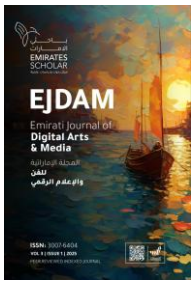

Emirati Journal of Digital Arts AND Media
Vol 3 Issue 1 (2025)
Pages (14 - 30)

Available at www.emiratesscholar.com
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Gamified and Accessible Cultural Heritage: An AR Framework for Inclusive Experiences

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ARTICLE INFO

Published on 25th of September 2025
Doi:10.54878/5g267244

KEYWORDS

Gamification, Digital Cultures, Augmented Reality, Edutainment, Accessibility, Multisensory Design.

HOW TO CITE

Gamified and Accessible Cultural Heritage: An AR Framework for Inclusive Experiences. (2025). *Emirati Journal of Digital Arts & Media*, *3*(1), 14-30.

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ABSTRACT

Designing accessible yet engaging Cultural Heritage (CH) experiences is a necessity for a more inclusive edutainment experience that both preserves CH and expands people's knowledge and interest in their heritage more broadly. Many designers have explored the integration of concepts, including multisensory design, digitization of CH, gamification, and emergent technologies in their CH experiences to achieve that. However, researchers often address these concepts individually, leaving a gap in combining them to create a holistic guideline for designing enjoyable CH experiences for all. This research investigates the question of whether we can design a comprehensive framework that merges digitalization, gamification, multisensory design, and accessibility to enhance CH experiences for all. This study introduces the CHx toolkit, which is the output of desk research and data analysis in order to identify the overlapping elements and sub-features across a pilot project in digital CH, including enjoyable informal learning, gamification, and multisensory design, through Augmented Reality (AR). The toolkit is then tested through two experiments in the context of Egyptian CH, each focusing on a different sensory stimulus and AR application. The first experiment is a gamified experience conducted at the Modern Museum of Egyptian Art; the second one is an AR scavenger hunt game at the National Museum of Egyptian Civilization. While this stage did not involve formal evaluation, preliminary qualitative feedback from observers suggested the approach was engaging and accessible. These exploratory applications demonstrate the framework's adaptability and inform the design of future, measurable user studies to validate its impact.

Introduction

"Though we see the same world, we see it through different eyes." ~ Virginia Woolf

Perception shapes how we experience the world. The same events can have different impacts on different people, as each individual's sensory system and cognition react to various stimuli differently (UNESCO, 2020). As a result, different people perceive the same environment uniquely, influenced by personal background, cognitive biases, and sensory capabilities (A. Sanderson & College, 2022).

For designers, creating experiences that resonate with diverse audiences presents a challenge. Designing in the CH field is no different. CH experiences should be inclusive and engaging, ensuring accessibility for all individuals, regardless of physical or sensory differences (UNESCO, 2020). Accessibility in CH includes both physical and virtual (data) accessibility. (Deffner et al., 2015). Museums, galleries, and libraries increasingly use digital tools to expand cultural access globally (UNESCO, 2020). Beyond accessibility, technology has introduced new dimensions to CH experiences. Virtual reality (VR) and augmented reality (AR) not only enhance inclusion but also improve engagement. By incorporating gamification and immersive storytelling, these technologies create more memorable learning experiences (Parsehyan, 2020). Studies show that integrating AR into CH settings transforms static artefacts into interactive, multisensory experiences, increasing engagement and retention (Nofal et al., 2018; Partarakis et al., 2017). Despite research on digital CH, accessibility, gamification, and multisensory design, these concepts are often addressed separately. Existing frameworks focus on individual aspects, such as AR-driven informal learning (Chandini Pendit et al., 2014). or CH experiences for individuals with hearing impairments (Baker, 2019). However, no comprehensive framework combines them all. Although the universal design for learning (UDL) framework promotes flexible learning environments to accommodate diverse needs (Meyer et al., 2014), UDL has not been extensively explored within cultural heritage (CH) experiences, where learning occurs informally rather than based on structured curricula.

This research proposes a standardized guideline for designing multisensory, accessible, gamified CH experiences using AR. In addition to integrating UDL into CH, conducting literature analysis, and examining case studies in Egyptian CH contexts, this study explores various sensory stimuli inside and outside museum settings to validate the framework's applicability and potential for global implementation.

Literature Review

The following diagram represents an overview of the literature review of the main concepts addressed in it.

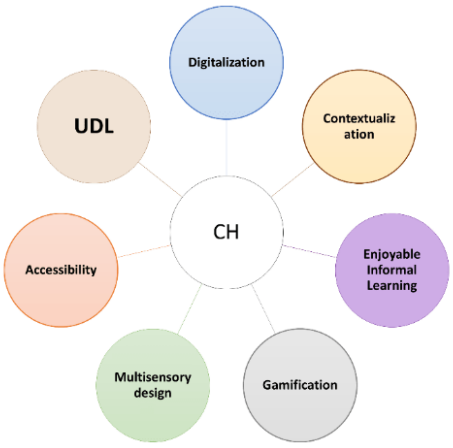


Figure 1 Literature review framework

Digital CH

Technological evolution has revolutionized the CH industry using VR, AR, digital storytelling, virtual tours, digital twinning, and online repositories. This advancement has significantly increased and enhanced the overall CH audience experience and CH digital preservation. (Parsehyan, 2020; Partarakis et al., 2017). The restoration of the Telamon statue at the Syracuse Museum (Kurosu, 2019) and the Terracotta AR warriors in Philadelphia (Mohammed-Amin, 2015) are just the beginning of a new era in museum experiences and AR applications transforming museums from passive spaces into interactive environments.

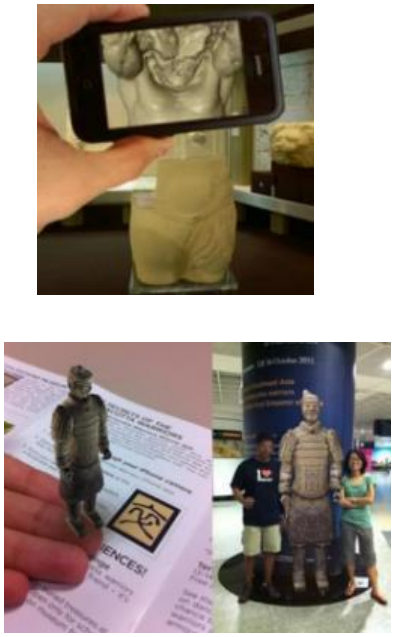


Figure 2 Telamon at the Syracuse Museum on the left, Augmentation scenarios from the Terracotta Warriors AR application on the right

Contextualization of CH

While museums provide a rich atmosphere for historical and cultural engagement and education, the displacement of the artefacts from their original environments poses a significant challenge. This displacement causes a loss in their contextual and spatial information (Thompson, 1994). The Royal Museum of Art and History (RMAH) in Brussels has taken a step towards addressing this issue by creating an AR 3D-reconstruction of the Nimrud Palace to contextualize the Genius relief. This initiative has not only increased the memorability of the information related to the artefact and its scale by the visitors but also highlighted the importance of contextualization in preserving our cultural heritage (Nofal et al., 2018).

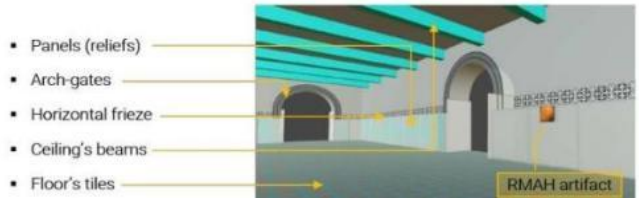


Figure 3 (a) The relief of the Genuis head collected from Nimrud Palace (b) an abstract 3d visualization of reconstructing the original location of the RMAH artifact in the Nimrud Palace, and the surrounding architectural features (Nofal et al., 2018)

Enjoyable Informal Learning (EIL) and Edutainment

EIL in cultural heritage depends mainly on three principles: mindfulness, enjoyment and enjoyable technology. Such concepts create an edutainment experience that is now being adopted by educational institutes like schools, libraries, archives, and museums (SLAMs) for a more engaging CH experience (Partarakis et al., 2017). For example, The Prambanan Temple in Indonesia created an AR mobile application, creating a multisensory experience that improves the visitors' learning and engagement (Chandini Pendit et al., 2014).

Gamification in CH

SLAMs are at the forefront of integrating gamification and serious games to promote interactive CH learning (Du, 2020), such as scavenger hunts, quizzes, and AR mobile games (Maria, 2020; Partarakis et al., 2017). For instance, the Louvre Museum's 3D audio guide, with its artifact models, videos, and interactive descriptions, empowers visitors to digitally manipulate exhibits and take virtual tours (Tieryas, 2017).

Multisensory Design

Humans perceive the world through multiple senses, and integrating multisensory design enhances cultural heritage (CH) experiences. Mobile technologies, especially AR, enable multisensory engagement through hybrid reality visuals, audio, and even olfactory elements, as seen in the Palazzo Dei Diamanti Museum, where

animations, scent-releasing 3D-printed sculptures, and paintings act as AR markers to deepen visitor engagement (Carulli & Bordegoni, 2020). The use of multisensory design is a key to unlocking more exciting and memorable museum visits (Harada et al., 2018). It is crucial for accessibility (Thevin et al., 2021).

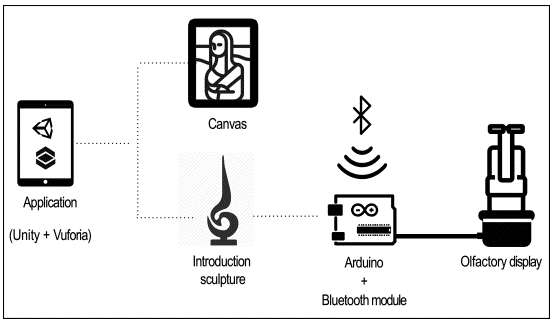
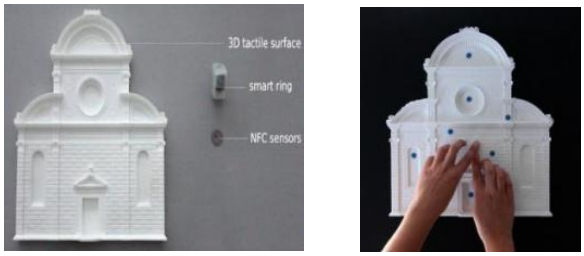


Figure 4 Architecture of the olfactory experience in Palazzo dei Diamanti the museum (Carulli & Bordegoni, 2020).

Accessible CH

Many CH apps, like AI Museum, enhance accessibility for visually impaired users through AR, screen readers, and customizable text (Guedes et al., 2020). Tools like Tooteko enable blind users to explore tactile surfaces with audio feedback (D'Agnano et al., 2015). Similarly, MARHIME, a mobile AR app, enhances museum experiences for hearing-impaired visitors through interactive 3D visuals (Baker, 2019).



(a) (b)

Figure 5 (a) Tooteko system parts, (b) hotspots/NFC TAGS (D'Agnano et al., 2015).

UDL

The UDL guideline has three core pillars; providing multiple means of engagement, representation, and action/expression, ensuring accessibility for all learners, including those with disabilities (Meyer et al., 2014). The UDL framework has succeeded in both digital and traditional learning environments (Rose et al., 2005).

Key Findings

The integration of AR, VR, and gamification into CH sites transforms how visitors engage with and understand historical artifacts. Monuments contextualization, immersive storytelling, and enjoyable informal learning enhances the memorability and the visitors' experiences. Multisensory and accessible design create more inclusive journeys. AR and interactive technologies offer immersive learning. By integrating UDL into CH, we can ensure that CH experiences are inclusive and adaptable, accommodating visitors with different abilities, learning preferences, and cognitive backgrounds. By applying these principles, future research and implementations can further bridge the gap between traditional CH education and interactive, technology-driven engagement for all.

Aim

The aim of this research is to create a holistic standardized framework that can be used by anyone to design experiences that include learning about CH in an immersive and inclusive way using AR as a technological solution depending on research done before and cross refencing identified elements addressed in the literature review under the titles of: digital CH, edutainment & gamification in CH, multisensory design in CH and accessibility in CH. Then testing the validity of the framework through different experiments conducted in the context of the Egyptian CH with the intention of its global spreading. AR technology was chosen due its accessibility and affordability as it doesn't require special gadgets and depends mainly on cell phone.

Methodology

Experimental research by design and simulation methodologies were used. The CHx framework formulation was a result of dedicated desk research, including secondary data collected and analysed from previously conducted research and primary data resulting from text analysis of the literature review and manual observations. This manual process allowed the researcher to find

connections between the main and sub-elements of the toolkit. The CHx framework was developed from the researcher's observations of repeated concepts, design elements, and features across topics such as digital cultural heritage (CH), edutainment and gamification in CH, multisensory design, and accessibility. By identifying overlapping patterns between these areas, the framework serves as a guideline for creating more inclusive CH experiences. It is applied in various case studies to test its practicality. Figure 6, created manually from literature review analysis, maps six main concepts (nodes) and uses colour coding to show their overlapping sub-features, with the following table providing the key.

Node Color	Meaning	Outline Color	Relevance
	Accessibility in CH main Node		Related to senses
	Accessibility in CH sub-Nodes		Related to accessibility
	Multisensory design in CH main Node		Related to fulfillment and achievement
	Multisensory design in CH sub-Nodes		Related to inclusive design
	Gamification in CH main Node		Related to technology in CH
	Gamification in CH sub-Nodes		Related to the user control
	Digital CH main Node		Related to game types
	Digital CH sub-Nodes		Related to enjoyable learning
	AR in CH main Node		Related to ordination and physical presence
	AR in CH sub-Nodes		Related to Multimedia
	Edutainment in CH main Node		Related to AR mobile applications
	Edutainment in CH sub-Node		

Figure 6 Diagram of the intersecting elements of different features addressed in this research in CH

Upon the organization of the central and sub nodes, multiple common or overlapping nodes were found which resulted in the attempt to connect between the concept (nodes) in multiple organizations represented in Figure 7 and Figure 8. it was found that eventually, all the central nodes are connected via sub-nodes, proving the relevance and the connection of the central nodes. Trials of the nodes' connections and overlapping are illustrated in

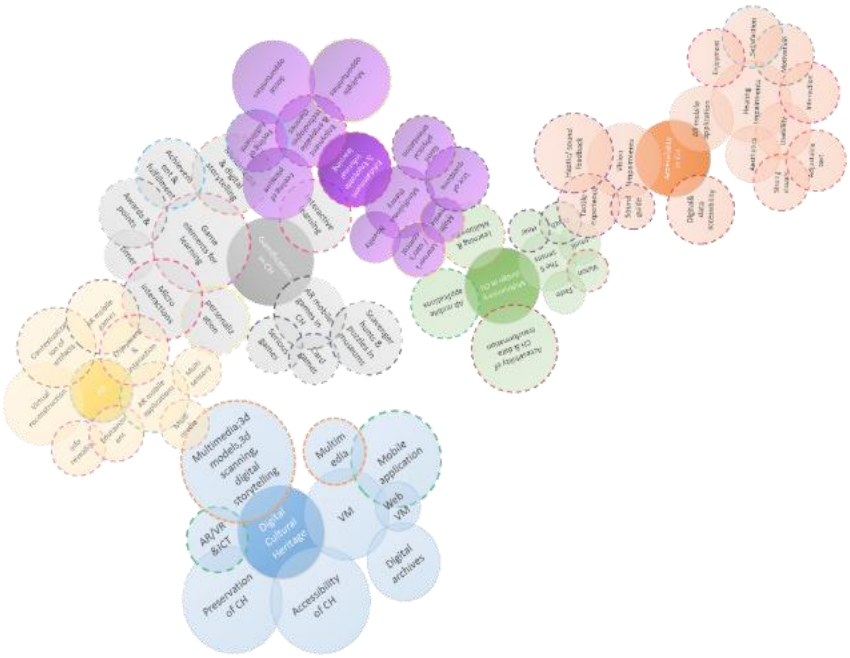


Figure 7 diagram of the first iteration of the connections of the nodes

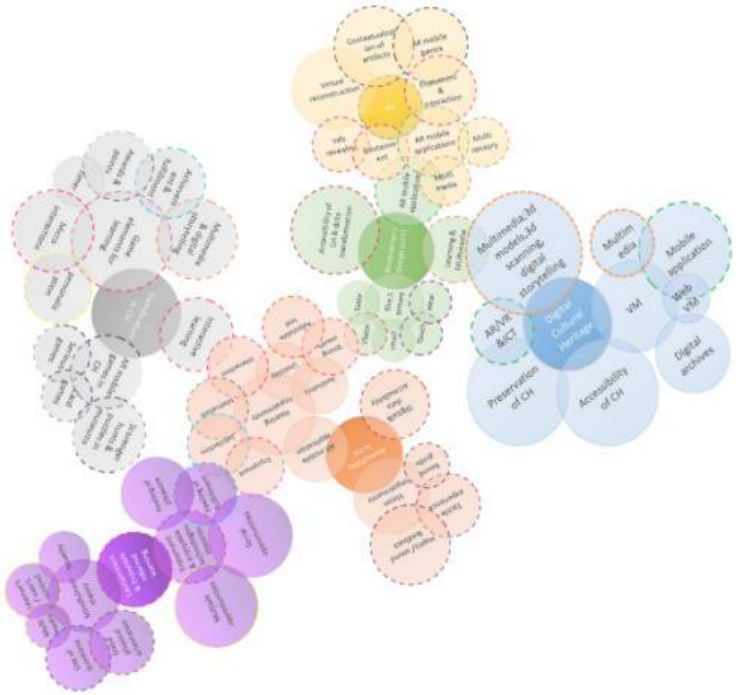


Figure 8 diagram of second iteration of the connections of the nodes

By analysing the diagrams above it was concluded that all the elements lie under three pillars and their founding elements which can be summarized as; Technological solutions (technology, multimedia communication), the human interaction (interaction) and the human response to the experience (motivation, fulfilment and enjoyment). These pillars were used to create the CHx toolkit.

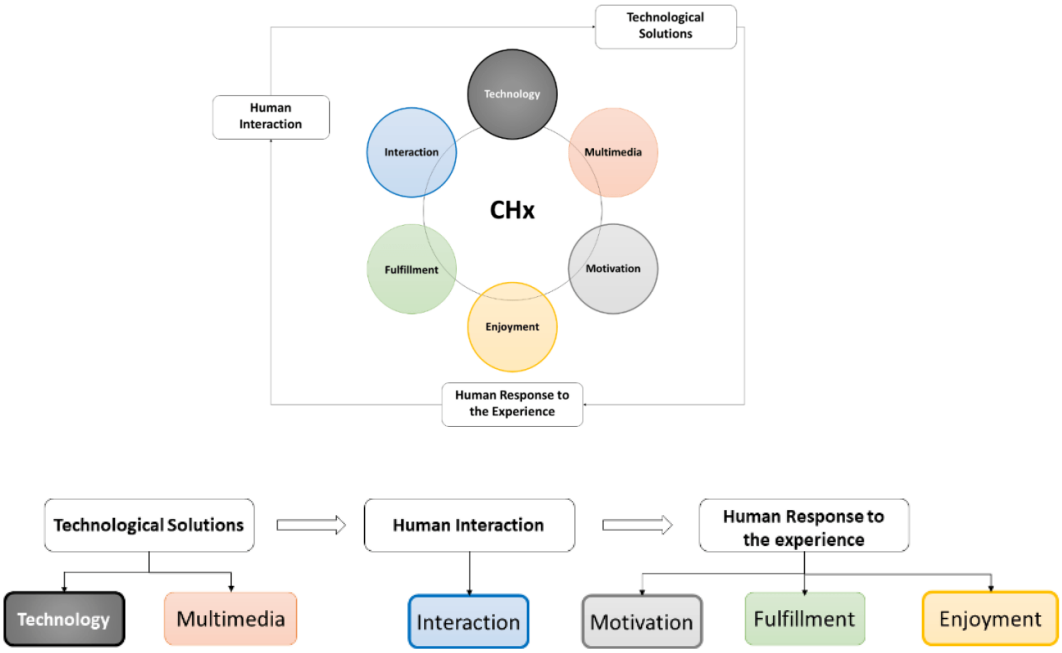


Figure 9 pillars of the CHx toolkit

Suggestions for achieving the main concepts and their sub-features are further illustrated in the diagram below. These concepts include **Technology** with AR as a sub-element, **Enjoyment,** which depends on storytelling, entertainment, and good physical orientation *(which aligns with UDL Multiple Means of engagement)*. **Multimedia communication** with sub-elements of Digital, physical, and mixed media *(which aligns with UDL Multiple Means of representation)*. **Interaction** includes user control of the experience, multiple choice and opportunities provided to the user and hybrid interaction, **Motivation** with the help of a surprise factor, points/ rewards, personalization of the experience and social interaction, **Fulfilment** gained by the senses of achievement and happiness and the connection between the user and the experience itself *(which aligns with UDL Multiple Means of Action & Expression)*.

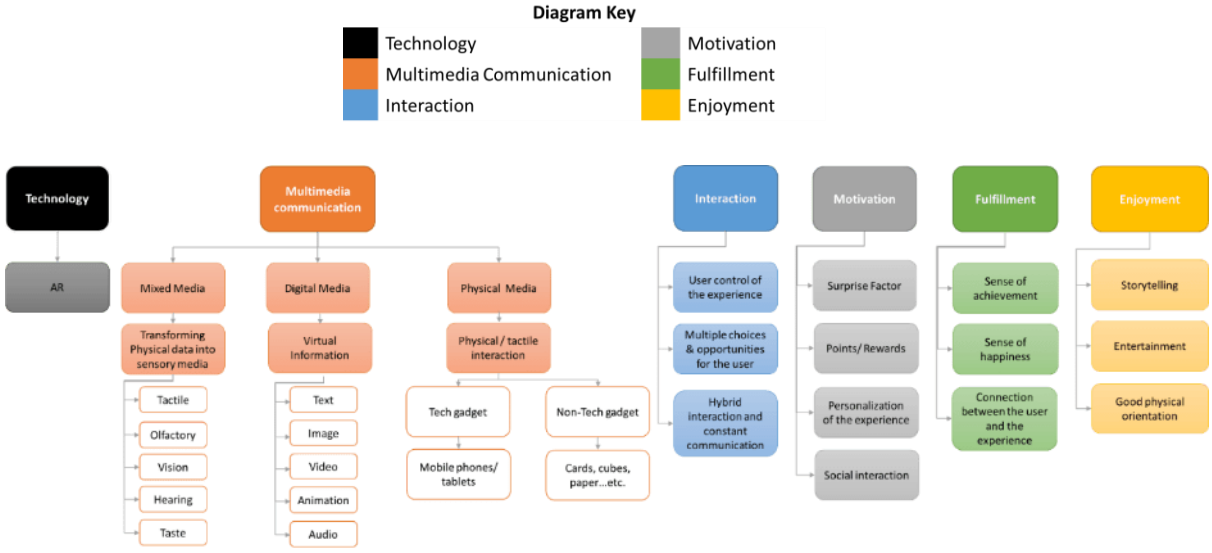


Figure 70 Breakdown of CHx toolkit

Framework Implementation

1. The Living Paintings experience

Objective:

The Living Paintings experiment is an AR gamified experience implemented at the Modern Museum of Egyptian (MMEA), focusing on audio-visual effects as a sensory stimulus, and testing the validity of the CHx framework whilst bringing the museum paintings to life through AR, image manipulation, animation, and audio. The following 4-layered visualization illustrates the transformation of the museum paintings into living art using animation, sound generated from the images and its visualization where the whole experience can be unveiled using AR.

Framework Implementation overview:

In this experiment, based on the CHx framework, For the Technological aspect, Artivive AR platform is used for its ease of use and non-programming setup. Artivive allows uploading target images and multimedia (text, images, audio, animation) to an online editor, which are then revealed through the mobile app. The AR experience's success depends on the app's usability and smooth multimedia performance. The multimedia communication had three pillars:

1. Digital media: bilingual text annotations, painting images, and animations, with success measured by clarity, functionality, and user appeal.

2. Physical media: mobile devices used to access experience, assessed by willingness to install the app.

3. Mixed media: converting data between senses (e.g., sound to animation, visuals to audio), judged by the participant engagement and recognition of the transformation.

User interaction is supported by giving visitors freedom to explore the paintings, with engagement measured by immersion and interest. Motivation is encouraged through surprise elements, social sharing opportunities, and memorability. Fulfillment comes from learning about MMEA artifacts and enjoying a novel AR experience, while enjoyment is driven by entertainment value, curiosity, and user comfort, all evaluated through perceived satisfaction and ease of interaction.

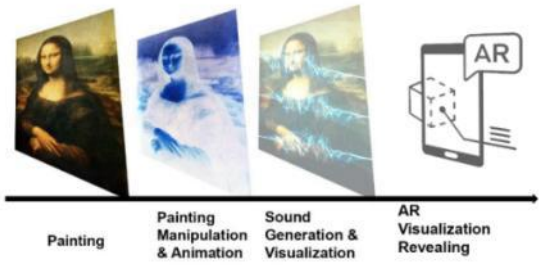


Figure 1 conceptual illustration of the living painting experiment implemented on the context of the Mona Lisa Painting

Implementation:

Site visits to MMEA concluded the need for a digital archive since many of the museum's artefacts were poorly curated, and the museum itself lacked an appropriate digital presence. The digital archive started with the museum's ground floor with an expansion intention for data preservation and accessibility for all. The researcher did the archive manually by collecting data from the museum and digitizing them using Flourish Platform for data visualization. The Card style was chosen from Flourish for its suitability to the dataset created. Each card includes an image of an artefact and its annotations, including the art piece name, the artist's name and other relevant data in both Arabic and English. It's color-coded according to the artists' names, with their name's legend at the top. The order of the artefacts in the archive corresponds to their actual placement order in the museum from right to left in the display hall.

Figure 12 Screen shot of the digital archive

"The Rural Girl" painting by Youssef Kamel was selected from the archive as an initial prototype to become a living painting. The image of the painting was manipulated using the "Hit Paw" AI face animator. Sound visualization was done using Veed.io. Finally, Artifice Bridge and App were used for creating the AR experience.

Figure 13 Yousef Kamel's "A rural Girl" after the AR Experience.

Findings:

While initial informal feedback from observers was positive, formal evaluation methods have yet to be implemented to gather measurable data. Users were actually impressed by the flourish platform as digital archiving tool outside of the museum walls and one user was inspired to created here own digital archive of other urban heritage elements in Cairo.

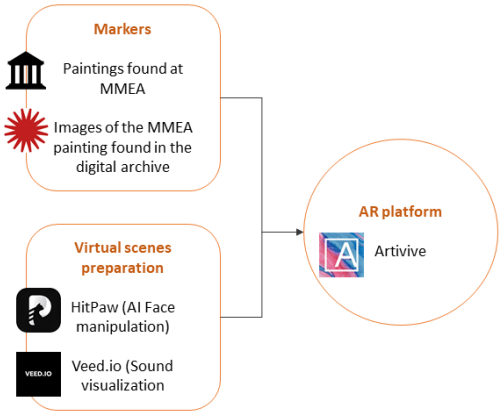


Figure 2 The Living Painting Experience Architecture.

2. AUGI: Extend Your Reality Experiment

Objective:

AUGI: is the second experiment intended to create a memorable museum experience whilst using the CHx toolkit as a guideline focusing on visual effects as a multimedia input. It is implemented within the context of the National Museum of Egyptian Civilization (NMEC) to create the illusion of a museum within a museum experience, revealing the beauty and history of the artefacts without changing their original state, creating a hybrid reality edutainment experience. AUGI is an augmented reality scavenger hunt game intended to engage the museum visitors in an interactive search for the museum artefacts whilst learning about them and reviving the dead zones of the museum. Upon arrival at the museum, visitors are to download the AUGI app, look for the artefacts in its treasure map, scan them to unveil the AR experience, and collect more points. By scanning more monuments, they collect more points and they can earn incentives from the gift shop at the end of the game/tour. i.e. The player is to navigate and collect different monuments across the progression of the Egyptian civilization to complete the game. The experiment was done collaboratively with fellow researchers, Mirhan Ayman, Rana Akeel, and me. NMEC was chosen for its large capacity and display of diversity, representing the progression of the Egyptian civilization through time. AUGI was implemented in the museum's main hall which is the largest and has the highest visitor traffic. The image below illustrates the rough placement of different artefacts in the museum's main hall according to civilization evolution.

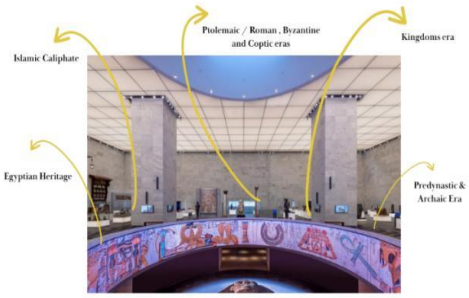


Figure 3 illustration of the civilizations' organization in the main hall

The journey starts with the visitor's arrival at the museum, where signage is used to guide them and introduce them to the game. They scan a QR code to download the app, which contains a treasure map for them to collect.

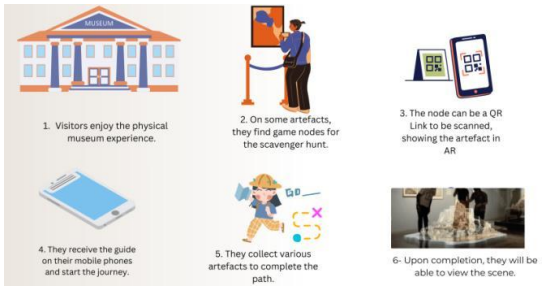


Figure 4 illustration of the player's journey.

The selection of the monuments to be included in the game resulted from our research, site visits, and interviews with the museum personnel. From this, it was decided to include the main artefacts that least represented in the main hall and least interacted with by the visitors. This has created a dead zone in the hall as they were represented in the shape of mock-ups. These artefacts included the Sabil, the Nubian House, and a glass display, which includes The Description of Egypt Book.

Figure 5 Sabil Mock-up on the left image and on the right, we can see the Nubian house mock-up

Figure 13 The Description of Egypt book.

And a set of secondary items representing daily objects like chairs, writing tools and Mosaic Floor. These items were included to create a connection and a sense of relevance between the monuments and our contemporary lives as heritage is not that distant away; we are currently creating our future CH. Visitors learning about CH and relating it to their lives are more likely to appreciate it. The game is designed so that the player collects three artefacts from each era found in the museum's main hall to complete the game, where each primary monument represents two points and each secondary one represents one point in the game's progress bar. Below are the final items listed in the hunt map, their relevance to the different eras of the Egyptian Civilization, and their location in the museum's main hall to include more items in later game versions.

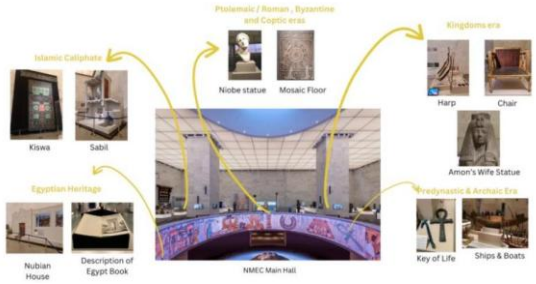


Figure 14 The final artefacts selected for the scavenger hunt and their locations in the main hall.

AR was chosen to create a feasible and accessible immersive user experience as users can use their own cell phones in the AUGI adventure no special devices are needed.

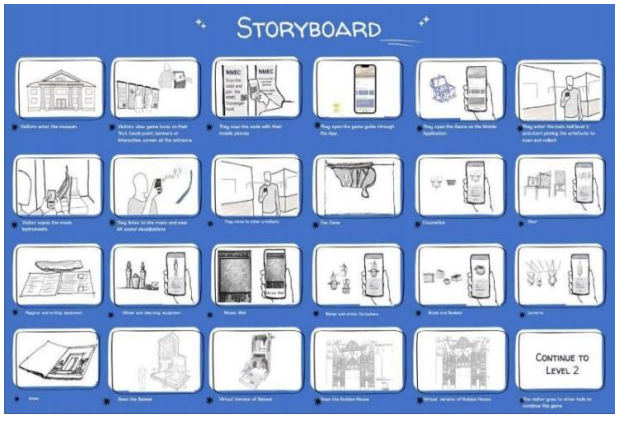


Figure 6 illustration of AUGI storyboard.

Framework Implementation overview:

The AUGI experiment, developed using the CHx framework, employed the Vuforia package for Unity 3D to create an AR museum game. Vuforia

was chosen for its flexibility in scaling and rotating virtual content, diverse AR options (image targeting, 3D object tracking, placement), and its ability to trigger multimedia experiences by scanning artifact images. The AR's success depended on app usability and smooth multimedia performance. Multimedia communication included:

1. Digital media: onboarding text and artifact annotations, image targets and infographics, and AR animations, videos, GIFs, and music. Effectiveness was assessed by clarity, user appeal, technical smoothness, resolution quality, and relevance to the artifacts.
2. Physical media: mobile devices used by visitors, assessed by their willingness to download the app.
3. Mixed media: planned features converting onboarding text into narration for accessibility and creating tactile information panels for visitors with visual impairments (pending approval by the museum administration).

Interaction design allowed participants to control their own museum tour, choosing which artifacts to scan and collect, with artifacts distributed in different zones to encourage exploration. Engagement was measured by variety of collected artifacts, level of immersion, and desire to continue playing. Motivation was boosted by surprise multimedia, gift shop rewards for game completion, and opportunities for social interaction and sharing. Personalization was planned via customizable avatars.

Fulfillment was linked to feelings of achievement, learning about artifacts, and building a connection to the museum, evaluated by completion rates, satisfaction, and perceived learning. Enjoyment came from storytelling, artifact narratives, and multimedia elements that sparked curiosity, with evaluation based on understanding, comfort, and ease of interaction.

Implementation:

AUGI's experience was done to test the CHx framework with emphasis on visual effects represented in the AR virtual scenes and the Application design. Each AR experience was designed and implemented in relevance to its correspondent artefact at NMEC, using the artefacts as image-based markers for tracking and initialling the AR hybrid reality experience.

Design Development:

1. Proof of Concept

3D object tracking was tested using an image of a chair on campus and ARtivive bridge software to track the 3D chair using its 2D image to test the validity of creating AR scenes that would overlay the museum-chosen monuments using their 2D images as target images for activating their AR scenes.

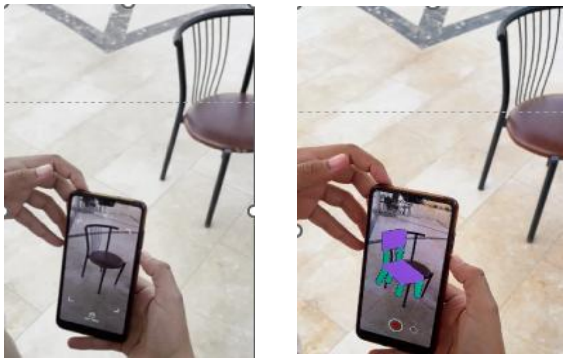


Figure 7 Illustration of the AR 3D object tracking using 2D image through Artivive platform.

The above images indicate the concept's success; however, the experience itself was glitching due to the complexity of the chair's details as a 3D physical model and the continuous change in lights and shadows affecting the chair's image detection. So, it was decided to use Unity 3D and Vuforia, images of more planar artefacts at NMEC as markers for image tracking, and AR foundation and model placement for more complicated and detailed items to ensure a more stable user experience.

2. Testing the Primary object detection:

The following images illustrate the preliminary image detection and model placement of The Sabil AR Foundation testing, Nubian House, and The Book of Egypt Detection.

Figure 8 Image detection of the Nubian House at NMEC.

Figure 9 The Description of Egypt Book image detection at NMEC.

Figure 10 Sabil model placement testing at NMEC.

3. AR scenes preparation:

The goal for AUGI was not only to increase the museum visitors' engagement with the museum artefacts but also to create interactive narratives for a hybrid reality edutainment experience that teaches people about the artefacts beyond their existing state at the museum rather their original forms and context for a more historically accurate learning experience. With that in mind, working with the first artefact "The Nubian House", its design concept aimed to reveal the beauty of the Nubian architecture, vibrant colours, and fascinating details, which were missing from the Nubian House mock-up at the museum.

Figure 11 on the left the Nubian house presented in the museum, on the right Sample of the Nubian houses in real life.

The AR scene design included colorizing the grey mock-up and returning it to its original colourful atmosphere. Two versions were created the first one used the Nubian doorway as a marker for AR image tracking and overlaying it with an AR experience. Below is the design development of the AR scene.

Figure 12 Diagram that illustrates the Nubian facade design and testing at the museum

The second version was to create a model placement version showing the context and the whole Nubian atmosphere in the 3D model including the vegetation, the river Nile and even the Nubian music in the scene

Figure 13 Diagram of the Nubian House Environment Progression.

The second artefact was The Description of Egypt Book . The book is exhibited in a glass display and is not accessible, so the design concept was to create virtual replicas

of the book pages flipping with an animated character that narrates the content of the book for a more accessible CH.

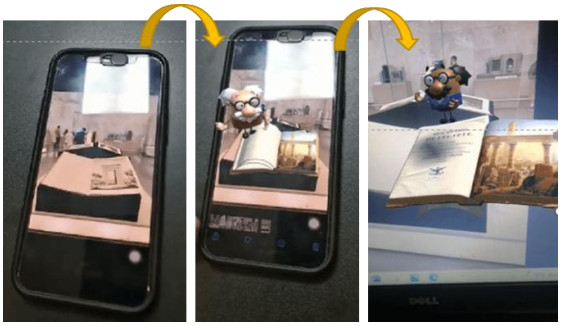


Figure 14 The Description of Egypt Book Design Progression.

The third primary item on the list was the Sabil , its design concept intended to unveil and teach people about its fascinating water mechanism through an animated full 3d model of it.

Figure 15 The Sabil Design Progression.

The secondary items' visual scene designs depended on the goal of the communicated data through the experience. For instance, in The Mosaic Floor, a reconstruction was designed for its missing parts, and the Kiswa , a translation of one of its Qur'anic verses from Arabic to English was made to teach more people about its meaning and value. For the Harp, we had a 3D model accompanied by a musical note that can be produced by it. Different multimedia components were used from 3D and 2D assets, animations, music, and voiceovers depending on the artefact itself and what we concluded was missing from the users learning adventure at the museum. Below is a sample of the secondary items and their AR scenes.

Figure 25 The Kiswa before and after the translation

Figure 26 The mosaic floor before and after its reconstruction

Figure 16 The different types of harps and their 3D model

The final phase was to develop the mobile App itself and create a more engaging UI/UX design, including the onboarding screens, registration screens, a treasure map list, and a hint screen that describes the intended artefact to look for and its location at the museum, along with the winning screens. For a more inclusive experience, both text and voice-based annotations were added to all the scavenger hunt items in both Arabic and English.

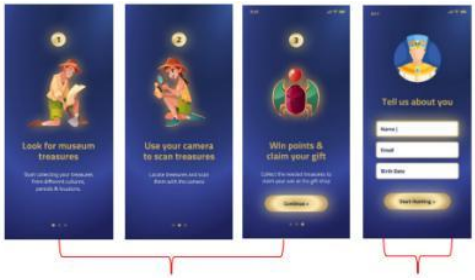


Figure 17 AUGI onboarding screens Registration screen

Figure 18 A selection of AUGI Prototype screens.

Findings:

In the Augi case study, informal feedback from children, museum visitors, and administrators showed encouraging early reactions to the application. Children demonstrated a high level of curiosity, frequently approaching the researchers and asking if the experience was a game, which suggested that the gamified elements and interactive design were immediately engaging to younger audiences. Museum administrators expressed enthusiasm for the project's potential, noting its ability to attract and hold visitor attention. Several adult visitors highlighted the primary section on the Kiswa and the Sabil, explaining that they had not previously understood or visualized these cultural elements. They reported that the app provided clarity and enriched their understanding of these artifacts. As it as it contextualizes the mock-ups and brings them back to their original state. While these observations were not collected through formal or measurable evaluation methods, they offer preliminary qualitative indications of the CHx framework's capacity to foster curiosity, engagement, and cultural understanding within a museum context. The whole experience video can be accessed here. For future work, more museum halls will be added along with more artefacts, for a more significant gamified experience.

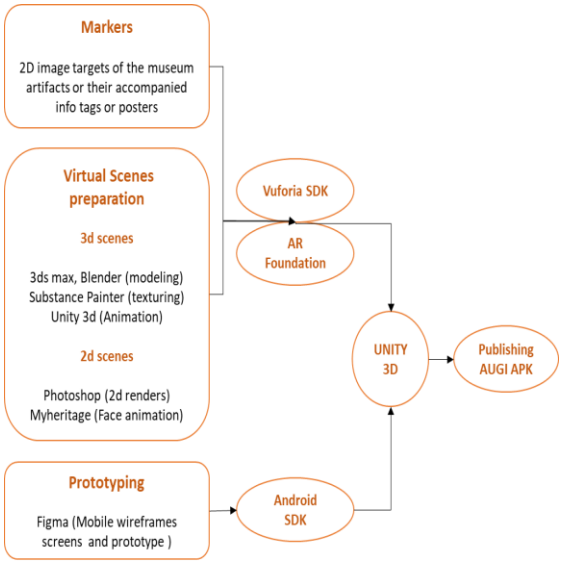


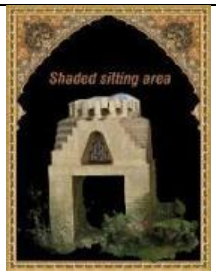
Figure 19 AUGI's Architecture

Conclusion and Future Work:

The CHx framework, developed through this research, enhances cultural heritage experiences by integrating technological solutions, interactive media, and human-responsive experiences using different sub-components like gamification, immersive storytelling, and multisensory interactions. It integrates UDL principles as well, developing a UDL-CH hybrid model that personalizes CH experiences for a broader audience. This model ensures engagement through gamification, multiple representations of content through AR/VR and multimodal interfaces, and diverse interaction methods, including touch, audio, and adaptive navigation tools.

The experimental applications ranging from AR-based museum storytelling to gamified scavenger hunts demonstrated that multisensory design and interactivity can enhance engagement, understanding, and accessibility in CH contexts. These findings affirm the potential of the CHx framework as a dynamic and adaptable toolkit for CH learning, making cultural sites, museums, and digital archives more inclusive and immersive.

For Future work, C[AR]ds™ represent an opportunity to take the CHx framework beyond the walls of the museum. Conceived in this research as a conceptual design, C[AR]ds™ apply many of the framework's features with a focus on olfactory and haptic sensory engagement. The project envisions multisensory AR cards that reveal virtual scenes upon scanning, capable of embedding any CH data within and beyond the Egyptian context. Initially developed as a CH preservation tool, C[AR]ds™ began by creating 3D photogrammetry models of architectural details from Bayt al-Suhaymi, hosted on Sketchfab for open access and reuse. Annotated versions of these models were then used to produce an educational prototype card. In the future, C[AR]ds™ could evolve into a tactile, educational game platform adaptable by any SLAM institution worldwide, fostering a global network for sharing and engaging with CH in an accessible, playful, and multisensory way.

Photogrammetry model of Bayt Al-Suhaymi architectural elements				
Architectural element	Mashrabya	Shading Structure	3d models were then annotated and used to create an Educational C[AR]d™ as a prototype.	

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