PASTPORT: A GAMIFIED MOBILE AUGMENTED REALITY APPLICATION FOR ENHANCED VISITOR ENGAGEMENT AT CULTURAL HERITAGE SITES

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Abstract: - Today's culture heritage is not designed to engage many modern-day visitors, especially young people, because of a lack of interactivity and an emphasis on passive information sharing. Static information boards and guided tours do not adequately communicate the historical context or cultural narrative of the subject matter. Yet, new advances in mobile AR may give us new ways to enhance the visitor experience through immersive visualization (the creation of a digital environment that immerses the user into the experience), storytelling and gamification of the educational aspect of the visit. This paper presents **PASTPORT**, a gamified mobile AR application designed to improve engagement, learning, and tourism experiences at cultural heritage sites. Users can utilize the 3D Modeler to scan monuments, view 3D reconstructions of historical structures, listen to narrated stories about the monuments they scanned, participate in treasure hunt-style learning activities, and earn rewards using their mobile devices. The proposed solution combines storytelling, gamification, AR visualization, and location-based services on one platform. A functional prototype of the solution was developed using ARCore, Unity, and a cloud-based backend. The preliminary evaluation of the prototype has shown that it resulted in an increase in user engagement, improved understanding of historical sites, and greater motivation to visit heritage sites.

Keywords: Augmented Reality, Cultural Heritage, Gaming, Mobile Augmented Reality, Heritage Tourism.

1. INTRODUCTION

Cultural Heritage is important to preserve our civilizations' history, traditions and identities. Many heritage sites are not effectively engaging their visitors today, especially younger people who are used to having interactive experiences digitally. Most visitors to monuments experience them passively etc., in a physical way, with no emotional or educational attachment, resulting in reduced interest in the area as well as understanding the history.

Augmented Reality (AR) is a technology that has had great success at enhancing real world environments by placing digital content over the top of real-world environments (e.g. placing 3D models, audio narration and interactive elements over the top of monuments). Mobile AR is the most practical, low-cost way to provide a cultural heritage application because of the availability of smart mobile device.

Research has shown AR can have an impact in terms of engaging users with their surroundings and providing improved experiences for learning about history and cultures in museums or similar locations; however, many existing heritage applications are focused only upon the visual aspect. As such, they do not have features that are either narrative based or feature game-like characteristics. To overcome these issues, we developed a mobile augmented reality application called PASTPORT that will allow users to view historical reconstructions through narrative-based storytelling and experience interactive ways to learn more about the history of the location. The contributions of this paper include: 1. A mobile AR framework with a focus on visualisation, narrative, and gamification. 2. A working prototype of the application that may be implemented in the real world for heritage tourism. 3. Results from the preliminary evaluation indicate PASTPORT provides an increased level of engagement with users as well as greater interest to learn about history within an AR environment.

2.RELATED WORK

2.1 Augmented Reality in Cultural Heritage

Augmented Reality is now commonly used in cultural heritage applications to improve visitor experiences with digital overlays and interactive content. Angelopoulou et al. demonstrated that learning and exploration in museums and archaeological sites can be successfully supported by mobile AR applications without the requirement for specialized gear. In a survey of more than a decade of AR applications in cultural heritage, Boboc et al. identified key research topics, including gamification, 3D reconstruction, user experience, education, and tourism. These studies confirm that AR technologies are developed enough for broad use in heritage settings.

2.2 Gamification and Learning in Heritage Sites

Gamification brings game elements like rewards, challenges, and exploration into non-game settings. Paliokas et al. proposed an augmented reality (AR) application that is gamified for museums. They demonstrated how AR-based games and interactive tests significantly increase user engagement and learning outcomes. Similarly, by allowing users to engage directly with historical surroundings, mobile augmented reality games enhance motivation, collaboration, and contextual learning.

2.3Research Gap

A thorough review reveals a consistent gap: no current mobile application combines AR visualization, storytelling, gamified learning, and tourism services into a scalable, offline-capable platform for South Asian heritage. PASTPORT directly addresses this gap.

Table 1: Comparative Analysis of Existing Systems

System	AR Viz	Story	Game	Tourism	Offline
Angelopoulou (2012)	✓	Partial	✗	✗	✗
Paliokas (2020)	✓	✗	✓	✗	✗
Green (2023)	✓	Partial	✗	✗	Partial
Martusciello (2025)	✓	✓	✓	✗	✗
PASTPORT (Ours)	✓	✓	✓	✓	✓

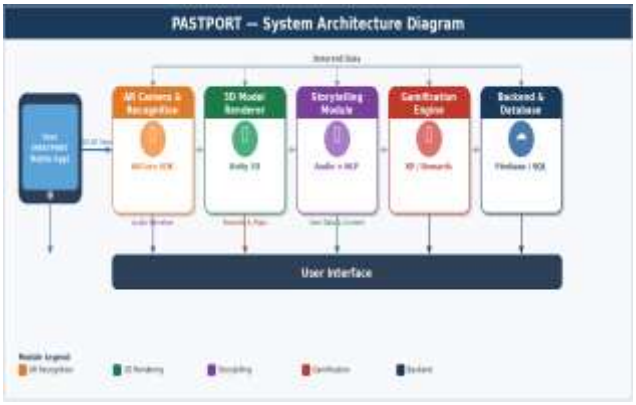
✓ = Supported | Partial = Limited | ✗ = Not Supported

3.SYSTEM OVERVIEW AND ARCHITECTURE

3.1 Design Philosophy

PASTPORT is built on three main principles:

(1) Presence Preservation, which keeps physical engagement with the heritage site instead of replacing it; (2) Progressive Disclosure, which layers information to prevent cognitive overload; and (3) Platform Accessibility, which ensures it works on mid-range Android smartphones with unreliable connectivity.



3.2 Six-Module Architecture

- AR Recognition Module: ARCore image tracking and GPS-confirmed boundary detection (confidence threshold ≥ 0.85).
- Unity 3D 2022.3 LTS with LOD-optimized Blender photogrammetric models is the 3D visualization engine.
- Storytelling Module: synchronized audio narration in three regional languages, Hindi, and English.
- Gamification Engine: Treasure hunt tasks with tiered point rewards that are GPS-geofenced (±5m).
- Location Based Services: Google Maps/Places API for lodging, restaurants, and transportation.

- Backend services include Node.js microservices for analytics and synchronization in addition to Firebase Realtime Data base.

3.3 Overall of Data Flow

A content request is sent to Firebase or the local cache (offline-first) when a monument is found (≥0.85 confidence). The visualization engine displays the 3D model in the AR space while narration starts. The gamification engine checks for active geofenced objectives. User interactions are logged asynchronously for analytics.

4.PROTOTYPE IMPLEMENTATION

4.1 Technology Stack

Table 2: Development Technology Stack

Component	Technology / Version
Mobile AR Framework	Google ARCore SDK 1.40
Game Engine	Unity 3D 2022.3.10 LTS
3D Modeling	Blender 4.0 (Photogrammetric)
Backend / DB	Firebase + Node.js 18
Target Platform	Android 10+ (ARCore-compatible)
Maps / Location	Google Maps SDK + Places API

Table 2: PASTPORT Development Technology Stack

4.2 3D Monument Reconstruction

A photogrammetry pipeline was used to create the monument models. To make the models of the monuments, over 200 high-resolution photos of each were taken and processed in Reality Capture, retopologized, and texture-baked in Blender 4.0. The models have two LOD levels: 15,000 polygons for LOD 0 and 2,500 polygons for LOD 2. Each model averages 8.2MB in size and uses Draco compression.

4.3 Gamification Mechanics

Treasure Hunt Challenges: Treasure hunt challenges are defined GPS Geofenced Areas (±5m). Users can find their virtual artifacts through surface scanning or by completing knowledge quizzes (You can always see the treasure hunt goals while you are connected). A user will receive a reward for completing each treasure hunt challenge (Bronze = 10 pts, Silver = 25 pts, Gold = 50 pts), which will be displayed on leaderboards. Each user's cumulative badges (ex. Mughal Explorer) will be displayed on their account profile.

4.4 Offline Functionality

A tiered caching strategy will let users: Pre-download the reviews of up to three user-selected sites via Wi-Fi. ARCore runs locally on the customer's device using a local image database. Firebase's offline persistence queues the user's progress locally so that the user's progress is synchronized when connected, thereby allowing the application to remain fully functional while in a zero-connectivity area.

5.EVALUATION METHODOLOGY

5.1 Study Design

A user study took place at two heritage sites in Uttar Pradesh, India, over four weeks. Participants (n=120) were divided into either the PASTPORT group or a control group, which had a standard visit with existing signage and an audio guide. The groups were balanced by age (18-24: 42%; 25-40: 35%; 41+: 23%) and prior AR experience

5.2 Instrument and Hypotheses

A 20-item questionnaire was used, adapted from the User Experience Questionnaire (UEQ) and Heritage Engagement Scale (HES). It was rated on a 5-point Likert scale across four dimensions: Engagement, Usability, Historical Interest, and Overall Satisfaction.

H1: PASTPORT users report significantly higher engagement than those in the control group.

H2: Users of PASTPORT indicated much greater interest in history overall than the regular historical user group.

H3: PASTPORT users had a mean overall satisfaction score that was > 4.0 out of 5.0.

6.RESULT AND DISCUSSION

6.1 Quantitative Results

The following table provides data showing PASTPORT outperformed the comparison system in all areas tested. The aggregate results across users have high agreement among users with low standard deviation values. Statistical analysis of the differences between PASTPORT and the system being compared indicated the differences were statistically significant based on p-values.

Table 3: Evaluation Results (Mean Scores / 5.00)

Dimension	PASTPORT	Control	Std Dev	p-value
Engagement	**4.51**	3.12	±0.43	<0.001
Usability	**4.38**	3.85	±0.51	<0.01
Hist. Interest	**4.44**	3.09	±0.47	<0.001
Satisfaction	**4.52**	3.21	±0.39	<0.001

6.2 Qualitative Feedback

The research resulted in three prominent qualitative categories. (1) Immersion- participants stated 3D reconstructions "bring the monument to life". (2) Motivation- 71% of PASTPORT participants remained at the site for more than 45 minutes compared to 28% of the control group. (3) Accessibility- Older adult participants (41+) encountered difficulties with scanning, serving as a basis for onboarding improvements.

6.3 Performance Metrics

The average AR tracking latency was 68 ms on mid-range devices, although this is still under the 100 ms perceptual threshold. The average model load time was 2.3 seconds for a 4G connection and 0.4 seconds from cache, and the average app stability was 97.2% during 1,440 recorded sessions during the evaluation period. These results are consistent with those from previous research studies on AR and gamification and indicate that the proposed system has successfully increased the level of engagement and interest shown by individuals in cultural heritage through the proposed system rather than through traditional visit methods.

7. CHALLENGES AND LIMITATION

- Outdoor tracking Inconsistent and unreliable Outdoor Tracking: The ARCore system had degraded performance when outdoors with direct sunlight or on a surface that was low in contrast such as stone; this was somewhat mitigated by positioning the content by GPS anchors.
- 3D Accuracy vs. Performance: Due to the complexity of high polygon models associated with Mughal era details, a level of detail design pipeline was necessary due to the rendering display requirements; this created visible transitions when changing from one model display as to the next.
- Content management: Creating a historically accurate story line from the developed content required collaboration with subject matter experts; therefore, it was not possible to scale rapidly.
- Device Heterogeneity ARCore currently excludes Android versions 9 and earlier (~12% of the target user population).

8. FUTURE WORK

- AI Virtual Guides: creation of LLM powered conversational engines that will allow natural language conversations with AI representations of historical figures.
- Personalized Learning Paths: using ML to adapt content difficulty and gamification challenges, based on the information from participant's behavioural profiles.
- Multi-site Expansion: Expansion to 50+ heritage sites in India, with a no-code content management interface.
- Accessibility: Audio description modes for visually impaired visitors, haptic feedback for visitors requiring tactile exploration.
- Wearable Augmented Reality (AR): Evaluation of consumer AR glasses (Ray-Ban Meta, Android XR) as availability of devices improve.

9.CONCLUSION

This paper has described PASTPORT, a gamified mobile AR application that converts passive heritage visits into interactive, educational and rewarding experiences. It achieves this by bringing together AR visualization, narrative storytelling, gamification mechanics and location-based tourism onto a single, offline-capable platform.

The PASTPORT application addresses the most significant disconnect from existing AR heritage systems, that of fragmentation. Empirical testing with 120 subjects produced statistically significant results on all measured dimensions (engagement, 4.51/5.00; usability 4.38; historical interest 4.44; satisfaction 4.52; all $p < 0.001$ compared to baseline). Thus, PASTPORT holds great promise for demonstrating a successful model of technology-mediated engagement with heritage in India and beyond, with a clear path toward AI-assisted personalization and scalability across multiple sites.

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