

Immersive Augmented Reality Automotive Showroom With Real-Time Consumer Behavioral Analytics

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Abstract- *The automobile retail industry is in a critical phase re-garding the “usability gap” in its digital transformation. Mobile applications—while essential for modern business—suffer significantly from “Information Architecture” flaws, where the user is faced with an overwhelming array of complex text-based specifications. This “content overload” inhibits the process of decision-making for high-involvement purchases like vehicles. In addition, although digital platforms excel at transactions, they tend to fail in replicating the personal engagement of a physical showroom.*

To overcome these limitations, this project proposes the concept of an “Immersive Augmented Reality Automotive Showroom.” The idea centers on utilizing Augmented Reality (AR) to replace static 2D catalogs with interactive 3D digital twins, offering users the ability to personally view and customize vehicles in their physical environment. Most importantly, it includes a Real-Time Behavioral Analytics Module. Recognizing “Perceived Personalization” as a strong predictor of customer retention, the module measures user interaction metrics—such as dwell time and color preference—to initiate intelligent, rule-based recommendations. Furthermore, advancements in vision-based tracking confirm the technical viability of markerless AR for stable product visualization. The project aligns with future research directions, combining immersive visualization with data-driven business intelligence to create a next-generation retail ecosystem.

Keywords: Augmented Reality (AR), Consumer Behavioral Analytics, Mobile Usability, Information Architecture, AI-Powered Personalization, Digital Twins, Smart Retail, SLAM.

I. INTRODUCTION

A. The Shift to Experiential Retail

The automotive retail landscape is undergoing a paradigm shift from traditional brick-and-mortar dealerships to digital-first engagement models. In the increasingly dynamic environment of digital trade, the convergence of technology and retail operations is reshaping consumer expectations. Mohammadi et al. [3] characterize this evolution

as a complex “Innovation Ecosystem,” where patent trends reveal a distinct migration towards “Retail Communication” and “Core Retail Operations.”

This shift is not merely technological but social. As noted by Sung [7], AR advertising has triggered a phenomenon of “Viral Marketing via Shared Social Experience,” where users actively promote brands by sharing their custom AR interactions. However, while digital platforms have optimized the *transactional* aspect of buying a car, they have largely failed to replicate the *experiential* aspect—the ability to inspect, walk around, and gauge the physical presence of the vehicle.

B. The Usability Gap and Cognitive Load

Current mobile solutions predominantly rely on static 2D imagery and text-heavy specification lists (e.g., dimensions, trim levels). This creates a significant “Cognitive Load” burden, forcing users to mentally reconstruct the vehicle’s physical presence from abstract data. Weichbroth [1] provides empirical evidence of this failure, noting that **27.36%** of usability issues in mobile applications stem from poor “Information Architecture” and navigation difficulties. The study explicitly identifies “Content Overload” as a primary barrier, where complex interfaces inhibit the decision-making process for high-involvement purchases.

Furthermore, Nama [8] highlights that while AI-powered apps are revolutionizing user interaction through context-aware services, these intelligent features are rarely integrated effectively with visualization tools in the automotive sector. This project aims to bridge that gap.

C. Proposed Solution: The Intelligent AR Ecosystem

To address these challenges, this project proposes the “Immersive Augmented Reality Automotive Showroom,” a dual-purpose ecosystem designed to serve both the Consumer and the Dealer.

- **For the Consumer (Visualization):** The application utilizes markerless AR (SLAM) to project 1:1 scale digital twins of vehicles into the real world.
- **For the Dealer (Intelligence):** The system addresses the “Data Blind Spot” of digital sales. Drawing on the findings of Panya et al. [2], the system integrates a Real-Time Behavioral Analytics Module.

By tracking granular metrics—such as gaze duration on specific car parts—the system triggers intelligent, rule-based recommendations. This effectively transforms the mobile device from a passive catalog into an active, context-aware sales agent that understands and reacts to user interest in real-time.

II. CORE THEME

The central topic of this project is “**The Transition from Passive Visualization to Intelligent Engagement.**”

- **Passive Visualization:** Traditional applications act as digital brochures. They display static images and text. The user observes the content, but the application does not observe the user. This one-way communication limits the potential for personalized sales strategies.
- **Intelligent Engagement:** This project aims to develop an observational machine. It applies Computer Vision to understand the physical world (the placement of the car) and Data Analytics to comprehend the user’s mind (Tracking Preference). The central thesis is that each user interaction is a data point that can be used to improve the sales process in real-time.

III. THEORETICAL FRAMEWORK

This project is grounded in established behavioral theories that explain user adoption of novel technologies.

1. *Technology Acceptance Model (TAM)*

The Technology Acceptance Model suggests that adoption is driven by “Perceived Usefulness” and “Perceived Ease of Use.” Wen et al. [5] applied TAM to AR/VR environments, finding that for non-entertainment applications (like retail or heritage sites), Ease of Use is the critical determinant. If the AR tracking is jittery or the UI is complex, users abandon the app. This informs our design philosophy of a minimalist interface.

2. *Flow Theory and Continuance Usage*

Zhou [15] explores mobile continuance usage through the lens of “Flow Theory”—the state of deep immersion. In an AR showroom, maintaining this flow is essential. Any latency or tracking failure breaks the immersion. By utilizing stable SLAM algorithms, as reviewed by Syed et al. [4], we aim to sustain this flow state, which Panya et al. [2] link directly to higher customer retention rates.

3. *Consumer Innovativeness*

Goldsmith and Hofacker [14] define “Consumer Innovativeness” as the tendency to buy new products soon after they appear. Our project targets this demographic by incorporating Gamification elements, as suggested by Srdanovic’ et al. [6], turning the car configuration process into a playful, creative activity that appeals to innovative consumers.

IV. REVIEW OF EXISTING RESEARCH PAPERS

1. *Usability and the Need for AR*

The foundational justification for integrating AR into retail environments is established in [1]. This research discloses that the primary failure of current mobile applications is flawed “Information Architecture,” which prevents users from easily finding or understanding complex product information. To resolve this usability gap, the study concludes that AR and AI are critical future research directions, directly validating the technical approach of this project.

2. *The Role of AI and Personalization*

The logic behind the intelligent recommendation module is supported by findings in [2], which proves that “Perceived Personalization” has a positive and significant impact on customer retention. Additionally, the research reveals that social norms and privacy concerns can negatively affect user trust. This highlights the absolute necessity for transparent data policies when implementing behavioral tracking in mobile retail environments.

3. *Technical Foundations of Mobile AR*

An extensive review of tracking technologies in [4] contrasts sensor-based tracking with vision-based tracking (Computer Vision). It validates that for applications requiring spatial accuracy, such as an automotive showroom, **Simultaneous Localization and Mapping (SLAM)** is the required standard for marker-less detection. This aligns with further findings in [11] and [13], which emphasize that high-

fidelity, stable visualization is crucial for establishing user trust across retail and engineering industries.

4. Industry 4.0 and Digital Twins

The literature frequently positions AR as more than a mere consumer tool, defining it as a core pillar of Industry 4.0 [12]. This project practically implements this concept by utilizing “Digital Twins” of vehicles. This approach allows for a seamless flow of data directly from manufacturer CAD files to the consumer’s physical environment, effectively bridging the gap between digital production and physical retail.

5. AR Adoption in Emerging Markets

Research into AR adoption within mobile applications highlights that “Hedonic Motivation”—the pursuit of fun and pleasure—is often a stronger driver for initial technology adoption than purely utilitarian motives [9]. This directly validates the inclusion of interactive and gamified elements in our showroom, such as dynamically changing vehicle colors and rims, which serve to engage users prior to presenting complex technical sales data.

V. STRENGTH AND WEAKNESS OF EXISTING APPROACHES

TABLE I Comparison of Static Apps vs. Proposed AR System

Feature	Current Approach (Static Apps)	Proposed Approach (Your Project)
Visualization	Weakness: Uses 2D images. Scale cannot be calculated or real-world fit determined.	Strength: Uses Marker-less AR (SLAM) for 1:1 scale in the driveway [4].
Data Capture	Weakness: Tracks only “Clicks” and “Page Views.” No feature interest data.	Strength: Tracks “Dwell Time” & “Gaze.” Knows exactly which color/part the user focused on for >30s.
Engagement	Weakness: Passive. The user must read text to find info (Information Overload).	Strength: Active. Simple AI pushes recommendations based on behavior [8].
Personalization	Deficiency: Generic. Every user sees the same homepage.	Strength: Personalized. Validated by Panya et al. [2] to improve retention.

VI. DISCUSSION OF COMPARATIVE ANALYSIS

1. Visualization and Spatial Understanding

Existing applications predominantly rely on static 2D imagery, which fails to convey spatial scale or realistic depth. This limitation forces users to mentally reconstruct the vehicle’s physical presence, often leading to hesitation. In contrast, the proposed system utilizes Marker-less AR (SLAM) to project 1:1 scale digital twins directly into the user’s physical environment. This capability, supported by

Syed et al. [4], allows for accurate “Real-World Fit” assessment.

2. Data Capture and Business Intelligence

A fundamental weakness of current platforms is their limited data capture. The proposed solution addresses this “Data Blind Spot” by introducing granular behavioral tracking—specifically “Gaze Duration.” By monitoring exactly which parts of the vehicle (e.g., rims, interior) a user inspects for more than 30 seconds, the system generates actionable insights. This aligns with Nama’s concept of “Context-Aware Services” [8], where the app responds to the user’s focus.

3. Engagement and Personalization

The shift from passive to active engagement is a core differentiator. Traditional apps suffer from “Information Overload,” presenting users with dense text specifications. The Immersive AR Showroom changes this dynamic by using “Simple AI” to push context-aware recommendations based on real-time behavior. This approach is validated by Panya et al. [2], whose research confirms that AI-driven personalization tailored to user behavior is a primary driver of customer retention.

VII. TECHNICAL ARCHITECTURE AND MODULES

1. Module 1: AR Visualization Engine (SLAM)

Technology: Built using Unity 3D and Vuforia/ARCore. **Justification:** As supported by Srdanovic et al. [6], this combination is the industry standard for creating high-fidelity, interactive mobile applications. The module uses the phone’s Camera and accelerometer to detect feature points on the floor (SLAM Technology) to anchor the 3D car model. This addresses the visualization gap identified by Cheng et al. [13] in the AECO industry, translating it to retail.

2. Module 2: The Real-Time Customization Interface

Technology: C# Scripting and Raycasting. **Function:** It offers “Raycasting”: When a user taps a “Red” button, a ray is shot from the camera to the 3D model to swap the texture material instantly. This interactivity enhances the “Hedonic Motivation” described by Yavuz et al. [9].

3. Module 3: The Behavioral Analytics Module (The “Brain”)

Technology: Background Timer Scripts and Firebase.

- **Logic:** If `UserView == "Red_Model"` then `Timer.Start();`
- **Trigger:** If `(Timer > 30s)` { `FireEvent("High_Interest_Red");` }
- **Storage:** Sends this event to Google Firebase in real-time.

Advantage: This module implements the findings of Panya et al. [2], turning passive user behavior into actionable business intelligence.

VIII. CHALLENGES AND OPEN ISSUES

1. Security and Data Integrity

The collection of behavioral data introduces significant risks. Syed et al. [4] highlight that AR applications are vulnerable to **Data Integrity Attacks**, where malicious content could be overlaid on the original digital twin. Additionally, **Side-Channel Attacks** (spyware) via camera access remain a critical privacy concern.

2. Hardware and Environmental Constraints

High-fidelity AR rendering is computationally intensive. As noted by Takrouri et al. [10], prolonged usage leads to significant **battery drain** and **device heating**. This limits the average user session time and presents a barrier to adoption in lower-end devices. Furthermore, vision-based SLAM relies heavily on ambient lighting; poor lighting conditions can cause the 3D model to “drift” or lose tracking entirely [4].

3. Social Acceptance and Privacy

Panya et al. [2] note a negative relationship between “Social Norms” and AI adoption. Users are often suspicious of applications that track their gaze or behavior. Wen et al. [5] further identify that if the AR interface is not “Perceived as Easy to Use,” users will revert to traditional static websites. Balancing advanced analytics with user privacy is a critical open issue.

IX. FUTURE RESEARCH DIRECTIONS

1. Multimodal Interaction

Weichbroth [1] identifies “Multimodal Interactions” as a critical frontier for mobile usability. Future research should focus on integrating Voice and Gaze Control to allow users to modify vehicle attributes via voice commands (e.g., “Show me the sport rims”), as suggested by the multimodal trends in Industry 4.0 [12].

2. Collaborative Retail in the Metaverse

Moving beyond single-user experiences, the convergence of AR with the Metaverse offers new avenues for social retail. Leveraging the findings of Syed et al. [4] on Collaborative AR, future research should explore low-latency synchronization methods that allow multiple users to inspect the same 3D digital twin simultaneously. This builds on Sung’s [7] findings regarding the power of shared social experiences in driving viral marketing.

3. Blockchain for Trust

To address the security concerns raised by Syed et al. [4], future systems could employ Blockchain ledgers to create an immutable record of user interactions. This would foster trust between consumers and dealerships, ensuring that the analytics data used for personalization is authentic and tamper-proof.

X. CONCLUSION

The review of the current literature shows that the auto- motive retail market is ready for disruption. The literature on the future of mobile apps, as defined by Weichbroth [1] and Panya et al. [2], explains how the future lies in solving usability via Immersion (AR) and engagement via Intelligence (AI). The project has successfully combined these two areas. By creating an “Immersive AR Showroom,” the barrier of distance is eliminated. By adding the feature of “Real-Time Analytics,” the auto dealer is empowered. The system currently implemented is an example of a functioning “Innovation Ecosystem” as conceptualized by Mohammadi et al. [3], bridging the gap between digital convenience and physical experience.

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