

Acre's Legacy: Gamified Outdoor Augmented Reality for Cultural Heritage Engagement

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Abstract

The paper presents Acre's Legacy – Memory Revival, a mobile Android augmented reality (AR) application designed to enhance visitor engagement with outdoor heritage sites in Acre (Akko), Israel, a UNESCO World Heritage city. The system combines GPS-based navigation, Vuforia model-target AR animations, multilingual audio-text narration, and a tiered badge-and-quiz gamification system. We conducted a two-phase evaluation: Phase A expert consultation with a licensed heritage guide, and Phase B heuristic evaluation with 18 expert participants across three knowledge and experience profiles. Participants completed an average of 3.22 out of 4 badges (80.6%), exceeding our 80% engagement target. Inductive thematic coding of open-ended responses identified nine recurring themes. A counter-intuitive finding was that AR-experienced evaluators preferred the non-AR cinematic mode at higher rates than AR-naïve evaluators, driven by quality expectations rather than interaction difficulty. Key contributions include an offline-first deployment architecture validated in a stone-walled historical urban context, a dual-expertise evaluation design, and eight evidence-based design recommendations for outdoor heritage AR systems.

Keywords

cultural heritage, outdoor AR, gamification, location-based services, heuristic evaluation

1. Introduction

The city of Acre (Akko) in northern Israel is one of the most historically layered urban environments in the world, shaped by Canaanite, Crusader, Mamluk, and Ottoman civilizations and designated a UNESCO World Heritage Site in 2001 [13]. Despite this recognition, heritage interpretation relies primarily on static signage and guided tours – methods that fail to engage visitors emotionally, particularly in outdoor environments where attention is fragmented [2]. Landmarks such as the Tower of Flies and Khan al-Hammer receive fewer visitors than prominent attractions partly because no interactive mechanism draws attention to their historical significance.

Augmented Reality (AR) has emerged as a promising technology for bridging this gap, enabling what researchers call “presence in the past” [1, 2, 11, 3] by overlaying digital content directly onto physical environments. Prior work demonstrates AR effectiveness in indoor heritage settings [2, 11, 14], but outdoor, location-aware systems addressing underrepresented sites remain rare.

Acre's Legacy – Memory Revival addresses this gap through three distinguishing design decisions: (1) targeting lesser-known, visually recognized but historically obscure sites; (2) offering a non-AR cinematic fallback mode; and (3) coupling exploration with knowledge acquisition through a tiered badge-and-quiz system.

This paper contributes: (i) an implemented outdoor heritage AR system with documented architectural decisions for real-world deployment; (ii) a two-phase evaluation yielding nine inductively coded themes; (iii) a counter-intuitive finding on AR mode preference by expertise group; and (iv) eight design recommendations grounded in the full thematic dataset.

Workshop on Advanced Visual Interfaces for Cultural Heritage (AVICH 2026), June 08, 2026, co-located with the 18th International Conference on Advanced Visual Interfaces, Venice, Italy.

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2. Related work

2.1. AR in Cultural Heritage: From Laboratories to Urban Sites

The application of AR to cultural heritage has a history spanning more than two decades. Early landmark systems such as ARCHEOGUIDE [15] demonstrated AR overlay of reconstructed 3D content onto archaeological sites [8]. However, both ARCHEOGUIDE and the LIFEPLUS project [1] required specialized wearable hardware and controlled environments – conditions far removed from the variable realities of a living heritage city like Acre. The proliferation of smartphones transformed outdoor heritage AR into a broadly deployable medium [2, 16]. Our system adopts a hybrid approach, using GPS for map navigation and Vuforia model-target detection for precise AR activation at each site.

A recurring finding across outdoor heritage AR studies is that the physical and cognitive demands of the AR interface can undermine the immersive experience the system is designed to provide [8, 9, 7]. This AR interaction cost emerged as the most frequently cited theme in our evaluation (T1, 50% of participants), validating it as a primary design constraint in outdoor heritage AR contexts.

2.2. Narrative and Storytelling in Immersive Heritage Systems

Narrative is increasingly recognized as the organizing principle transforming historical facts into emotionally resonant heritage experience. Falk and Dierking’s contextual model of museum learning [4] identifies personal context as the primary mediator of heritage engagement. AR provides a uniquely powerful vehicle for heritage storytelling by delivering narrative at the precise physical location where events unfolded – what Gruber et al. [5] term “spatial anchoring of memory.” Katifori et al. [7] found that narrative coherence was a stronger predictor of satisfaction than visual fidelity. Our evaluation results support this: content depth (T6, 61%) was the second most frequently discussed satisfaction theme.

2.3. Gamification in Heritage and Educational AR

Hamari et al.’s meta-analysis [6] of 24 empirical gamification studies found that badge and achievement systems consistently increase task completion and time-on-task. Casillo et al. [1] demonstrated that gamified scavenger-hunt mechanics encourage visitors to explore sites they would otherwise ignore, with visitors using the gamified guide visiting 40% more locations than those using a conventional audio guide. Lacher et al. [9] showed that quiz-gated progression improves knowledge retention compared to free exploration. Our evaluation confirmed this design intent: gamification and quiz quality (T4, 44% of participants) was explicitly credited as the mechanism motivating closer attention to narration content.

2.4. Location-Based Mobile AR and Hybrid Triggering Architectures

While consumer GPS accuracy on modern smartphones is approximately 3–5 meters under favorable conditions, urban canyon effects in densely built historical districts can degrade accuracy to 10–20 meters [8]. Our hybrid architecture uses GPS for map display and proximity awareness, while Vuforia model-target recognition governs AR activation at each landmark – particularly suited to heritage sites where traditional 2D markers cannot be affixed [16].

3. System Design

3.1. Site Selection and Content

Two consultative sessions with a licensed Acre heritage guide drove site selection and content validation before evaluation. The guide recommended prioritizing visually recognized but historically obscure sites: Tower of Flies (Burj al-Dhubbab), originally built by the Phoenicians and later expanded by the Crusaders as a fortified lighthouse; Khan al-Hammer, an Ottoman ammunition depot destroyed in

the 1840 British-Austrian-Ottoman bombardment; and Acre's Eastern Wall Cannons, site of the 1799 Napoleonic siege. Session 2 identified and corrected a quiz error attributing the Tower's construction to the Crusaders, with the correct Phoenician/Canaanite origin absent from the answer choices.

3.2. Application Workflow and Architecture

On launch, users select a narration language (English, Hebrew, or Arabic) and create or load a profile. An interactive GPS-tracked map displays site markers; tapping a marker opens an animation scene that defaults to AR mode via Vuforia model-target detection with synchronized audio-text narration. A toggle switches to non-AR cinematic mode. After viewing, a quiz of five timed questions (30 s, four options) unlocks a silver badge; animation viewing alone awards bronze; completing all three sites awards a gold badge.

The system follows a three-layer architecture: Presentation (UI, map, AR/non-AR rendering, quiz, badge display), Application (scene management, AR control, GPS tracking, badge logic), and Database (local assets: audio, narration text, quiz banks, 3D model targets, map tiles). A critical architectural decision was migrating from a Firebase backend to a fully local-storage model: persistent internet instability in Acre's stone-walled old city caused unreliable content retrieval. All assets are cached on-device at install time. A second decision relaxed the GPS proximity gate, as GPS accuracy degradation in the dense urban fabric could deny access to users physically at a site. Technologies: Unity 6 (v6.000.42f1), Vuforia Engine 11.4.3, ARCore, Android SDK min. API 29.

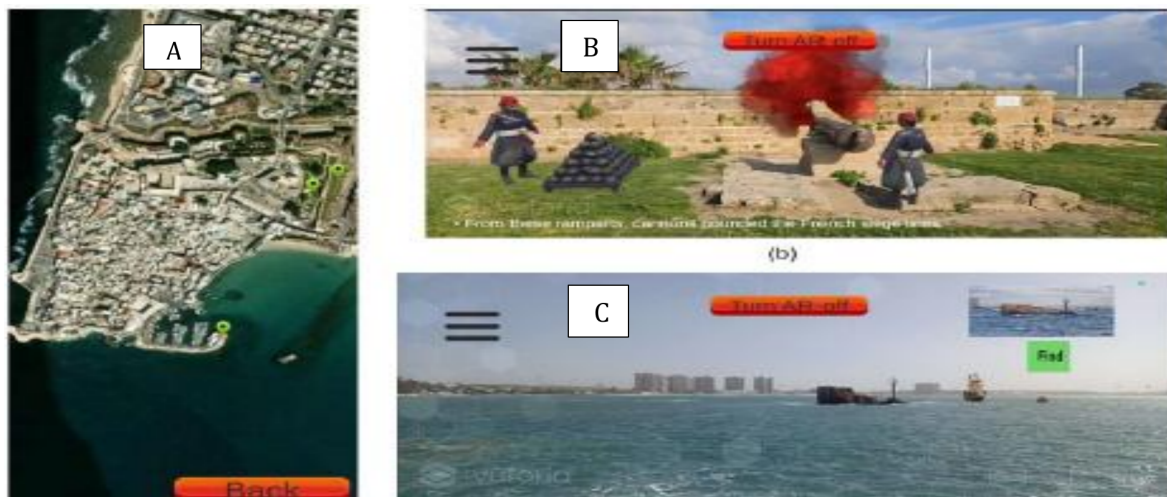


Figure 1: AR Legacy selected screens. A: Interactive map. B: Khan Al Hamir. C: Tower of flies.

4. Evaluation

We recruited 18 participants (ages 22–61, $M \approx 35.2$) for the heuristic evaluation. All qualify as expert evaluators through direct, first-hand familiarity with Acre's old city, satisfying Nielsen's domain-expertise requirement [5]. The panel varied along two dimensions: History-Expert ($n = 7$, deep knowledge of Acre's history) vs. History-Moderate/Little ($n = 11$, general site familiarity); and AR-Experienced ($n = 7$, prior AR application use) vs. AR-None/Basic ($n = 11$, a first-use perspective). Each participant explored all three sites on a provided Android device and completed an open-ended heuristic questionnaire without usage assistance. Responses were inductively coded and clustered into recurring themes with frequency counts.

4.1. Badge completion

Participants completed an average of 3.22 out of 4 badges (SD = 0.88), a completion rate of 80.6%, meeting the pre-defined target. Nine participants completed all 4 badges. The AR-experience subgroup showed the largest completion gap (3.71 vs. 2.91), a pattern consistent with interface familiarity reducing cognitive overhead and allowing experienced users to focus on task completion rather than on navigating the interaction model itself. An age-related gap was also observed (3.40 for ages 22–30 vs. 2.88 for ages 31–61); four of the five lowest-completing participants were over 55, suggesting that age-related factors such as reduced comfort with mobile interfaces or lower tolerance for technical friction may compound the completion challenge, particularly at sites with higher AR detection demands.

4.2. Preferred mode

Overall, 55.6% of participants preferred non-AR (cinematic) mode over AR mode. Counter-intuitively, AR-experienced evaluators preferred non-AR at a slightly higher rate (57%) than AR-naïve evaluators (55%), though the difference was narrow. The reasoning behind these preferences diverged meaningfully between the two sub-groups. Experienced evaluators attributed their preference to the superior visual quality and narrative flow of the cinematic animations, suggesting that once the novelty of AR wears off, production quality becomes the dominant criterion. AR-naïve evaluators, by contrast, cited novelty and a heightened sense of physical presence as motivating factors for preferring AR mode, indicating that the immersive framing still carries persuasive weight for first-time users. This divergence implies that the two modes may serve different audience profiles, and that retaining both options within the application is justified rather than redundant.

4.3. Thematic analysis

The most-cited technical barrier was AR detection sensitivity (T1, 50%), driven primarily by the offshore position of the Tower of Flies, where unstable target acquisition repeatedly interrupted the experience. The map and navigation component emerged as the highest-satisfaction element across the evaluation (T2, 72%), with the offline GPS capability independently praised by multiple participants as critical for a heritage site where network connectivity cannot be assumed. Historical content depth (T6) and site expansion desire (T8) each reached 61%, reflecting strong user engagement and an appetite for richer or broader experiences beyond the three sites covered in the current version. The language mismatch issue (T9), in which a participant who selected Arabic narration encountered English-language quiz questions, measurably suppressed badge completion for that user and constitutes a design failure specific to multilingual audiences. This inconsistency breaks the localization contract implied by language selection and risks alienating precisely the segment of the local population the application aims to serve (see Table 1).

Taken together, the nine themes reveal two orthogonal concern classes that align with evaluator expertise. Interface-focused themes (T1, T3, T5) were dominated by AR-Experienced evaluators, while content-focused themes (T6, T7, T8) were dominated by History Experts. T7 illustrates this divide most sharply: the ship-scale inaccuracy in the Tower of Flies animation was raised exclusively by History Expert evaluators, invisible to both AR-Experienced and History-Moderate/Little participants. T8's 61% expansion request rate serves as a behavioral proxy for genuine engagement, with History Experts leading at 71%. T9 surfaced a design failure specific to multilingual audiences: language mismatch between narration and quiz suppressed badge completion among Arabic-speaking participants and constitutes the highest-equity-impact finding in the dataset.

5. Discussion

The 80.6% badge completion rate demonstrates that tiered gamification successfully motivated full engagement even in an expert panel. The AR/non-AR preference inversion – experienced users preferring

Table 1
Main inductive coding themes

ID	Theme	Freq	Valence	Quote
T1	AR Detection Sensitivity	9/18 (50%)	Barrier	"I had to keep the camera pointed at the landmark even though I already scanned it and it was verified."
T2	Interactive Map & Navigation	13/18 (72%)	Positive	"What helped the most was that the app relies on GPS, not on an internet connection which was really helpful because not all places have a good internet connection."
T3	Audio-Text Synchronisation	5/18 (28%)	Mixed	"The voice sound and the subtitles aren't synchronized."
T4	Gamification & Quiz Quality	8/18 (44%)	Positive	"The quiz element addition makes it way more engaging to the user, which made me want to focus more on the info."
T5	UI & Menu Usability	6/18 (33%)	Barrier	"The exit button can be mistaken for a button that quits the app."
T6	Historical Content Depth	11/18 (61%)	Mixed (expert gap)	"The information presented were basic, more info about each site could have been added."
T7	Historical Accuracy Concerns	2/18 (11%)	Barrier	"In the Tower of Flies animation, the ship looked way too big compared to the islet, which is not really realistic."
T8	Desire for Site Expansion	11/18 (61%)	Positive	"With the addition of extra places to discover, this would be a great app for travellers when they arrive."
T9	Language & Accessibility Barriers	3/18 (17%)	Barrier	"It is very difficult to watch a video in one language (such as Arabic) and then answer the questions in English."

cinematic mode more than novices – points to a quality-expectation gap rather than interaction difficulty alone. Addressing requires both engineering improvements (LiDAR-assisted detection, ARCore world-locking, fire-and-forget audio trigger) and higher-fidelity AR animation production.

Eight design recommendations emerge from the thematic dataset: (R1) bind quiz language to the selected narration language (T9); (R2) decouple audio playback from continuous AR detection to eliminate the steady-hold burden (T1); (R3) add color-coded map completion indicators per Nielsen's visibility heuristic (T2, T5); (R4) implement timestamp-locked subtitle synchronization (T3); (R5) enforce minimum 44 × 44 pt button targets and 14 sp body text for accessibility (T5); (R6) rename the exit button and add a quit-confirmation dialog (T5); (R7) resize the Tower of Flies ship model to historically proportionate scale (T7); (R8) add an optional deep-dive content layer via long-press for expert audiences (T6).

6. Conclusions

Acre's Legacy demonstrates that a carefully designed outdoor AR system combining GPS navigation, model-target AR animation, tiered gamification, and trilingual narration can achieve meaningful engagement with UNESCO heritage sites. The first offline architecture, validated in a challenging stone-walled urban environment, offers transferable guidance for heritage AR practitioners. The dual-expertise evaluation design – recruiting both history experts and AR-experienced evaluators – surfaces orthogonal usability issue classes essential for comprehensive heuristic evaluation of heritage AR. Future work will address LiDAR-assisted detection at offshore landmarks, longitudinal knowledge-retention assessment, and expansion to additional Acre heritage sites, as requested by 61% of evaluators.

Declaration on Generative AI

During the preparation of this work, the authors used Claude.ai to: Grammar and spelling check. Claude (Anthropic) assisted in manuscript structure, literature synthesis, and technical descriptions. After using these tools and services, the authors reviewed and edited the content as needed and take full responsibility for the publication's content. All research design, data collection, analysis, and interpretation remain the authors' original contributions.

Acknowledgments

We would like to thank Abed Ammar for his contribution to the development of the application.

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