



**Bridging Alexandria's Heritage and Innovation:
Sustainable Interior Design Strategies for the
Bibliotheca Alexandrina through an XR-Based
Virtual Museum Environment**

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DOI:

<https://doi.org/10.21608/ijdar.2025.418660.1040>

IJDAR

**International Journal of Design and Applied
Research**

Volume (4). Issue (16). Oct 2025

E-ISSN: 2812-6246

P-ISSN: 2812-6238

<https://ijdar.journals.ekb.eg/>

Publisher

**Association of Scientific Research Technology
and the Arts**

<https://srtaeg.org/>

The Visual Effects of Arabic Calligraphic Elements and Their Role in Constructing Contemporary Aesthetic Composition

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ABSTRACT

The Bibliotheca Alexandrina, as an effort to resurrect the ancient Library of Alexandria and an institution, presented by the UNESCO, as a cultural symbol, has to contend with the twofold task of preserving the cultural heritage of the Alexandrian region and being responsive to both educational and social needs of modern times. The traditional exhibits in the west Wing of the library despite being valuable, have spatial, temporal and convenience constraints that normally lock out the younger people, and even the people who are reluctant to come due to distance.

It is becoming increasingly clear that digital technologies are revolutionary to museums, but most of the literature on these topics is limited to Virtual Reality (VR) or Augmented Reality (AR), rather than the extended reality (XR) as a longer-term sustainable and encompassing approach.

Motivation This research paper suggests and analyzes an XR-based dynamic museum in the main building of the Bibliotheca Alexandrina. Unlike any other VR-only or AR-only solution, XR flexibly integrates opportunities of both technologies by providing the option of flexible digital concourse that

will work at the levels of immersive and non-immersive engagement. The flexibility is capable of providing on-site and off-site involvement, thus fitting the strategic priorities of Egypt through its Vision 2030 within the spheres of education, innovation, and the preservation of cultural heritage. This study proposes and experiments with a digital setting encompassing immersive narration, sustainable interior design and inclusive design to promote cultural interaction and long-term learning. The results prove that XR technology has high potential to make cultural appreciation more pronounced, enhance accessibility, and raise sustainability awareness and maintain usability and aestheticity. The project provides input in increasing the preservation of heritage by eliminating the need to handle physical artifacts, and lessening the physical wear and tear that is generated by such handling as well as increase the access to the heritage by making the museum more inclusive to audience through the innovation of the space. The work highlights how XR should not only be perceived as a technological innovation, but as a management strategy towards cultural sustainability, inclusion and digital diplomacy. By so doing, the Bibliotheca Alexandrina is both a keeper of memory, and a forerunner of long-term sustainable cultural experience.

KEYWORDS

Extended Reality (XR); Virtual Museums; Cultural Heritage; Sustainability; Vision 2030

جسر التراث والابتكار في الإسكندرية: ممارسات التصميم الداخلي المستدام لمكتبة

الإسكندرية من خلال بيئة متحف افتراضية قائمة على تقنيات الواقع الممتد (XR)

الخلاصة:

تُعد مكتبة الإسكندرية الجديدة، بصفتها إحياءً لمكتبة الإسكندرية القديمة ومؤسسة ثقافية حديثة معترف بها من قبل اليونسكو، كياناً يواجه التحدي المزدوج المتمثل في الحفاظ على الهوية الثقافية للإسكندرية من جهة، وتلبية الاحتياجات التعليمية والاجتماعية المعاصرة من جهة أخرى. ورغم القيمة التي توفرها المعارض التقليدية في الجناح الغربي للمكتبة، فإنها تظل مقيدة بعوائق مكانية وزمنية وإتاحة محدودة، مما قد يُقضي فئات أساسية من الجمهور مثل المتعلمين الشباب، والزوار البعيدين. لقد حظيت التقنيات الرقمية باعتراف متزايد كوسيلة تحويلية للمؤسسات المتحفية، إلا أن معظم الدراسات ركزت بشكل ضيق على تقنيات الواقع الافتراضي (VR) أو الواقع المعزز (AR)، دون التطرق بشكل شامل لإمكانات الواقع الممتد (XR) كإطار مستدام وشامل.

تقترح هذه الدراسة وتقييم بيئة متحف افتراضي قائمة على الواقع الممتد (XR) في الجناح الغربي لمكتبة الإسكندرية. وعلى عكس الحلول القائمة على VR فقط أو AR فقط، يجمع الواقع الممتد بين مزايي التقنيتين من خلال توفير تفاعل رقمي مرّن يعمل في أوضاع غامرة وغير غامرة. وتُبرز هذه المرونة إمكانية المشاركة سواء في الموقع أو عن بُعد، بما يتماشى مع أولويات رؤية مصر ٢٠٣٠ في مجالات التعليم والابتكار ووصون التراث الثقافي. وقد طوّرت هذه الدراسة بيئة رقمية متكاملة تتضمن السرد الغامر، والخصائص الداخلية المستدامة، والممارسات الشاملة بهدف تعزيز التفاعل الثقافي ودعم التعلم طويل الأمد.

تُظهر النتائج أن الواقع الممتد قادر على تعزيز التقدير الثقافي، وتحسين سهولة الوصول، وزيادة الوعي بالاستدامة، مع ضمان سهولة الاستخدام والجاذبية البصرية. ومن خلال إعادة تصور المتحف كمكان للتعلم النشط بدلاً من كونه معرضاً ثابتاً، يساهم المشروع في حماية التراث من خلال تقليل الاعتماد على القطع الأصلية، ويوسّع نطاق الوصول إلى جماهير متنوعة محلياً وإقليمياً وعالمياً. وتؤكد الدراسة أن الواقع الممتد ليس مجرد ابتكار تقني، بل يمثل نهجاً استراتيجياً لتحقيق الاستدامة الثقافية، والممارسات الشاملة، والدبلوماسية الرقمية. وبهذا، تتموضع مكتبة الإسكندرية كحارس للماضي ورائد للتجارب الثقافية المستقبلية المستدامة.

الكلمات المفتاحية: الواقع الممتد (XR)، المتاحف الافتراضية، التراث الثقافي، الاستدامة، رؤية

1. Introduction:

The Bibliotheca Alexandrina is an ideal blend of a revivalist project aimed at resurrection of the old Library of Alexandria and a modern cultural institution focused on innovations, knowledge sharing, and inter-cultural communication (Butler, 2016). Being a UNESCO-recognized heritage site, the library has a unique task of preserving the cultural identity of Alexandria, on the one hand, and responding to current education and social demands on the other. This mission would be of utmost importance to the West Wing of its Exhibitions Center where thematic exhibits link Alexandria to the universal narration not as people know through manuscripts, archaeological objects, and modern cultural manifestations (Tocatlian, 2003).

Although the physical exhibitions have been helpful in providing good cultural experiences, they have tended to be confined to spatial, temporal, and accessibility parameters (Bonn et al., 2007). Conventional museological practices have the risk of detaching key

audiences who may be younger learners, visitors who have disabilities, or foreign visitors who may not be able to visit the site, which are dependent on fixed exhibitions and text-driven explanations (Forrest, R. 2013). Past studies have also evidenced the possibility of digital technologies as a means of converting the museum into the active learning institutions (Kirchberg et al., 2012). But a great part of work is still divided, so that research is conducted from a comprehensive Extended Reality (XR) system that implements immersion, inclusivity and sustainability (Baradaran Rahimi et al., 2022).

Although there can be found many works paying praises to Virtual Reality (VR) or Augmented Reality (AR) and how they bring value to museum education and participation in heritage, there is not much research on how Extended Reality (XR) can be utilized in this context as a long-term and consistent strategy (Kim, S. 2018, Hoang et al., 2018). VR has been intensively researched in terms of its

ability to provide sensory-rich recreations of past structures that elicit strong emotive responses and empathy on cultural levels (Carrozzino & Bergamasco, 2010; Champion, 2015). Meanwhile, praise has been heaped on AR because it augments physical exhibits with contextual overlay and this helps contextualize the physical exhibits, improving accessibility to complicated heritage stories and help people learn on-the-job (Damala et al., 2008; Yoon et al., 2017). Both technologies have limits, however, VR being limited by the need of special devices (headsets), and AR limiting online synchronization by the need of being physically present in the museum. Newer research has started to frame XR as the combination of the best of both VR and AR. XR enables the deployment of a flexible digital experience within immersive and non-immersive modes, adapting the cultural institutions to both in-site and off-site engagement (Davies, J. 2014). The case of the Nicosia Folk Art Museum initiative suggests how

virtual spaces may be used to turn folk heritage into performative learning processes (Casillo et al., 2025), and larger-scaled surveys indicate that XR holds the promises of raising sustainability to the extent of artifact handling and the creation of digital surrogates (Bekele et al., 2018). However, systematic experiences with the implementation of XR in heritage settings are scarce, especially when it comes to projects that are in line with sustainability strategies and national visions on cultural policy.

This study fills this gap with the proposal to create an XR-based virtual museum in the West Wing of the Bibliotheca Alexandrina. In contrast to VR-only solutions, which usually need headsets and other dedicated hardware, XR offers an opportunity of versatile mode of interaction that can be realized both in immersive form and on a standard display and thus becomes apt to on-site exhibitions as well as off-site access (Baradaran Rahimi et al., 2022). This research will seek to develop and test a sustainable,

inclusive, pedagogically sound digital space that can generate more culturally engaging experiences, enhance the culture of inclusive practice in museums and support the Strategy 2030 of Egypt in terms of education, innovation, and cultural heritage preservation in Egypt (Singer, N. 2020). This necessitates a study that goes beyond technological novelty and focuses on how XR can be adopted in museums as one of a system to understand how this can be implemented in a manner that is suitable to cultural sustainability, inclusiveness and long-term education (Anwar et al., 2025). Our proposed study is intended to go further to impact culture and enhance the need to work toward more inclusive museum behavior (Li, P. 2024) by integrating sustainable interior features, immersive narrative, and molecular inclusivity to achieve the Egyptian vision 2030 priorities in year 2030 in education, culture preservation, and innovation (Singer, N. 2020).

The proposed environment balances between tradition and innovation, re-conceptualizing a museum as an active learning place in which visitors can participate in learning to the fullest (Forrest, R. 2013; Kirchberg et al., 2012) It does not only help preserve delicate cultural objects against overuse of physical contact, but also widens the space of access to multiple audiences, local, regional and global, and allows them to access the heritage of Alexandria (Rojas et al., 2006). The shift highlights the transition of the Bibliotheca Alexandrina as a central location of cultural diplomacy and this again support the presenter as an agent of the past that also include future oriented, sustainable cultural activities (Butler, 2016).

2. Literature Review

Existing literature has shown the promise of both the immersive reconstruction environment of Virtual Reality (VR), as well as the overlapping information of Augmented Reality (AR), to foster cultural understanding (Carrozzino & Bergamasco, 2010;

Champion, 2015) and making physical exhibitions more accessible and useful (Damala et al., 2008; Yoon et al., 2017). Nonetheless, VR has limited flexibility due to its use of headsets and AR has limited scalability due to the physical nature of presence. Recent literature implies that Extended Reality (XR), as a combination of both VR and AR, provides a more versatile format of sustainable museum practices, as it allows both immersive and non-immersive experiences, minimizes object handling, and is inclusive (Bekele et al., 2018; Lupu et al., 2021). However, it is rare to find systematic uses of XR in heritage practices; as such notable cases like the Nicosia Folk Art Museum have been pioneer examples to show the power of XR in terms of teaching about culture (Santaniello et al., 2025). Our research fills this gap by using XR technology to create a virtual museum tour experience of the West Wing of the Bibliotheca Alexandrina, integrating sustainable interior design ideas, immersive narrative techniques and multilingual accessibility to higher

levels of cultural engagement, inclusion in museum-related activities, and supporting the education, preservation and innovation objectives outlined in Egypt Vision 2030.

2.1. Sustainability, Cultural Engagement, and Inclusive Practices

Sustainability is now a core issue in modern museology not only in environmental terms, but also in maintaining such institutions as beneficial and non-discriminatory spaces to many communities (Merriman, N. 2008). Virtual museum settings have a role to play in ensuring sustainability by limiting physical damage to delicate objects, conservation of energy costs related to long travel to museum destinations, and assuring digital replicas as a preservation method (Müller, K. 2002; Bekele et al., 2018). These solutions coincide with international development plans that focus on responsible consumption, inclusive education and equal cultural practice. Notably, sustainability here does not only involve environmental causes but

also includes social-sustainability, whereby museums play an active role in inclusion and cross-cultural communication (Meskell et al., 2015). XR-based virtual museums and their potential to enable multilingual access, support differently abled users through assistive technologies, and widen the potential to participate beyond physical geographic boundaries, promote cultural engagement and inclusive learning (Qayyum et al., 2024). Such activities indicate that there is a developing understanding that cultural heritage institutions are obliged to incorporate the concept of sustainability in their work and at the same time enable communities to be in touch with their heritage in a more participatory manner (Li, P. 2024; Bonn et al., 2007). Those approaches very much align with the message of the Egyptian Vision 2030 (Singer, N. 2020), that places high priority on the preservation of culture, innovation, and access to knowledge especially in terms of balancing accessibility with

diversity and equity being a crucial trademark of its theme.

The framework of the study follows a sustainability-based model and is based on the United Nations Sustainable Development Goals (SDGs), more specifically in educative, inclusive, and cultural preservation, See Figure 1. SDG 4 (Quality Education) is in the center of the project, and it is promoted by the establishment of a multilingual and easy-to-access virtual museum environment that promotes the learning culture and knowledge exchange throughout lifetime. The project also touches on the SDG 10 (Reduced Inequalities), as the inclusive design will incorporate features into the project, so differently abled visitors can access the project, and marginalized groups will enjoy good access to the project. Considering cultural and environmental sustainability, the project pertains to SDG 11 (Sustainable Cities and Communities), because it will alleviate physical burdens to vulnerable

artifacts, it advises the promotion of digital surrogacy, and it engages in sustainable heritage processes that help reinforce Alexandria as a cultural center. The project further support SDG 13 (Climate Action) indirectly by reducing the carbon footprint of physical movement involved in the exhibition through the virtual offering

of access to that exhibition. All these embraced SDGs align the Bibliotheca Alexandrina initiative within a global sustainability discourse, something that underpins its intended sustainability as a heritage guardian as well as an agent of change within the Egyptian vision 2030.



Figure 1. Illustrates the Sustainability Vision of the study

Source: Researcher, 2025

This merger of sustainability and the Bibliotheca Alexandrina project represent the two-pronged role that the project can play: not only is it part of the preservation of cultural heritage, but it also becomes the leader of innovative educational practices (Qayyum et al., 2024). The drive of putting the principles of sustainability into the creation of the virtual museum space places the action directly into the

context of global development priorities that look at inclusive education, equality of opportunities, and preservation of cultural assets (Meskell et al., 2015). More to the point, sustainability in this respect extends beyond the environmental to include social sustainability, so that the cultural heritage is not only maintained but experienced in participatory and transformative terms by different

audiences (Merriman, N. 2008). By doing that, the Bibliotheca Alexandrina in the conglomeration with heritage values and innovation, demonstrates how a heritage landmark can be signified as a source of the sustainable cultural experience. The positioning of this endeavor relative to particular Sustainable Development Goals (SDGs) is shown in Table 1 below.

Table 1. Illustrates the SDGs adopted by the study, its relevance and the impact on the museum environment.

Source: Researcher, 2025

SDG	Relevance to Virtual Museum Environment	Impact on Cultural Engagement & Inclusivity
SDG 4: Quality Education	The virtual museum provides such benefits as easily accessible, multilingual, and interaction-based cultural learning, which can bring the learning outside the four walls.	Increases access to learning to students, researchers and world populations, facilitating informal learning and life-long learning.
SDG 10: Reduced Inequalities	Using inclusive design (assistive technology, captioning, multilingual interface, etc.) to include those that may be disadvantaged and discriminated against.	Facilitates fair distribution of heritage and privileges all guests to be able to experience Alexandria in cultural storytelling.
SDG 11: Sustainable Cities and Communities	Digitally holds onto cultural life of Alexandria and advocates sustainability of urban culture.	Strengthens the city as a world cultural city and improves community engagement.
SDG 12: Responsible	In digital surrogacy, there is less physical handling of fragile	Promotes sustainable ways of heritage conservation and yet

SDG	Relevance to Virtual Museum Environment	Impact on Cultural Engagement & Inclusivity
Consumption and Production	artifacts thereby lessening environmental impact of travel/exhibition.	affords the mass participation in the cultural aspects.
SDG 13: Climate Action	Reduces Carbon footprint due to online access towards exhibitions, which reduces travel needs.	Promotes cultural tourism, environmentally-friendly visitor interaction.

2.2. Museums, Education, and the Shift toward Interactivity

Museums have traditionally been envisaged as holders of material artifacts with little importance attached to active, interactive activity. With the emergence of the new museology in the late 20th century, however, researchers and practitioners have focused more on museums as spaces of active learning that are inclusive, critical and participatory (Hooper-Greenhill, 2007; Black, 2012). The paradigm shift not only recasts museums as keepers of heritage, but also as places of education, cultural exchange, and sense of identity (Simon, 2010). Recent research

supports this transformation through emphasis on the interactive digital technologies used to facilitate it. As one of several examples, Parry (2013) discusses ways in which digital platforms expand museum collections to the wider audience, and Anderson (2012) claims that immersive technologies can help museums transcend their physical boundaries, and access to interpretation of heritage. New immersive museum case studies worldwide demonstrate the role of digital technologies in transforming the cultural space into a non-hierarchical interactive area of experience and learning and the future

like Louvre Museum (France) that Offers VR tours of iconic works (e.g., Mona Lisa) and architectural spaces; provides accessibility for remote or mobility-limited audiences, Natural History Museum London (UK) that Engages diverse audiences through interactive dinosaur models, soundscapes, and gamified mobile apps, and British Museum (UK) which Enhances engagement with the Rosetta Stone via touchscreens, 3D

scans, and hieroglyph-writing challenges.. The role of XR and digital art is illustrated by decentralization models that optimize cultural access through such flagship initiatives like the Museum of the Future (UAE), teamLab Borderless (Japan), and Atelier des Lumieres (France), which can reinvent the standards of the museum practice overnight, see table 2.

Table 2. Shows new immersive museum case studies worldwide

Source: Researcher, 2025

Museum / Location	Type & Highlights	Visitor Experience
Natural History Museum (London , UK)	Interactive Exhibitions & Apps.	 Life-size animatronic dinosaurs, quizzes, games that Appeals to families, enhances science education. <i>Picture 1. Illustrates the Interactive Exhibitions in Natural History Museum (London, UK)</i> <i>Source: Blond, K. (2017)</i>

Museum / Location	Type & Highlights	Visitor Experience
British Museum (London, UK)	Interactive Digital Kiosks	Rosetta Stone 3D scans, touch tables, hieroglyph-writing that Bridges ancient heritage with modern learning technology.  <i>Picture 2. Illustrates the Interactive Exhibitions in British Museum (London, UK)</i> <i>Source: Caulton, T. (2006)</i>
Louvre VR Museum (Paris, France)	Virtual Reality Tours	 VR-based gallery exploration incl. Mona Lisa and architecture. <i>Picture 3. Illustrates the Louvre VR Museum (Paris, France)</i> <i>Source: Banfi et al., 2023</i>

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Museum / Location	Type & Highlights	Visitor Experience
Museum of the Future (Dubai, UAE)	Futuristic XR/VR/AI museum inside a torus-shaped architectural landmark	 Space shuttle to orbital station, AI-guided wellness, “Vault of Life” biodiversity, hands-on robotics. <i>Picture 4. Illustrates Museum of the Future (Dubai, UAE) Source: Koch, N. (2024)</i>
teamLab Borderless (Tokyo, Japan)	Boundary-free digital art museum; immersive + interactive environments	 Art flows between rooms, tea ceremony blossoms, living evolving canvases <i>Picture 5. Illustrates the interactive environments of teamLab Borderless Museum (Tokyo, Japan) Source: Grassi, J. (2022)</i>

Museum / Location	Type & Highlights	Visitor Experience
Atelier des Lumières (Paris, France)	Immersive art & digital gallery in a repurposed 19th-century foundry	 Large-scale projections (“Egypt at the Pharaohs,” “The Orientalists,” “Foreign Nature”) <i>Picture 6. Illustrates the interactive art galleries in Atelier des Lumières (Paris, France)</i> <i>Source: Çeltek, E. (2021)</i>

2.3. Virtual Reality (VR) in Cultural Heritage

The Virtual Reality (VR) has increasingly become an effective means of heritage learning as it presents a simulated fully interactive reconstruction of a historic place. Research confirms that VR uses the best of emotional connection and knowledge retention by means of a user being able to interact with past environments in situations impossible with only physical artifacts (Carrozzino

& Bergamasco, 2010; Champion, 2015). The VR has been shown to preserve the heritage through several projects. As an example, the ‘Rome Reborn’ initiative could simulatively recreate ancient Rome, according to which tourists could visit the urban areas virtually (Dylla et al., 2009). In a parallel manner, there are museum projects like the VR Bronze Age experience of the British Museum, which show how the VR can help situate the artifacts in the cultural

context in which they were created. Nevertheless, VR does not lack problems. It may be limited in accessibility by being dependent on specific headphones and subject-controlled conditions, which may undermine its usability in under-resourced institutions or difference in

the visitor population (Forrest, R. 2013). In addition, the immersiveness that VR emphasizes can also pose a risk to detaching the visitor to the physical museum settings that might negate the social and dialogical aspect of the museum (Sylaiou et al., 2010).



Picture 7. Illustrates the VR Bronze Age experience of the British Museum (London, UK)

Source: Li et al., 2024

2.4. Augmented Reality (AR) in Museums:

Augmented Reality (AR) presents an alternative solution with objectives to superimpose digital information to the physical world. AR in the museums is frequently characterized by the use of mobile apps (so-called smart glasses) that can provide extra layers of interpretation e.g. 3D models, animations, or descriptive text coming on the top of the artifacts or exhibition rooms (Damala et al., 2008). Scientific

research proves the positive role of AR in increasing visitor engagement and knowledge acquisition. In one example, Yoon et al. (2017) demonstrated that the incorporation of ARI enabled better comprehension of artifact functions and histories in heritage contexts by placing them in the contexts where they were interactive. In a similar fashion, Tom Dieck and Jung (2017) established that AR enhanced not only perceived value of visiting museums but also the

satisfaction of visitors. However, it is also true that in the case of AR, physical being a part of the museum setting is a requirement and, hence, it might not be as immersive as VR in terms of

storytelling. It is contextual in success and fails to cover the audiences who are unable to reach the heritage sites physically.



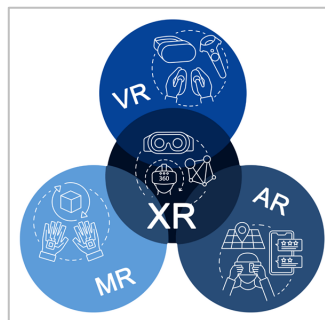
Picture 8. Illustrates the Augmented Reality in the museum of the Future (Dubai, UK)

Source: Koch, N. (2024)

2.5. Extended Reality (XR): A Holistic Approach

The concept of Extended Reality (XR) including both VR and AR (and in some cases Mixed Reality) is an overarching structure that combines new media spaces within a real life interaction context, See Picture 1. Because XR can

be implemented on multiple platforms (fully immersive headsets, mobile devices, and 2D display screens), the technology opens opportunities to institutions to deploy the content across. XR has green benefits in terms of legacy.



Picture 9. Illustrates the concept of Extended Reality (XR) including both VR and AR

Source: Ariya et al., 2025

2.5.1. What is the difference between Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR)?

The differences between Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) all relate to how technology modifies the reality we experience. AR adds to reality, VR replaces reality, and MR merges real and virtual environments (Farshid et al., 2018). Extended Reality (XR) including both VR and AR (and in some cases Mixed Reality) is an overarching structure that combines new media spaces within a real life interaction context (Speicher et al., 2019).

VR immerses users in a fully virtual environment. It cuts off the physical environment to replace it with a digital one, usually with a head-mounted display. AR technology overlays virtual content on the real world. It enhances, but not replaces, your view of your surroundings. XR also provides access

to collections by eliminating physical pressure on delicate artifacts and increasing access to collections around the world (Bekele et al., 2018). In addition, XR enables inclusive design approaches as it includes accessibility settings, e.g., captions, multilingual environments and audio descriptions that cater to marginalized people to whom a traditional visit to the museum is not directed (Lupu et al., 2021).

Another aspect of adapting VR technologies, such as the project of the Nicosia Folk Art Museum, increased the engagement of folk heritage and educational activities (Santaniello et al., 2025). By extending this precedent, XR adds to the pedagogical potential the immersion of VR along with the contextual nature of AR learning and simultaneously enables non-headset access- presenting high versatility in educative applications, including challenges on poster form.

Table 3. Comparative overview: Nicosia Folk Art Museum project vs. Bibliotheca Alexandrina Alexandrina initiative

	Nicosia Folk Art Museum Project	Bibliotheca Alexandrina Initiative
Dimension	 Picture 10. Shows Nicosia Folk Art Museum in Cyprus. Source: Santaniello et al., 2025	 Picture 11. Shows Bibliotheca Alexandrina in Alexandria, Egypt Source: Butler, 2016
Institutional Context	Small-scale folk art museum in Nicosia, Cyprus	Large-scale cultural landmark and UNESCO-recognized heritage site in Alexandria, Egypt
Primary Focus	Preservation and promotion of Cypriot folk traditions	Integration of Alexandria's layered heritage (ancient, medieval, modern) with innovation and sustainability
Technological Approach	VR-based virtual museum environments	XR-based virtual museum environment (flexible mix of VR, AR, and non-immersive display access)
Educational Goal	Foster cultural appreciation and participatory learning of folk traditions	Advance cultural engagement, inclusive museum practices, and heritage education aligned with Egypt Vision 2030
Scale of Engagement	Targeted audiences: students, researchers, and local community	Broader audiences: local, national, and international

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		visitors, including differently abled communities
Design Implications	Showed feasibility of VR for folk heritage education	Extends design approach to sustainable interiors, immersive storytelling, and multilingual inclusivity
Sustainability Impact	Reduced handling of physical artifacts; digital preservation of fragile items	Holistic sustainable practice: preservation, digital access, inclusive design, and reduced environmental footprint

Given experiences gained after the Nicosia project (Santaniello et al., 2025). the Bibliotheca Alexandrina project expands the principles to a new direction and a bigger and more complicated cultural setting. The design methodology presented here embraces XR as not only a technology innovation but also, a sustainable and inclusive model of redesigning interior practice in a heritage landmark in UNESCO framework.

3. Methodology

A mixed-method and design-based research approach is used in this research, See figure 2. The method is shaped by values of critical

Museography, sustainable interior practices, and educational technology design, ensuring that the proposed virtual museum environment is both contextually grounded and future-oriented. The study provides an empirical study with a unified approach of combining data analysis with a design process which allows for a sustainable and practical approach to improving cultural interaction in the West Wing Exhibition Center in the Bibliotheca Alexandrina. The methodology will follow three interlinked phases (1) a contextual analysis based on both qualitative investigation and on-site observation,

(2) a design-based methodology, integrating museographic and virtual interior-design procedures, and (3) a quantitative analysis in the form of a structured post-intervention questionnaire. Collectively, these steps

make it possible to do a comprehensive study of how immersive and sustainable protocols can be integrated into museum settings to foster acceptance, accessibility, and cultural creativity.



Figure 2. Illustrates the Methodology adopted for the study

Source: Researcher, 2025

3.1. Phases (1): On-Site Observation

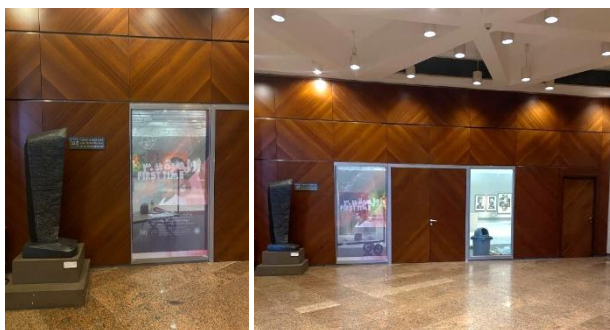
Contextual analysis started with the site visitation of the West Exhibition Hall at the Bibliotheca Alexandrina Conference Center in Basement 1 (B1) and a total floor space of about 500 m2, See picture 12, 13. This is a temporary exhibition, visiting display area, and a poster session area and thus the kind of environment that is less flexible but space is limited, See Picture 14. Its size and structure can offer valuable circulation design parameters as well as visitor and movement patterns as well as incorporating digital installations like the proposed virtual museum world



Picture 12. Shows the entrance of Bibliotheca Alexandrina Conference Center in Basement 1 (B1)

Source: On-Site Researcher, 2025

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Picture 13. Shows the entrance of the West Exhibition Hall

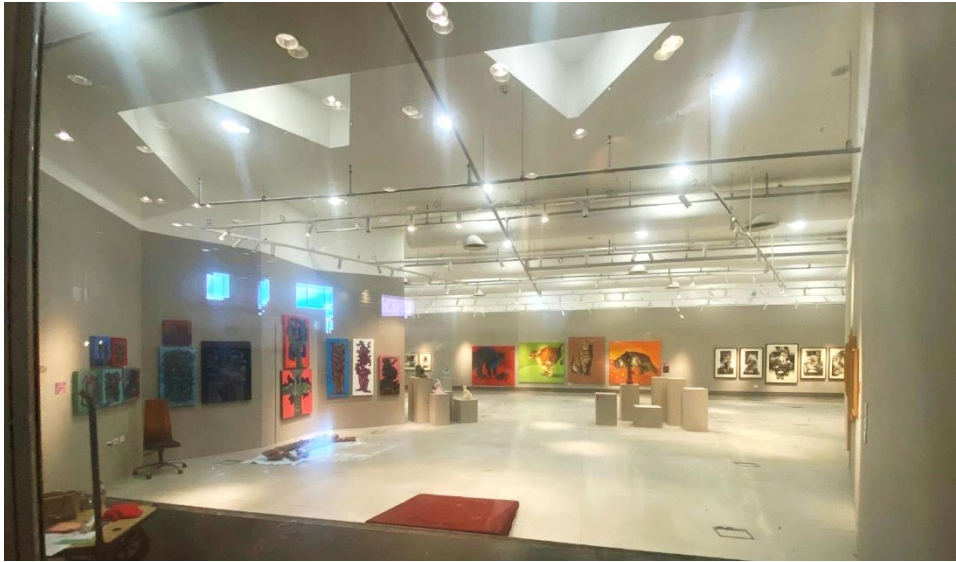
Source: On-Site Researcher, 2025

When it comes to audiences, the Bibliotheca Alexandrina (BA) is by far one of the most active cultural centers in the Middle East region, and it welcomes more than a million visitors per year (Butler, 2016). It is worth noting that it is predominantly used by the students and researchers, about 80 percent of its users, which indicates that the library should first and foremost be seen as an educational facility and not only a tourist attraction. Nevertheless, permanent and temporary exhibitions at the BA have proven to be rather popular as, during one of the reporting years (2011,2012), about 160,000 people have visited the exhibitions (Tocatlian, J. 2003); however, the vast capabilities

of the West Wing that target wider and more diverse populations have yet to be fulfilled. These numbers reflect the educational importance of the institution and the necessity of strategies that scale cultural learning in an interactive, accessible and cohort-adaptable ways. The accessibility observations also further agree that the BA already enjoys solid institutional resources in the field of inclusive design. Accessibility observations confirmed that although the more general Bibliotheca Alexandrina has considerable inclusive resources (e.g., ramps, elevators, and the Taha Hussein Library serving the visually impaired), the West Wing itself has not fully harnessed such resources to realize

digitally inclusive or universally designed exhibition accessibility. Such failure of integration justifies the necessity of environmentally sustainable, technology-oriented

interior interventions, which may lead to turning the hall into an evolving environment of learning and getting into the world of culture. (Nevárez, J. 2020).



Picture 14. Shows the on-site observation of the West Wing Exhibition Center, located in Basement 1 of the Bibliotheca Alexandrina Conference Center (BACC)

Source: On-Site Researcher, 2025

Application of a thorough field visit to the examination of the West Wing Exhibition Center, which, in this case, is in Basement 1 of the Bibliotheca Alexandrina Conference Center (BACC). Since the hall opened happens to be totally below the ground, it lacks a source of natural light and thus solely relies on ambient and artificial lighting systems. Although this is quite

practical, it also results in increased energy demands and reduced chances of integrating daylight, which is essential to sustainable practice of interior design. In addition, it was observed that the West Wing is not considered to be implemented with the use of sustainable materials in terms of displaying the finishes and the design components of the exhibition.

Technological integration is one of the features of the hall due to largely traditional practices of exhibitions and a lack of immersion technology through interactive digital interfaces, augmented reality, or extended reality (XR).

The issue in context: coming together, the West Wing of the Bibliotheca Alexandrina has to undergo a metamorphosis in the form of a transformed, physically displayed learning environment into one that is inclusive, high-impact and that meets modern education demands as well as minimizing environmental cost. It is on this contextual basis that the design criteria of the project is determined, which are as follows: establishing educational relevance, supporting culture participation and creative economy, as well as improving inclusive access and low-impact interior solutions.

3.2. Phases (2): Design-Based Approach

Further developing a contextual analysis, a second phase involved the

design-based approach, which combined museographic regulatory principles with the processes of virtual interior decoration. This design based process was an iteration that allowed the creation of an XR enriched virtual museum suitable to the West Wing. The museographic structure created an accentuation of interpretive narration, multi lingual access, and digital surrogacy to weak goods and the interior design plan developed sustainable strategies that included low-energy lighting, effect-inquiring systems and material proficiency. This step was able to incorporate aspects of the traditional methods of exhibition with the new XR technologies, a factor that linked physical and online cultural experiences and made sure that the museum environment remained relevant not only to the cultural engagement expectations of Egypt in Vision 2030, but also to the broader picture of global heritage innovation.

Slide 1 – VR, AR, and XR: Framing Immersive Technologies

The First slide familiarizes readers with the differences between Virtual Reality (VR), Augmented Reality (AR), and Extended Reality (XR), as a background knowledge base required to justify the methodological approach to choosing the XR as the theoretical framework of the study, See picture 15. This clarification of the differences makes the slide stipulate that VR supports completely immersive examinations of inaccessible or vulnerable collections, AR allows superimposing on reality digital data and heritage stories, and XR combines them into a hybrid experience; their combination is unified. The given comparison explains why XR as an umbrella method is the most appropriate instrument to meet

the demand of the case study of the Bibliotheca Alexandrina because of the connection of the immersion, inclusiveness, and flexibility to various visitor types. In addition to technological novelty, the commentary also highlights sustainability potential of immersive tools as they potentially minimize the environmental impact through a reduced need of physical replicas, the transport of exhibitions, or installations that require a lot of materials. In order to accentuate the point furthermore, sustainability and inclusivity icons or symbols would support the notion that the XR vision is not only or solely the technological answer but the approach that aligns with the objectives of educational, cultural, and social sustainability.

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Picture 15. Shows the 1st Slide of the Design-Based Approach

Source: Researcher, 2025

Slide 2 – Introduction & Study Gap – Bridging Heritage and Innovation

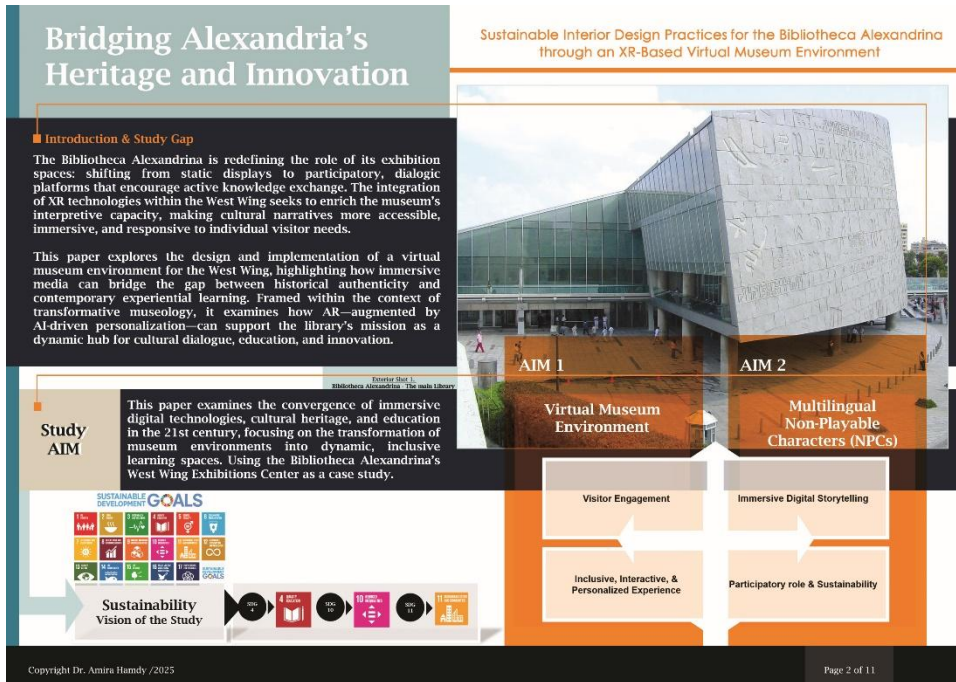
This slide establishes the intellectual basis to the proposal as it focuses on the phasing out of static displays to the immersive XR-based storytelling. The imprint of your design is clear through how you conceptualized Bibliotheca Alexandrina West Wing as a 21st century dynamic cultural hub bridging between the historical and present-day experiences. Having framed the study gap, i.e. how museums can be changed to participatory, cooperative spaces, in

terms of solving the problem of cultural sustainability, see picture 16.

Through this, the study is suggesting a design-driven approach to the solution that fits the transformative museology and is in line with the Sustainable Development Goals (SDGs). Scenario Development, Prototyping. Authoring an XR-based virtual museum consisting of simulation of the three thematic areas within the museum, The Ancient Library, The Pharos Lighthouse, Cosmopolitan Alexandria. Incorporation of a Non-Playable

Character (NPC) avatar with multilingual abilities to facilitate as a cultural mediator in order to be

inclusive and engaging among the visitor segments.



Picture 16. Shows the 2nd Slide of the Design-Based Approach

Source: Researcher, 2025

Slide 3 – Methodology: Design-Based Approach

The slide does not only visualize the research methodology but also gives the site analysis of the case study concerning the Bibliotheca Alexandrina. The West Wing Exhibition Center which has been highlighted in Basement 1 is recognized as being the zone to be developed into building up the

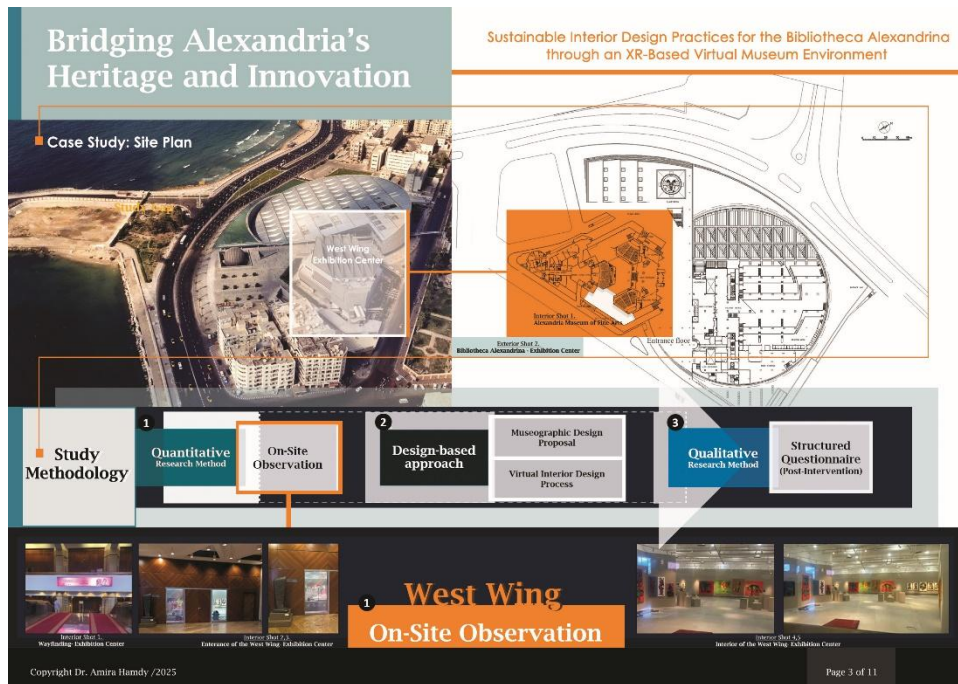
proposed virtual museum environment. The basis of the design process of the methodology is this spatial and functional mapping per se because site specificities, namely, the nature of its 500 m² underground location, the absence of natural daylight, the extensive use of artificial lighting and the absence of sustainable materials and immersive technologies, all testify to the necessity of

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intervention. Depending on this diagnosis, the research of the study is manifested as a design-based form of research that is both analytical and of applied design innovation.

Under this stage, the Museographic Design Proposal covers interpretive storytelling, circulation plans, multilingual inclusivity, and heredity interactions, and the Virtual Interior Design Process will utilize XR

prototyping and 3D visualization to simulate environmental friendliness in lighting, material, and efficiency in digital interaction. This slide supports the fact that a design-based approach is most appropriate by connecting directly to the physical and programmatic realities of the West Wing by fronting the methodology itself in direct relationship to these situational realities, See picture 17.



Picture 17. Shows the 3rd Slide of the Design-Based Approach

Source: Researcher, 2025

Slide 4 – Design-Based Approach: Virtual Museum Layout Proposal

The slide is graphical presentation of how the research work is translated into a spatial strategy. The bird view map represents precisely selected flow of areas: Alexandrian Figures Zone, Alexander the Great Zone, Heritage & Innovation VR Zone, see picture 18. In this way, the design proposal demonstrates that immersive AR/VR

interventions are not haphazard overlay, but rather, well thought out within the spatial narrative. Another point brought out by the zoning is the interaction of circulation flow and thematic storytelling that go hand in hand. The design proposal unified the elements of technology, heritage and visitor experience into a cohesive future architecture.



Picture 18. Shows the 4th Slide of the Design-Based Approach

Source: Researcher, 2025

Slide 5 – Design-Based Approach: Interior Experience through Virtual Museum environment Visualization

The suggested interior visualization constitutes visualization of the design-

based approach translated into a user-centered immersive museum space. The seamless inclusion of OLED panels is a crucial aspect to ensuring an adaptive exhibition medium; their thin

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profile, window-like solidity, and high resolution immersive visual capability provide the benefit of them acting as a projection element and skinny wall panels at the same time. In the digital art exhibition area, OLED panels have been arranged along conveyor belt-like modular partitions and surface treatments that allow smooth transitions between the tangible art works and an augmented reality (AR)-basing storytelling experience.

Technically, the fixation approach uses layered detailing- including glass substrates, specialty diffusers, and Infuse LED modules- a component that

maintains structural integrity and continuity in aesthetics, see picture 19. By layering the panel assembly onto the wall, this wall and panel cladding becomes the multifunctional display systems that can be used to host projections that can dynamically display AR content, without jeopardizing the integrity of the spatial composition (Lim et al., 2025). The outcome is a space in which tangible qualities of sculptural artefacts are reinforced with digital overlays, creating an immersive storytelling environment that can go further than fixed exhibition-based design.



Picture 19. Shows the he seamless inclusion of OLED panels is a crucial aspect to ensuring an adaptive exhibition medium for augmented reality (AR)-basing storytelling experience.

Source: Lim et al., 2025

The role of the interior architecture in this configuration is not to sit on the sidelines as a mere decorative element but rather act as an active story-telling

element, with the contents of the AR being embedded within the beautiful surfaces of the exhibition, see picture 20. Such dichotomy, where

construction detail is equalized with technological immersion, creates additional reinforcement of the

sustainability, adaptation role in re-conceptualizing the museum visitor experience.



Picture 20. Shows the 5th Slide of the Design-Based Approach

Source: Researcher, 2025

Slide 6 – Design-Based Approach: Alexandrian Figures Zone

The design underlines a combination of the Alexandrian heritage in an augmented exhibition setting. The methodology of the augmented reality experience is the OLED screens positioned in the most strategic way out of the cladding composition to give a layered effect of the interaction, See

picture 21. In design-based research perspective, this practice represents how VR and XR can be seamlessly integrated with cultural interiors in striking the balance between conservation and innovation, encouraging audience participation and retaining the integrity of physical objects.

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Picture 21. Shows the 6th Slide of the Design-Based Approach

Source: Researcher, 2025

Slide 7 – Design-Based Approach: Alexander the great zone

The design of Transparent OLED panels play an important role in this area with innovative possibilities to dynamically layer digital reconstructions of people and objects to the physical busts and sculptural fragments. In the context of design-based research, the convergence shows how immersive media can provide both more interpretive reach with little architectural intrusiveness. Flexibility through technical fixing of OLEDs into the modular cladding

frames also provides the curators an opportunity to change narratives as time goes by without structural redesigns of the module-a criterion that is critical in sustainability of exhibition structures, see picture 22. This places primary emphasis on immersive experience as a means of generating empirical knowledge related to how visitors will interact with the space, the accessibility of the space, and how these immersive technologies can be applied to further extend cultural interpretation.



Picture 22. Shows the 7th Slide of the Design-Based Approach

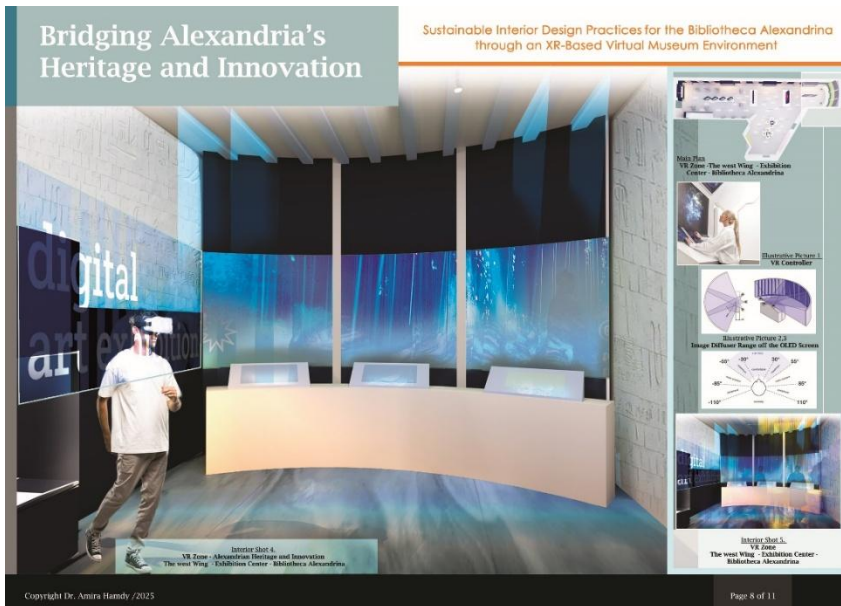
Source: Researcher, 2025

Slide 8 – Design-Based Approach: VR Zone

The VR zone brings to prominence the synthesis of large-scale OLED screens with the immersive spatial structures. In this case the technical attention to detail of curving screens and diffuser spectrum generates an immersive space that augments virtual rebuilds of Alexandrian tradition. The design-based approach is aimed at viewing these screens not as a technological supplement but rather as architectural surfaces as a part of the cladding system of the exhibition. This

strengthens the connection of the physical and virtual space, in favor of a multisensory and inclusive visitor experience. Moreover, the VR system has a special pair of glasses that is aligned to the OLED screens, which visitor can change by choosing educational material, the level of information, and desired language. The use of 360 projection adds to the depth of immersion so that not only is learning an interactive process, it is mobile to reach multifarious audiences and populations.

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Picture 23. Shows the 8th Slide of the Design-Based Approach

Source: Researcher, 2025

3.3. Phases (3): A structured post-intervention questionnaire

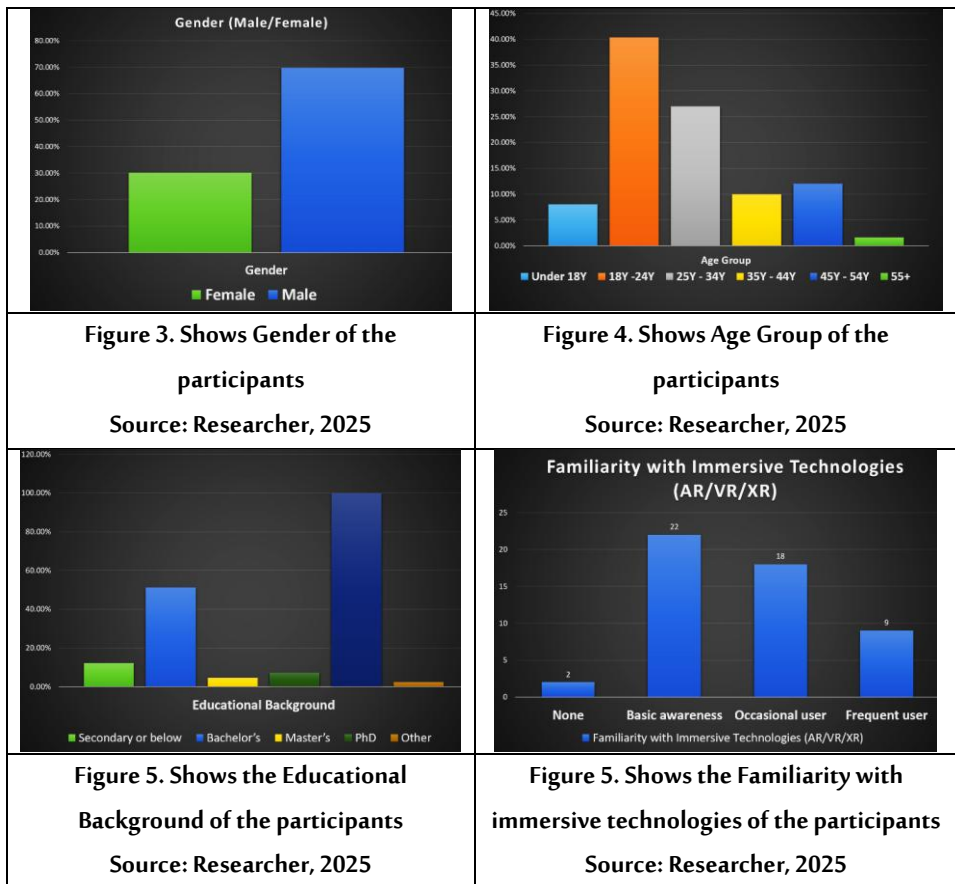
The quantitative data also played a pivoting role in evaluating the immersive verse of the virtual museum, its pedagogical usefulness, and its future implementation. The design proposal was assessed with the help of a structured questionnaire provided Onsite: QR codes placed at the West Wing Exhibition Center directing visitors to the Google Form, and Online: Links distributed through via the Internet using Google Forms.

The goal of the questionnaire is to obtain quantitative data about visitor experience with the project on a number of areas, such as: cultural engagement, sustainability awareness, educational value, technological immersion, aesthetic and spatial design, and overall satisfaction. The questionnaire responses were captured on a 5-point Likert scale with an anchor view of 1 = strongly disagree to 5 = strongly agree therefore providing clear answers as to the attitude and experience of the participants. Such a methodology can

be confident of consistency in the collection of data and give quantifiable outputs on how the design proposal

facilitates cultural participation, user-centered design as well as sustainable heritage practice.

3.3.1. Demographic Data of the Participants



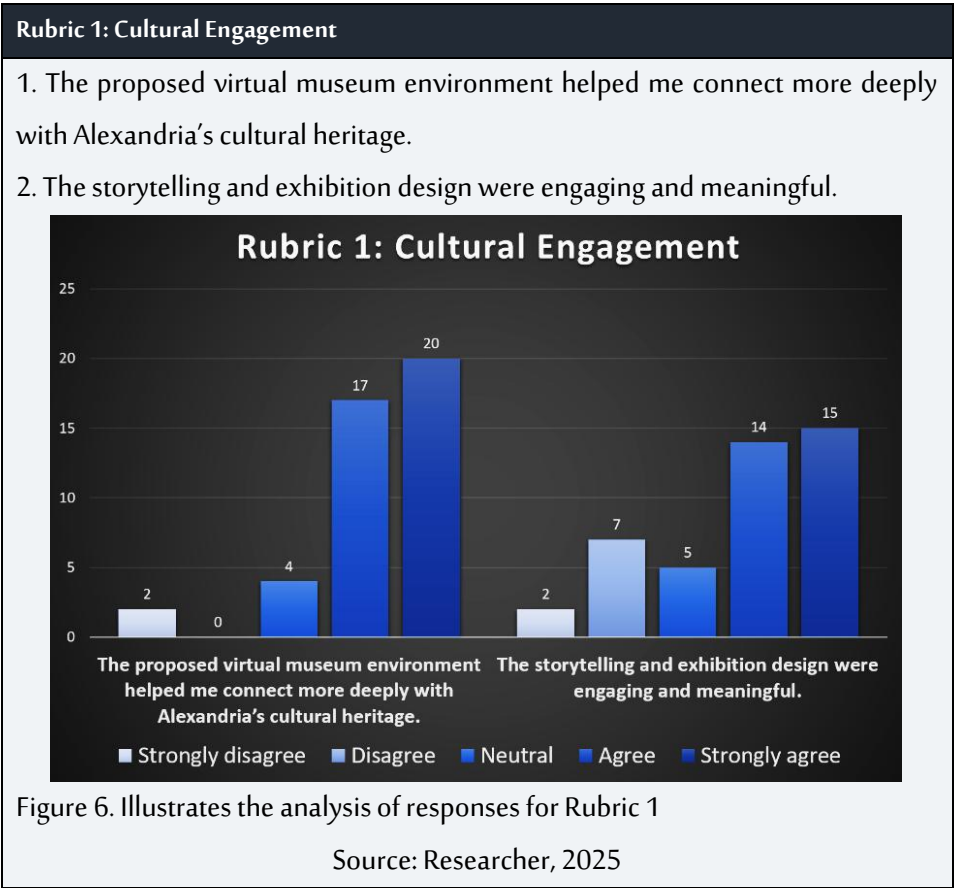
3. 3.2. Rubric 1 Cultural Engagement:

The following points were addressed in the aim of the success at which the virtual museum and encourages

interactivity with heritage and storytelling.

Table 4 illustrates the responses for Rubric 1

Source: Researcher, 2025



3. 3.3. Rubric 2 Sustainability

Awareness:

The following points were addressed in the aim of the recognition of cautious of resources and environmentally-friendly practices among the visitors during the exhibition.

Table 5 illustrates the responses for Rubric 2

Source: Researcher, 2025

Rubric 2: Sustainability Awareness

1. I believe the virtual museum promotes environmentally responsible practices (e.g., reducing resource use, sustainable interiors).
2. The design raised my awareness about sustainability in cultural spaces.

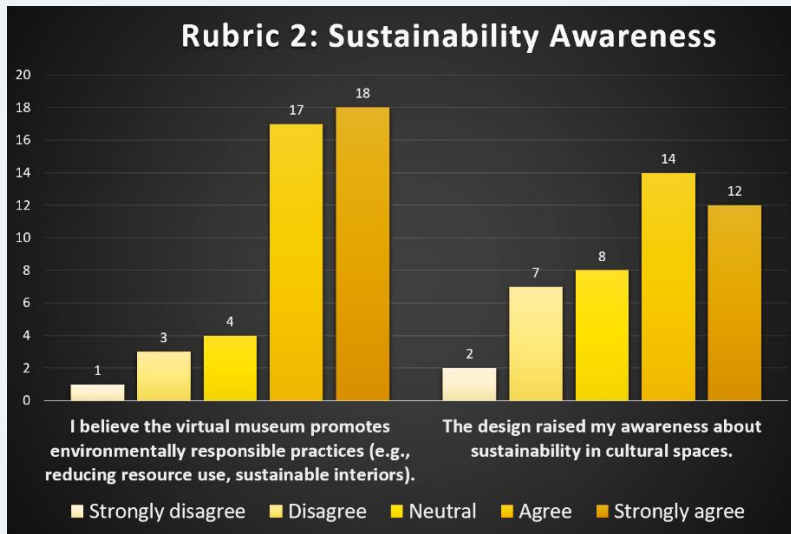


Figure 7. Illustrates the analysis of responses for Rubric 2

Source: Researcher, 2025

3. 3.4. Rubric 3 Educational Value:

The following points were addressed in the aim of how the proposed design environment favors learning, reflection as well as cultural knowledge retention.

Table 6 illustrates the responses for Rubric 3

Source: Researcher, 2025

Rubric 3: Educational Value

1. The virtual museum provided valuable learning opportunities.
2. I feel I gained new knowledge about Alexandria's heritage through this experience.

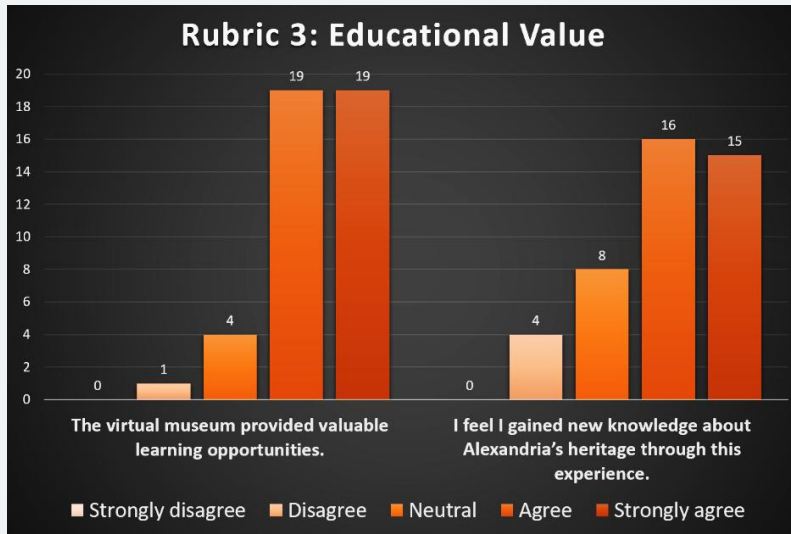


Figure 8. Illustrates the analysis of responses for Rubric 3

Source: Researcher, 2025

3. 3.5. Rubric 4 Technological Experience:

The following points were addressed in the aim of how the proposed design is Comfortable with XR/virtual environment, ease of use and interactivity.

Table 7 illustrates the responses for Rubric 4

Source: Researcher, 2025

Rubric 4: Technological Experience

1. The virtual tools and interactions were easy to use.
2. I felt comfortable engaging with the digital/immersive features.

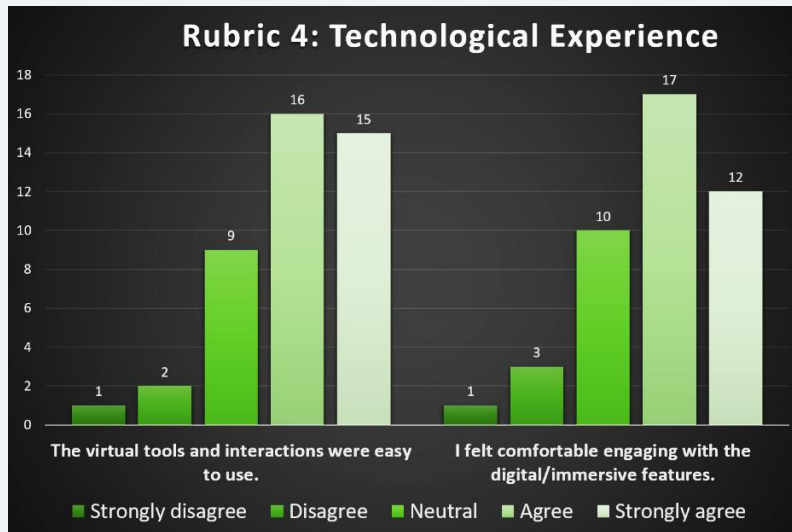


Figure 9. Illustrates the analysis of responses for Rubric 4

Source: Researcher, 2025

3. 3.6. Rubric 5 Aesthetic, Spatial**Design and Overall Satisfaction:**

The following points were addressed to evaluate Impressions of layout, orientation and appearance. In addition to how satisfied is the user with the overall feeling and value the participating.

Table 8 illustrates the responses for Rubric 5

Source: Researcher, 2025

Rubric 5: Aesthetic, Spatial Design and Overall Satisfaction

1. The exhibition design was visually appealing.
2. The circulation within the environment were clear and effective.
3. Overall, I am satisfied with the experience of the virtual museum environment.
4. I would recommend this type of experience to others.

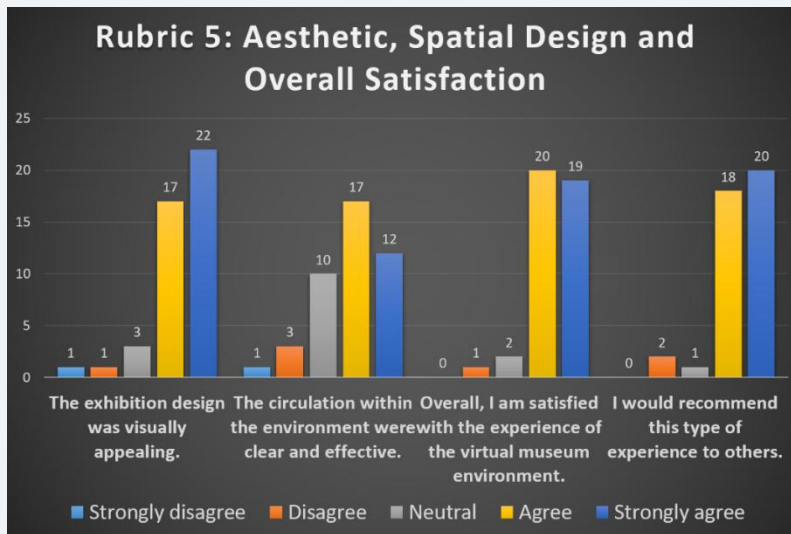


Figure 10. Illustrates the analysis of responses for Rubric 5

Source: Researcher, 2025

4. Results and Discussion

The composition of demographics showed that there were a nearly equal distribution of participants of both sexes and most subjects were younger. In particular, it was about 65 percent between 18--34 years, representing a digital savvy audience

who understand intelligent tools. Educational-wise, the respondents were much-educated with two-fourths having a Bachelor degree and three-fifths having at least an additional Masters degree, whereas a few of them reported that they only had secondary education or lower

levels. This profile would indicate that the respondents were in a good position to give informed feedbacks of the virtual museum experience.

In terms of knowledge of the immersive technology AR, VR and XR, 36 percent of the participants were regular users and 32 percent were occasional users and 8 percent stated that they were unaware of immersive technology. It means that there was a good basis of input since 92 percent of the respondents had a basic level of knowledge or above about the immersive technologies.

In the evaluation rubrics, the outcome shows positive input to the proposed virtual museum environment. With cultural engagement, 74 percent of participants either agreed or strongly agreed that the experience had allowed them to connect more deeply with the heritage of Alexandria, and 71 percent found the storytelling and the exhibition design to be interesting and emotional. This is an indication of the success of the project to help

increase cultural appreciation with the aid of immersive media.

Regarding sustainability awareness, 81 percent of the respondents found that in the virtual museum, the initiatives that were environmentally responsible embraced sustainability awareness, with 78 percent concurring that there was a heightened awareness towards sustainability in cultural spaces. Such results help conceptualize the value addition to digital heritage projects as a promoter of sustainable design thinking.

Educational aspects of the experience were also well founded with 79 percent claiming that the museum provided useful educational experiences and 74 per cent claiming to have obtain fresh knowledge about the heritage of Alexandria. It indicates the power of a vivid storytelling to provide not only cultural but also educative results.

Another strength of the project turned out to be technological usability. Eighty-five percent of the

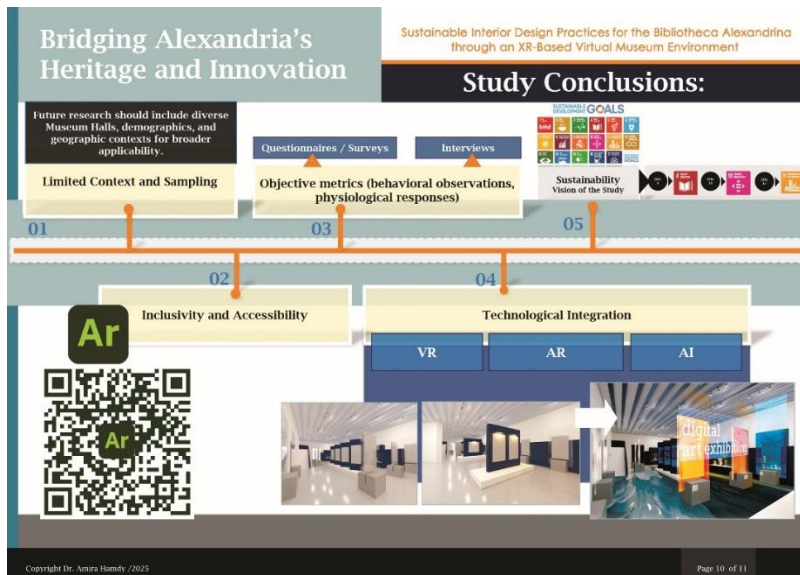
respondents indicated ease of use of tools and interactions with 40 percent strongly agreeing. Additionally, 79 percent were comfortable to interact with the immersive and digital features and this reinforced an idea that technical barriers did not and would not impede participation or learning.

Lastly, the aesthetical and spatial design elements played a big part towards pleasure. Eighty three percent of the respondents described the environment as visually attractive, 76 percent of the respondents made

affirmative statements about circulation in the environment being clear and effective and 81 percent of the respondents stated an overall satisfaction of the experience at the virtual museum. Notably, 79 percent of respondents said they would recommend this form of experience to others, which validates its wider application and generalizability.

5. Study Conclusions

The study draws the conclusions in the form of the synthesis of design-based experimentation on five main thematic points, see picture 25:



Picture 25. Shows the 10th Slide of the Design-Based Approach

Source: Researcher, 2025

- Limited Context and Sampling

The pilot was run at the west wing exhibition halls of Bibliotheca Alexandrina. Although this context was necessarily restricted, this manageable size enabled the project to quantify XR systems, and especially OLED-integrated cladding functionality, in an actual architectural environment. Expansion to other museum halls, demographics and geographic locations will be needed in the future to ensure generalizability.

- Inclusion and Accessibility

The XR proposal shows that immersive environments can make the heritage available in a non-elitist way. Prior to XR, the challenge in museums was that the visitor could only interact with the objects displayed and interpretive text. Post-XR, visitors can customize their learning experiences by selecting their learning pathways, desired language, and level of content by interacting with OLED displays and AR overlays, thereby, providing

customized learning experiences to meet the multiple demographics.

- Interviews, Surveys and questionnaires

Mixed-method evaluation process was used, which involved subjective responses (interviews and surveys), and objective behavioral observations. These tools emphasized the superior engagement, dwell times and affect of the XR system over conventional displays.

- Technological Integration (VR, AR, AI)

The project also portrays the opportunity of VR areas, AR overlays and AI content administration in developing a hybrid museum model. Adobe Aero, in-particular provides an authoring tool of lightweight and versatile augmented reality, where curators can create augmented layers and project it directly on physical objects, using mobile devices. This also mitigates the need of complex coding pipelines and that assisting to make AR integration more available to curatorial teams.

- Study sustainability and Vision

The design-based method is consistent with the core tenets of the UN Sustainable Development Goals (SDGs), and can promote quality education, innovations, equitable inequalities, and sustainable cultural heritage. Such modular OLED cladding system also makes the XR interventions not wasteful add-ons; that part of a building structure that can be upgraded technologically without material replacement.

- Before vs. Following XR - Design Impact

Pre-XR: The museum experience was based on the use of non-interactive

artifacts, traditional lighting, and printed labels, where the interpretive level was low, and the extent of inclusivity to the general non-specialist visitor was low as well.

The presentation of OLED screens, the AR enabled by Adobe Aero, and VR projections will create an immersive and responsive context of the exhibition experience adapting or adjusting to the demands of visitors being able to co-navigate together the heritage narratives and active interface, co-browse, and develop other multilingual layers of educational information in either physical or virtual reality.



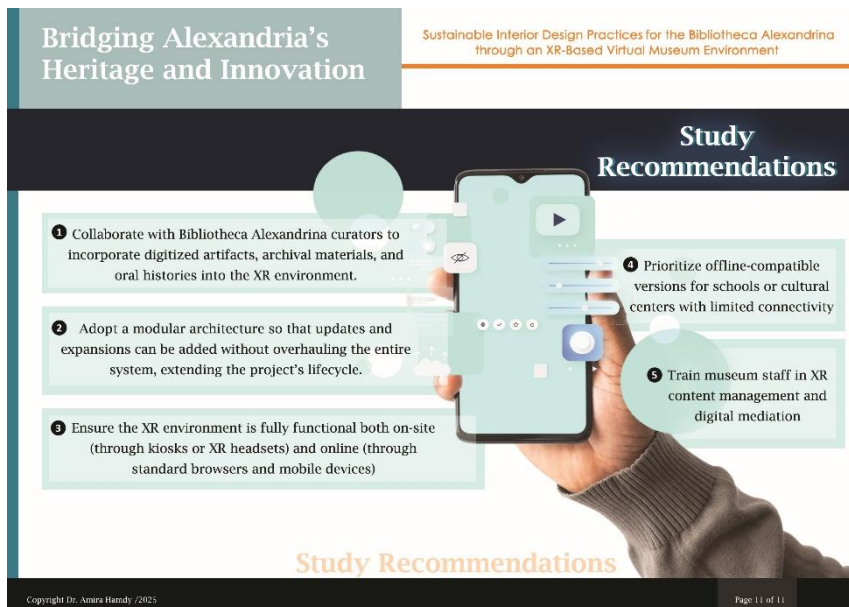
Picture 26. Shows the Before vs. Following XR - Design Impact

Source: Researcher, 2025

6. The Study Recommendations and Future Directions

The recommendations focus on a multi-layer approach in the aspect of

maintaining and expanding the XR-based virtual museum setting, see picture 27:



Picture 27. Shows the 11st Slide of the Design-Based Approach

Source: Researcher, 2025

- Curatorial Collaboration

Collaborate with the curators of Bibliotheca Alexandrina in the process of digitalizing artifacts, oral histories and archival records, so their cultural content can take a natural, contextualized and academically verified form in the XR space.

- Modular Architecture

Employ a dynamic scalable installation of OLED screens and AR interfaces that can be upgraded in the future without the need of total re-structure of the system.

- Hybrid Functionality

Ensure the XR platform is available on-site (kiosks and headsets) and online (browsers and cell phones) and ensure it breaks down digital divides and expands museum reach to new international audiences.

- Offline-Compatible Versions

Focus on installing minimal and offline-compatible modules in schools and cultural centers with poor internet connections and make the education available in equitable manner to all locations and not only

to the technologically-advanced areas.

- Capacity Building

Formalize XR content management and digital mediation skills of the museum staff, and that all know-how concerning OLED systems, AR clad installations and immersive projection systems are not vendor-specific as part of an institutional knowledge base.

Collectively, the recommendations situate the project within an adaptive and future-proof design model and its ability to evolve with the fast-paced advance in technology, without interfering with the cultural heritage of Alexandria and democratizing access to knowledge.

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