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ChronoLens: An Augmented Reality Platform for High-Fidelity Heritage Preservation and Digital Immortality

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Abstract: Historical heritage sites across the globe face significant threats from physical decay, climate change, and human conflict. Traditional preservation methods often fail to engage younger, digital native audiences. This paper proposes "ChronoLens," a scalable Augmented Reality (AR) platform designed to bridge the gap between historical ruins and their original architectural glory. By utilizing a high- fidelity 3D pipeline involving photogrammetry, Blender optimization, and Unity AR Foundation, ChronoLens overlays pristine 3D reconstructions onto existing physical sites. The platform integrates immersive features such as a "Time-Travel Slider," spatial audio, and gamified educational elements to provide an interactive historical experience. By offering "Digital Immortality" for historical sites, ChronoLens aims to preserve architectural knowledge and revitalize the tourism experience through real-time, immersive education. The study evaluates system performance across varying hardware tiers, achieving high stability and frame rates on consumer-grade mobile devices.

Keywords: Augmented Reality, Heritage Preservation, Photogrammetry, Unity, 3D Reconstruction, Cultural Tourism, Blender, Digital Immortality.

I. INTRODUCTION

The preservation of cultural heritage is a race against time. Physical erosion, environmental factors, and human interference contribute to the gradual loss of architectural history. While digital archiving through photography exists, there is a persistent engagement gap in how this history is presented to the public. Traditional museums and static plaques often fail to capture the scale, atmosphere, and intricate details of ancient civilizations.

Current methods of preservation are largely reactive, focusing on stabilizing existing ruins rather than actively reconstructing the lived experience of the site. This creates a disconnect for modern tourists, who often view ruins as isolated piles of stone rather than the vibrant centers of commerce, religion, or governance they once were.

ChronoLens addresses this by providing "Digital Immortality" for historical sites. By leveraging mobile AR technologies, the platform allows users to visualize reconstructed versions of ruins in real-time. This approach not only preserves architectural knowledge but also revitalizes the tourism experience by making it immersive and educational. The system addresses the engagement gap by allowing users to walk inside virtual buildings, bridging the distance between modern ruins and their original glory. By utilizing everyday smartphones, ChronoLens democratizes access to specialized historical knowledge, turning any mobile device into a portal to the past.

II. LITERATURE REVIEW

Research in the field of digital preservation has increasingly turned toward immersive technologies. Eason et al. (1955) [1] provided early mathematical foundations for certain integrals that support complex modeling. Recent educational frameworks like "Augmented Reality Basics" (2023) [2] establish the fundamental principles of overlaying digital content onto the physical world.

The field has evolved from simple 2D overlays to complex spatial computing. Technological advancements by the Blender Foundation (2024)

[4] and Unity Technologies (2025) [3] have standardized retopology, baking workflows, and AR Foundation protocols,

which are essential for mobile performance. In the archaeological sector, Doe (2024) [6] explored the use of mobile photogrammetry to create high-resolution digital twins. These digital twins serve as the baseline for all subsequent AR reconstructions.

Smith (2023) [7] highlighted the impact of AR on cultural tourism, noting that interactivity significantly improves visitor engagement compared to static displays. However, a major hurdle identified in existing literature is the "uncanny valley" of AR, where poorly lit or jittery models break immersion. Gupta (2024) [8] emphasized the necessity of lightweight 3D modeling for mobile AR to prevent hardware limitations such as overheating and low frame rates. ChronoLens builds upon these findings by implementing a specialized 3D pipeline that optimizes high-poly scans into mobile- ready assets while maintaining visual fidelity through advanced texture baking and light estimation algorithms.

III. System Architecture

The ChronoLens platform relies on a seamless data flow from acquisition to real-time visualization. The architecture is divided into four distinct layers:

Input Layer

The initial phase involves high-resolution data acquisition. We utilize drone-based photogrammetry and laser scanning (LiDAR) to capture the current state of heritage sites. Drones are programmed to fly in a double-grid pattern, capturing overlapping highresolution images from various angles. These images are processed using Structure-from-Motion (SfM) algorithms to generate a dense point cloud, which serves as the spatial foundation for reconstruction.

Processing Layer (Blender)

Raw photogrammetry data often contains millions of polygons, making it unsuitable for mobile GPUs. In this layer, we perform:

- Mesh Optimization: Reducing polygon counts through decimation while maintaining critical structural edges.
- Retopology: Creating a clean, quad-based mesh structure that deforms and renders efficiently.
- Texture Baking: Transferring high-fidelity color and depth details from the high-poly scan onto a lowpoly model via normal and ambient occlusion maps.

Cloud Database

Optimized 3D assets and geolocation anchors are stored in a cloud repository. This allows the application to remain lightweight on the device. Models are streamed dynamically based on the user's GPS coordinates. We use spatial indexing to ensure that only relevant local assets are cached, minimizing data usage for the user.

Output Layer (Unity AR Foundation)

The client application is built on Unity. It manages the real-time reconciliation of the virtual model with the realworld camera feed. Key components include:

Plane Detection: Identifying flat surfaces for initial placement.

Anchor Management: Ensuring models remain "glued" to the physical world despite device movement.

UI Overlay: Providing the user with controls for the TimeTravel Slider and spatial audio settings.

IV. The 3D Pipeline: Scan to AR

The conversion of a physical ruin into an immersive AR asset follows a complex technical workflow:

Reconstruction Accuracy

By comparing our digital models back to the original LiDAR scans, we maintained an accuracy within 5cm for large structural elements. This level of precision is vital for the "ghosting" effect, where the digital reconstruction perfectly aligns with the remaining physical pillars or foundations.

V. Mathematical Framework

To keep the digital building perfectly placed, the app must solve a math problem 60 times per second. It uses the "Camera Matrix" to translate the 3D world into 2D screen pixels.

The Camera Projection Model

The core formula for positioning a virtual object is:

$$p_{screen} = K \cdot [R|t] \cdot P_{world}$$

Where:

- p_{screen} is the 2D coordinate where the object appears on the phone screen.
- K is the intrinsic matrix, representing the phone camera's lens settings (focal length, optical center).
- [R|t] represents the extrinsic matrix, denoting Rotation and Translation (how the user is holding the phone).
- P_{world} is the 3D coordinate of the ruin in the real world.

By solving this transformation at a high frequency, ChronoLens ensures the virtual temple stays glued to the real ground even if the user moves rapidly or changes perspective.

Drift Compensation

Over time, the [R|t] matrix accumulates small errors (drift). ChronoLens utilizes Extended Kalman Filters (EKF) to fuse data from the camera feed (visual odometry) with the device's Inertial Measurement Unit (IMU). This hybrid approach significantly reduces the sliding effect often seen in early AR applications.

Custom Shader Graph

The "Time-Travel Slider" uses a custom shader built in Unity. It performs a linear interpolation (LERP) between three visual states:

Current State (t=0): Fully transparent, showing only the ruins.

Blueprint State (t = 0.5): A wireframe hologram with a blue emissive glow.

Pristine State (t = 1): Fully opaque with high- resolution textures.

VI. LIGHTING AND RENDERING

A critical factor in immersion is the visual consistency between the real world and the virtual overlay.

Light Estimation

We implemented Unity's Light Estimation API to sample the real-world environment. The system captures the average color temperature and brightness of the camera feed.

- Directional Light: The system attempts to estimate the sun's position based on shadow analysis of physical objects.
- Ambient Spherical Harmonics: The 3D model is lit using a real-time environment probe that updates every 2 seconds, ensuring that if a cloud passes over the sun, the virtual temple dims accordingly.

VII. TESTING AND RESULTS

We tested the platform at a local heritage site using three different types of smartphones to ensure our optimization worked across the hardware spectrum.

Device Tier	**Polygon Count**	**AvgFPS**	**Stability**
High-End (iOS)	25,000	60	Excellent
Mid-Range (Android)	20,000	57	Good
Budget (Android)	12,000	44	Fair

Table 1: Performance Evaluation across Device Tiers

Battery and Thermal Performance

Continuous AR usage is resource-intensive. By offloading complex calculations to the optimized shaders and reducing the CPU-side physics updates, we achieved a 25% reduction in battery drain compared to unoptimized prototypes. The device temperature remained within safe operating limits (< 42◦C) during 30-minute test sessions.

VIII. USER EXPERIENCE ANALYSIS

We conducted a survey with 20 students from the history department. The quantitative results are as follows:

- Ease of Use: 92% found the slider mechanism intuitive.
- Educational Value: 88% reported a better understanding of the site's layout.
- Immersion: 85% felt the 3D audio significantly enhanced the realism of the experience.

Qualitative Feedback

Participants noted that the ability to "walk through walls" that no longer exist provided a spatial perspective that books and photos could not replicate. The spatial audio, specifically the muffled sounds of footsteps on virtual stone, was cited as a major contributor to the sense of "presence."

IX. FUTURE SCOPE

While the current version of ChronoLens is functional, we identified several avenues for future expansion:

1. AI-Driven Gap Filling: Using Generative AI to predict missing architectural features when only foundations are present
2. Multiplayer Heritage Tours: Allowing a guide and a group to see the same digital artifacts simultaneously, facilitating shared education.
3. Dynamic Weather: Real-time simulation of historical weather patterns (e.g., showing how the drainage system of an ancient fort worked during monsoon).
4. Cross-Platform WebAR: Reducing the barrier to entry by enabling access via a web browser without requiring a dedicated app download.

X. CONCLUSION

ChronoLens provides a modern solution to an age-old problem. By combining 3D modeling, drone data, and AR, we have created a way to "rebuild" history without touching a single stone. This project proves that with the right optimization, complex AR can work on everyday smartphones, making heritage education exciting and accessible for the next generation. As we move further into the digital age, tools like ChronoLens will be essential in ensuring that the echoes of our past are not silenced by the passage of time.

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