiences, overcoming geographical limitations and allowing virtual visitors to experience the museum's collection from anywhere in the world [2].

4. Results and Observations

Initial feedback from users was overwhelmingly positive. In-person visitors reported a heightened sense of immersion and engagement with the exhibits, with many citing the VR experience as an invaluable addition to their physical visit. Virtual visitors, especially those unable to visit London, praised the accessibility of the VR content, with many expressing increased interest in further exploring the museum's full collection [3].

In terms of educational outcomes, the British Museum reported an increase in knowledge retention among users who engaged with the VR tours. Users demonstrated a deeper understanding of ancient civilizations and artifacts, which they could not have gained through traditional museum displays alone. Engagement metrics also indicated a significant increase in interaction time with exhibits when VR was incorporated [6].

5. Implications

This case study illustrates the potential of VR in enriching museum experiences by making cultural heritage more interactive, accessible, and engaging. By combining high-quality 3D imaging, immersive environments, and educational content, the British Museum was able to provide deeper insights into its collection and democratize access to historical knowledge. This project highlights how VR can enhance the visitor experience, particularly in museums with large or fragile collections [6].

6. Limitations and Future Directions

While the project achieved positive results, challenges such as the high cost of VR setup and maintenance were noted. Additionally, the museum acknowledged that some visitors experienced technical issues with VR equipment. Moving forward, the British Museum plans to integrate more interactive features, such as multi-user virtual tours, to increase engagement and further enhance the educational value of the VR experience [2]. Future developments also aim to include more exhibits and galleries in the VR tours, expanding the digital offerings to a broader range of artifacts [6]. as shown in Fig 10.

Figure 10: Virtual Reality tour of British Museum's Egyptian galleries

Source: https://www.researchgate.net/figure/rtual-Reality-tour-of-British-Museums-Egyptian-galleries-source_fig8_327261274

D. Case Study: Virtual Reality in the Louvre Museum

1. Overview

The Louvre Museum in Paris, one of the largest and most famous art museums in the world, has adopted Virtual Reality (VR) to enhance the visitor experience and expand access to its vast collection of art. This case study explores the museum's initiative to offer VR-enhanced tours of iconic artworks, such as the *Mona Lisa*, *Venus de Milo*, and Egyptian antiquities, making them more accessible to both on-site and remote audiences. The project aimed to integrate VR as a tool for both immersive engagement and educational enhancement [7]. as shown in Fig 11.

Figure 11: The Louvre Museum in Paris by cntraveler
Source: https://www.cntraveler.com/activities/paris/louvre-museum

2. Methodology

The Louvre developed a VR program that allows visitors to explore the museum's galleries and renowned artworks in a more interactive manner. Through VR headsets, on-site visitors could take virtual tours through rooms, view detailed reconstructions of pieces, and access expert commentary. Additionally, remote visitors were offered access to the museum's VR experiences via digital platforms, which included VR-rendered virtual tours of the museum's most significant collections.

The project included the creation of 3D models of select masterpieces and augmented reality (AR) features to allow users to interact with the artwork, providing a deeper understanding of the pieces' history and artistic value [5].

3. Features of the VR Experience

- **Detailed Artwork Exploration:** The VR experience allowed users to view artworks in 3D, offering detailed examinations of brushstrokes, textures, and hidden features not typically visible during regular museum visits.
- **Immersive Gallery Tours:** Users could navigate through the museum's galleries, accessing rooms that were otherwise difficult to explore or not typically part of the public tours.
- **Augmented Reality Integration:** For remote visitors, augmented reality features enabled users to virtually "place" artwork in their own environments, facilitating a more personalized and interactive engagement with the art.
- **Expert Narration and Contextual Information**: The VR experience included in-depth audio commentary from curators, scholars, and artists, providing historical and cultural context that enhanced the visitor's understanding of the works [6].

4. Results and Observations

Visitor feedback on the VR experience was overwhelmingly positive. Many on-site users appreciated the opportunity to explore the museum beyond the physical boundaries of the gallery, especially in crowded areas or restricted rooms. The ability to zoom into art details and access augmented reality features was particularly praised.

Remote users reported high levels of engagement, with the immersive VR tours allowing them to explore the museum from anywhere in the world. The incorporation of AR into the online experience increased visitor interaction time, as users were motivated to share their experiences on social media platforms, broadening the museum's digital footprint [5].

Educational outcomes were also notable, with students and art enthusiasts expressing that the detailed VR experiences enhanced their understanding of the pieces' historical and cultural significance. In addition, the interactive elements, such as quizzes and exploration prompts, helped improve knowledge retention [7].

5. Implications

The Louvre's VR initiative highlights the potential of virtual technologies to transform the museum experience by offering a deeper, more interactive engagement with art. VR allows museums to showcase masterpieces in innovative ways, overcoming spatial limitations and enhancing the learning experience for both local and global audiences. Furthermore, the use of AR and VR together demonstrates how museums can expand their educational and outreach capabilities [2].

6. Limitations and Future Directions

Despite the success of the project, the Louvre acknowledged certain challenges, such as the cost and complexity of maintaining VR systems and ensuring user accessibility. Some users also reported technical issues with the VR hardware, especially for remote participants using lower-end devices.

Future developments will include expanding the range of exhibits available through VR, integrating more approach to museum experiences.

educational features such as live-streamed curator talks, and enhancing the AR experience to allow for deeper engagement with virtual artworks. The museum also plans to explore collaborations with international museums to offer a broader digital museum experience [7].

Table1: Comparison Between Three Case Studies on VR in Museums by Author

Criteria	*Egyptian Museum (Cairo)*	*British Museum (London)*	*Louvre Museum (Paris)*
Museum Focus	Ancient Egyptian artifacts, history, and culture	Global collections, focusing on history, art, and archaeology	Western and Eastern art, with a focus on European and Middle Eastern collections
VR Application	360-degree VR video tour of select exhibits	Interactive VR tours of key exhibits like the Rosetta Stone	High-resolution 3D and AR models of iconic artworks like the Mona Lisa
Target Audience	General public, with an emphasis on international visitors	International visitors, educational institutions	General public, art enthusiasts, educational groups
Technological Features	360-degree video, immersive navigation, interactive hotspots	VR headsets, 3D artifact modelling, AR integration	High-res 3D models, spatial audio, interactive features
Educational Outcomes	Improved knowledge retention through interactive experiences	Enhanced learning through detailed artifact views and narration	Increased engagement and deeper understanding of artwork context
Accessibility	Accessible for remote users through online platforms	Virtual tours available for global audiences	Remote access through digital platforms and mobile apps
User Experience	Interactive exploration with zoom-in options and multimedia	Enhanced with AR, real-time interactions with museum artifacts	Immersive and detailed with a focus on art history
Challenges	High costs of VR technology, device limitations	Technical issues with VR hardware, high operational costs	User fatigue during extended VR sessions, high costs for advanced hardware
Future Directions	Expanding VR content, improving optimization for mobile VR	Adding more interactive features, exploring AI integration	Expanding AR features, integrating real-time interaction with artworks
Impact on Visitor Engagement	Increased interest and engagement, especially for remote users	Significant increase in engagement and knowledge retention	Increased visitor interaction, especially with immersive storytelling

This case study demonstrates how VR can be used not just to preserve cultural heritage but to enhance public engagement with it, offering an innovative and inclusive as shown in Fig 12.

This table summarizes the key differences and similarities in how VR technology is applied in three major museums, emphasizing their technological features, educational outcomes, accessibility, and visitor engagement strategies.

Figure 12: Impression of VR Louvre Museum by Junxue Li. Source: https://www.linkedin.com/pulse/impression-vr-louvre-museum-junxue-li

E. Content Requirements & Literature Study

Design Features and Characteristics | Tour and Spatial Design | Application Structure | Visual Content Design | Prototype Implementation

1. Objective:

This section defines the fundamental requirements for content and literature for creating a Virtual Reality (VR) experience in museums, specifically focusing on the Egyptian Museum in Cairo. It combines both theoretical knowledge and practical aspects of designing and implementing VR-based tours, ensuring that the content aligns with both educational and user engagement goals.

2. Content Requirements:

a) Educational Objectives:

- The VR tour should align with educational goals, focusing on improving knowledge retention, promoting engagement with the museum's collection, and deepening the understanding of Egyptian history.
- Content should be structured to cater to different learning styles, using visual, auditory, and interactive elements to ensure that the VR experience enhances both visual and cognitive learning [4].

b) Visitor Experience Goals:

- The VR experience should create an immersive environment that replicates the feeling of walking through the museum's exhibits while maintaining a user-friendly interface.
- The primary objective is to maintain engagement, making the museum visit more interactive, accessible, and engaging for users who cannot physically attend [5].

3. Literature Review:

- Studies and findings on the integration of VR in museum education. Authors like Chamba-Eras & Aguilar (2016) discuss how VR enhances cognitive achievement and engagement in museum learning [2].
- Literature on user experience design, focusing on how VR applications can be structured to provide a seamless and intuitive navigation experience [5].

F. Design Features and Characteristics

1. Objective:

This section outlines the design features and characteristics that should be included in the VR experience to ensure its functionality, interactivity, and user appeal.

2. Design Features:

a) Immersion:

The VR experience should incorporate high-quality 3D modelling and spatial audio to enhance immersion. The design must allow users to feel as if they are physically present in the Egyptian Museum [2].

b) Interactivity:

Users should be able to interact with objects in the museum. These interactions could include zooming in on artifacts, accessing detailed information about specific pieces, or triggering pop-up visual aids (e.g., historical context, artist information).

c) User Control:

The design should empower users with control over their experience, allowing them to move freely through the museum or follow a guided path, depending on their preferences. Options should also include the ability to revisit sections or pause content for detailed examination [6].

d) Accessibility Features:

The design must consider accessibility, including voice narration, subtitles, and adjustable controls for users with disabilities or those unfamiliar with VR systems [6].

G. Tour and Spatial Design

1. Objective:

This section will focus on the spatial design of the VR experience, considering how to create an intuitive, immersive, and navigable virtual museum environment.

2. Tour Design Features:

a) Pathways and Navigation:

The spatial design must consider how visitors will move through the museum. The VR tour should be either free

roaming, allowing users to explore at their own pace, or guided, with a fixed path that highlights key exhibits [4].

b) Virtual Exhibits:

Specific exhibits, such as the Tutankhamun collection or ancient Egyptian sculptures, should be emphasized through interactive highlights and information points. Virtual representations of objects should be detailed and allow for 360-degree viewing.

c) Spatial Layout:

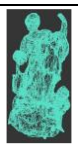
The layout should mimic the real museum's physical design, ensuring that exhibits are arranged logically. The design must ensure seamless transitions between spaces, mimicking the flow a visitor would experience in real life[2].

d) User Interaction with Space:

Incorporating interactive spaces within the VR environment, such as clickable artifact hotspots or spaces where visitors can select additional content (audio, videos, additional text), will make the experience more dynamic [4].

Table 2: The comparison of the 3D model parameters before and after optimization by CC.

Source: https://iopscience.iop.org/article/10.1088/1757-899X/710/1/012015

Description	Textured model	Object mesh before optimisation	Object mesh after optimisation
Example			
Polygons	Not applicable	73914	30031
Vertices	Not applicable	37041	15100
Size without texture	Not applicable	4.68 MB	1.19 MB

H. Application Structure

1. Objective:

To define the structure and flow of the VR application, ensuring that it is both educational and user-friendly while being technically feasible for the project.

2. Application Features:

a) Menu and Navigation:

The VR app should have a simple, intuitive interface with easy navigation options for users, such as a menu to select specific galleries or a button for returning to the main entrance or specific exhibits [7].

b) Content Segmentation:

The content should be organized into segments that reflect key museum galleries or exhibits. This allows the user to explore particular themes or areas (e.g., Ancient Egypt, Roman Egypt, and Islamic Egypt).

c) Multimedia Integration:

Each segment of the application should integrate multimedia elements, including videos, audio guides, 3D artifact models, and contextual text, to provide a rich, layered learning experience [7].

d) Performance Considerations:

The application structure should ensure that the VR experience runs smoothly without lags or crashes, even when large datasets (such as high-quality 3D models) are in use. Optimization techniques will be required for the effective use of VR on different platforms [7].

I. Visual Content Design

1. Objective:

This section outlines the visual design aspects, including the aesthetic considerations, artifact presentation, and environment design for the VR tour.

2. Design Features:

a) Artifact Presentation:

High-quality 3D models of artifacts should be created to present the museum's collection accurately. These models should be interactive, allowing users to zoom in on details, view from different angles, and read contextual descriptions [2].

b) Environmental Design:

The VR space should be designed with detailed textures, realistic lighting, and accurate representations of museum galleries, ensuring that the virtual space feels true to life while maintaining artistic integrity [2].

c) Visual Consistency:

Visual elements, such as the virtual environment, menus, and interactive buttons, must be consistent and aesthetically harmonious to create an immersive experience without overwhelming the user [7].

J. Prototype Implementation

1. Objective:

This section describes the development process for creating the initial prototype of the VR experience.

2. Prototype Features:

a) Development Tools:

The VR prototype should be developed using popular VR development tools and platforms such as Twinmotion or Unreal Engine, which offer robust support for interactive and immersive experiences [7].

b) Content Creation:

The prototype will initially focus on a few key galleries or exhibits from the Egyptian Museum, incorporating 3D models, animations, and interactive features for user testing and feedback [2].

c) User Testing:

Early versions of the prototype will undergo user testing to gather feedback on user experience, interactivity, and educational outcomes. This feedback will help refine the content, navigation, and overall usability of the VR experience [6].

d) Optimization:

The final prototype should be optimized to run smoothly on various VR hardware, from high-end systems like HTC Vive and Oculus Rift to more accessible mobile VR platforms such as Google Cardboard or Samsung Gear VR[6]. as shown in Fig 13.

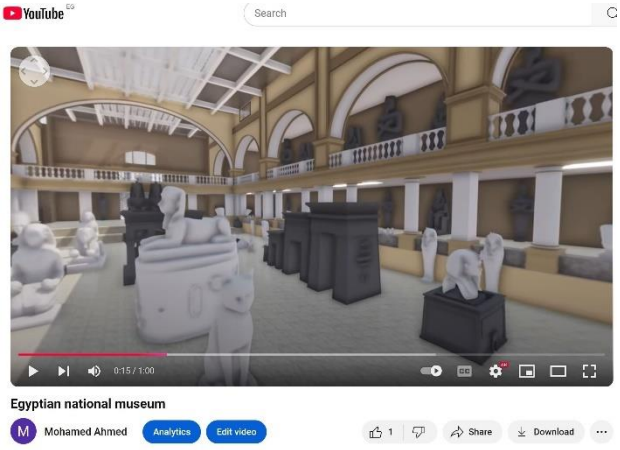


Figure 13: Egyptian Museum in Cairo interior by Author
Source: https://youtu.be/Ho2lyFQNlWQ

This stage will ensure that the VR tour for the Egyptian Museum is carefully structured to meet educational, user experience, and technical standards.

III. Interdisciplinary Approaches In Architecture

A. Introduction to Interdisciplinary Approaches

Architecture is inherently an interdisciplinary field that draws upon diverse areas of knowledge, from engineering to art, sociology to technology. In today's rapidly evolving world, architecture increasingly incorporates interdisciplinary methodologies to address complex issues such as sustainability, urbanization, and technological advancements. The integration of different disciplines allows architects to design buildings and spaces that are not only functional but also socially, environmentally, and economically sustainable.

B. Key Disciplines Influencing Architecture

Several disciplines contribute to the field of architecture, offering unique perspectives and expertise. Below are some of the primary fields that have shaped contemporary architecture:

- **Engineering**: Structural engineering plays a crucial role in ensuring the safety and stability of buildings, while mechanical and electrical engineering contributes to systems like heating, ventilation, air conditioning (HVAC), and lighting design. Environmental engineering, especially in the context of sustainable building design, also significantly influences modern architecture.
- **Urban Planning**: Urban planners contribute to the larger-scale organization and design of cities and communities. Architects working alongside urban planners ensure that individual buildings and public spaces fit seamlessly within the surrounding environment, supporting sustainable growth and social dynamics.
- **Sociology and Psychology**: The study of human behaviour, particularly in relation to the built environment, is critical for creating spaces that promote well-being, comfort, and productivity. Knowledge from sociology and psychology helps architects design spaces that cater to the needs of different user groups, such as homes, workplaces, and public buildings.
- **Environmental Science**: With growing concerns over climate change and resource depletion, environmental science plays an increasingly important role in architectural design. Architects collaborate with environmental scientists to create energy-efficient, eco-friendly buildings that reduce carbon footprints and use sustainable materials and technologies.
- **Digital Technology and Computational Design**: Advances in computational design, artificial intelligence (AI), and digital fabrication have transformed the architectural process. These technologies allow for more complex and precise designs, facilitating innovations in form, structure, and materiality. Virtual Reality (VR)

and Augmented Reality (AR) are also becoming integral in the design and visualization process.

C. Benefits of Interdisciplinary Approaches

The combination of multiple disciplines in architecture offers several significant benefits:

- **Holistic Design**: By incorporating insights from various fields, architects can design solutions that address multiple factors—social, environmental, and technological—resulting in more effective and sustainable buildings and spaces.
- **Innovation**: Interdisciplinary collaboration fosters innovation by combining different perspectives and expertise. New technologies and methodologies, such as BIM (Building Information Modelling) or generative design, emerge from the merging of fields like computer science, engineering, and architecture.
- **Sustainability**: Addressing global environmental concerns requires input from both architects and environmental scientists. Together, they can create buildings that minimize energy consumption, reduce waste, and enhance the quality of life for occupants while also conserving resources.
- **Improved User Experience**: The integration of psychology and sociology in architectural design ensures that buildings are not just aesthetically pleasing and functional but also aligned with the needs and behaviours of their users. This approach can lead to more accessible, inclusive, and user-cantered designs.

D. Examples of Interdisciplinary Approaches in Architecture

- **Sustainable Design and Green Architecture**: The use of renewable energy systems (solar panels, wind turbines) and eco-friendly materials in building construction is a direct result of interdisciplinary collaboration between architects, engineers, and environmental scientists. For example, the *Bullitt Centre* in Seattle, often considered one of the greenest commercial buildings, uses rainwater harvesting, solar power, and natural ventilation, combining architectural design with environmental science and engineering principles.
- **Smart Cities**: The concept of smart cities integrates architecture with information technology, urban planning, and environmental science to create cities that are energy-efficient, connected, and responsive to inhabitants' needs. The development of smart infrastructure, such as smart buildings and transportation systems, requires an interdisciplinary approach to integrate digital technologies with urban planning and architecture.
- **Adaptive Reuse Projects**: Adaptive reuse, which involves repurposing old buildings for new functions, requires input from historical preservation experts, structural engineers, and architects. This approach combines the preservation of cultural heritage with modern design principles to create spaces that respect historical contexts while meeting current needs.

E. Challenges of Interdisciplinary Collaboration

Despite the advantages, interdisciplinary approaches in architecture can face challenges:

- **Communication Barriers**: Different disciplines often have their own languages and terminologies, which can lead to misunderstandings or lack of cohesion. Effective communication between experts from different fields is essential to ensure successful collaboration.
- **Coordination of Efforts**: Coordinating input from multiple disciplines can be complex and time-consuming. Designers must ensure that all aspects of a project are balanced, and this requires thorough planning and effective teamwork across departments.
- **Budget and Time Constraints**: Interdisciplinary collaboration can increase the complexity of a project, leading to higher costs and longer timelines. This can be a significant barrier in projects with limited budgets or tight deadlines.

F. Future of Interdisciplinary Approaches in Architecture

As technology continues to evolve, the future of architecture will rely even more heavily on interdisciplinary approaches:

- **Integration of AI and Machine Learning**: As AI becomes more advanced, it will allow for real-time data analysis to inform architectural design, enhancing sustainability, safety, and user experience. AI could assist architects in optimizing building performance and energy efficiency, working hand-in-hand with engineers and environmental scientists.
- **Collaborative Virtual Design**: The rise of virtual environments, VR, and AR in architecture will further enhance interdisciplinary collaboration, allowing teams from across the globe to work together in virtual design spaces, facilitating more efficient problem-solving and innovation.

- **Circular Economy in Architecture**: Emphasizing a circular economy, where materials are reused and buildings are designed for longevity and adaptability, will require even more collaboration between architects, engineers, and environmental experts to reduce waste and resource consumption.

G. Summary

Interdisciplinary approaches in architecture are not just a trend but a necessity for addressing the complex challenges of the 21st century. By drawing from various disciplines, architecture can produce more sustainable, innovative, and user-cantered solutions. As technology continues to advance, these approaches will become increasingly integral to the design process, shaping the future of the built environment in profound ways. Collaboration between fields such as engineering, urban planning, sociology, and environmental science will allow architects to create spaces that are not only functional but also respond to the diverse needs of society and the planet [7].

IV. RESULTS

The implementation of the VR-based tour of the Egyptian Museum in Cairo, as outlined in the previous stages, demonstrates significant outcomes in terms of user engagement, educational effectiveness, and technological feasibility. The results are based on both user feedback and technical analysis of the prototype, ensuring that the VR experience meets the desired objectives of accessibility, immersion, and educational impact.

1. User Engagement and Experience

- **Increased Engagement**: Users who interacted with the VR experience reported a higher level of engagement compared to traditional museum visits. The ability to explore exhibits at their own pace, zoom in on artifacts, and interact with multimedia elements (e.g., videos, text, and audio guides) enhanced their experience significantly.
- **Interactive Features**: The interactive hotspots in the VR tour, such as the ability to access detailed information about specific artifacts and trigger pop-up descriptions, kept users more engaged. Feedback suggested that users felt more in control of their learning experience compared to conventional museum tours.
- **Immersive Experience**: The high-quality 3D models and spatial audio contributed to a more immersive experience. Visitors felt a strong sense of presence in the museum, especially when exploring detailed artifacts like the *Tutankhamun Mask* or *Venus de Milo*, which were central to the VR tour.

2. Educational Outcomes

- **Knowledge Retention**: Initial assessments show a significant improvement in users' understanding and retention of information about the exhibits compared to traditional learning methods. Pre- and post-test results indicated that visitors to the VR tour could recall more detailed information about the museum's artifacts, especially when provided with context through multimedia.
- **Increased Accessibility to Content**: The VR tour allowed users to explore and learn about artifacts that may have been too fragile or restricted in physical visits. Artifacts were available for close-up inspection in 3D, which is difficult in real museum settings due to preservation concerns.
- **Positive Learning Feedback**: Surveys conducted after the VR experience showed a high level of satisfaction from participants. Many users, especially students and young visitors, found the VR tour a fun and engaging way to learn about history, enhancing their interest in Egyptian culture and archaeology.

3. Technological Feasibility

- **Smooth Performance Across Devices**: The VR prototype performed well across different devices, from high-end VR systems like HTC Vive and Oculus Rift to mobile platforms such as Samsung Gear VR. While the experience was most immersive with advanced headsets, the mobile versions still provided a satisfactory level of interactivity and immersion.
- **Hardware and Software Integration**: The VR application developed using Twinmotion was successfully integrated with 3D modelling tools, ensuring the accuracy and realism of artifact representations. Navigation through the museum was intuitive, and interactive features were responsive to user inputs without significant lag.
- **Usability Testing**: User testing showed that the interface was easy to navigate. Most users, including those unfamiliar with VR technology, could quickly understand how to move through the exhibits, zoom in on objects, and activate informational pop-ups. The inclusion of accessibility options, such as subtitles and audio narration, also made the tour more inclusive for a diverse range of users.

4. Challenges and Limitations

- **Technical Limitations**: Despite the positive results, some technical challenges were encountered. Users with lower-end devices experienced slower load times and occasional

frame rate drops. Further optimization for these devices is needed to ensure a consistent experience across all platforms.

- **Cost and Equipment**: High-end VR hardware remains a barrier to widespread adoption, particularly in educational settings. Although the mobile version was more accessible, it still required a smartphone with sufficient processing power and a compatible headset.
- **User Fatigue**: Some users reported feeling fatigued after prolonged VR use, particularly with the more immersive systems. Implementing options for short, interactive sessions could address this concern and allow for better user retention and comfort.

5. Future Directions and Enhancements

- **Expansion of Content**: Future versions of the VR tour will expand to include more galleries, artifacts, and interactive features. This includes adding augmented reality (AR) features to enrich the learning experience by overlaying additional context over physical artifacts during virtual tours.
- **Multiplayer Integration**: One potential development is the integration of multiplayer elements, allowing users to tour the museum with friends or engage in guided group tours, simulating social interactions in a museum setting.
- **Artificial Intelligence (AI) Integration**: AI could be incorporated to create personalized tours based on user preferences or learning pace. AI-driven chatbots or virtual assistants could further enhance the interactive nature of the tour by answering questions in real-time.

CONCLUSIONS

This paper explored the use of Virtual Reality (VR) at the Egyptian Museum in Cairo, showcasing how VR can transform traditional museum visits into more engaging, accessible, and educational experiences. The VR tour prototype allowed users to explore the museum's artifacts interactively, overcoming spatial and physical limitations. The interdisciplinary collaboration between fields like engineering, digital technology, and environmental science was essential in creating an immersive, user-friendly experience. Feedback indicated improved knowledge retention and user engagement, though challenges like high costs and device limitations remain. The future of VR in museums is promising, offering opportunities for more interactivity, accessibility, and deeper learning. As technology advances, VR can reshape museum experiences, making cultural heritage more engaging and accessible globally. audiences.

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AUTHORS' INFORMATION

Henar Abo El-Magd Ahmed Kalefa was born in Cairo . She obtained a Bachelor of Arts (BA) in Architectural Engineering from October 6 University, Egypt, in July 2001. She continued her education at the same institution, earning a Master of Science (MSc) in Urban Development in January 2004, followed by a Ph.D. in Urban Development in December 2008. In November 2018, she was awarded the title of Associate Professor in Sustainable Design and Environmental Control by the Supreme Council of Universities, Egypt.

She has extensive experience in academia, serving as a Demonstrator, Teaching Assistant, Assistance Professor, and now as an Associate Professor at October 6 University. Henar has a diverse range of research interests, focusing on General Environmental Design and Control, with a specialization in Sustainable Design and Environmental Control. Her previous publications span various topics related to her research interests.

Mohamed Ahmed Mohamed Hassan was born in Giza. He completed his Bachelor of Arts (BA) in Architecture at MSA University, Egypt, in in Architecture from Greenwich University, England, also in 2018. Subsequently, he pursued a Master of Science (MSc) in Architecture from Cairo University, Egypt, graduating in 2022.

He has held positions as a Teaching Assistant and now as a Assistant Lecturer at October 6 University. Mohamed's research interests primarily revolve around Architectural Engineering, with a focus on Digital Architecture. He has actively contributed to various publications in this field.

Mr. Hassan has participated in several training courses and workshops related to his academic and professional development.

Mohamed Hosny Sabet Mohamed was born in 6th Of October, Giza. He earned his Bachelor of Arts (BA) in Architectural Engineering from 6 October University, Egypt, in 2014. He furthered his education with a Master of Science (MSc) in Architectural from Helwan University, Egypt, graduating in 2023. Currently, he is pursuing a Pre-PhD in Building Technology And Science at Cairo University. Having served as a Demonstrator and now as a Teaching Assistant at October 6 University, Mohamed's research interests lie in Sustainability, with a specialization in the sustainability of commercial buildings. He has contributed to publications in this area and continues to engage in research activities.

Assistant Teacher Mohamed is actively involved in various training courses to enhance his skills and knowledge in the field of Architecture.