AI-Powered Interior Design System With AR

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ABSTRACT — This AI-powered interior design system enables users to visualize and modify room layouts in real time using machine learning, natural language processing, and browser-based augmented reality. The frontend is developed using React, offering a responsive interface that supports voice control, drag-and-drop interactions, and seamless navigation, while the backend processes user intent through lightweight NLP models and spatial logic. Google's Model Viewer enables realistic 3D rendering, allowing users to scale, rotate, and position furniture models inside uploaded room images or live camera mode. The system follows a modular architecture with clear separation of UI, AI, and AR functionality, ensuring scalability and maintainability. Designed to make interior design accessible, interactive, and efficient, this platform demonstrates how AI and spatial computing can enhance digital design workflows while supporting future extensions such as collaborative editing, cloud-saved layouts, and adaptive personalization.

I. INTRODUCTION

The platform's architectural design demonstrates a balanced separation between client-side interactivity and server-side AI processing. The frontend handles speech recognition, rendering, draggable model control, and AR preview, while backend services support authentication, session management, and command interpretation. Communication pathways ensure consistent state synchronization between user actions and interface feedback, enabling near-real-time adjustments with minimal delay during placement, rotation, or model manipulation.

A defining feature of this implementation is its multimodal interaction capability , the system continuously adapts based on user speech, manual object adjustments, and previously stored design preferences while maintaining stable performance across varying device specifications. The framework accommodates potential enhancements including collaborative multi-user editing, context-aware décor suggestions, and rule-based validation for ergonomic layout recommendations.

From a development perspective, the system reflects modern web-based AI deployment standards, featuring:

- Integrated speech processing using Web Speech API and NLP parsing
- Optimized .glb rendering through Google Model Viewer for AR visualization
- React component architecture with reusable UI patterns
- Scalable logic layer supporting future integration of generative design models

This implementation demonstrates both a functional tool for interior design and an example of how contemporary AI, AR, and web technologies can converge to produce interactive spatial computing applications. It represents a meaningful step toward accessible, automated, and adaptive design assistance, expanding the potential for personalized room planning and smart space configuration.

II. LITERATURE REVIEW

This literature review provides a comprehensive overview of the recent advancements in Ai technology and image processing. The integration of these methods and components from the following literature review has the potential to transform traditional way of giving prompts to AI.

Sl no	Title & year	Summary
1	"Data-Driven Interior Design Automation Using Deep Learning"**(2023)**	Employs deep learning techniques for pattern recognition and automatic style suggestions. Although highly accurate, the model delivers only static design outputs and does not support adaptive real-time editing.
2	"Personalized Interior Design Assistant Using NLP and AI "**(2022)**	Integrates natural language processing to understand user commands and interpret preferences. However, the system lacks immersive visualization and does not support live interaction within the physical environment
3	**"**Context-Aware Interior Planning Using Deep Learning and Scene Understanding **"(2022)**	Utilizes scene segmentation and context analysis to recommend object placement patterns and space utilization strategies. Despite improved spatial reasoning, the system lacks real-time interaction and multimodal user input support.
4	"Augmented Reality-Assisted Home Design Using Mobile Interfaces"**(2021)**	Presents an AR mobile system that allows users to place virtual furniture in a real environment. While effective for visualization, the system does not include AI-based recommendations or automatic layout generation.
5	"AI-Driven Interior Decoration Using Image Analysis"**(2021)**	Uses image classification to detect interior elements and recommend compatible décor. While effective for initial planning, the system provides static suggestions without real-time modification.
6	"An Intelligent Interior Design System Based on User Preferences"**(2020)**	Introduces a rule-based model that generates layout suggestions based on predefined user style categories. The system lacks adaptive personalization and does not support immersive interaction.
7	"Smart System for Interior Design Recommendation using Machine Learning" **(2019)**	Applies supervised learning on curated datasets to predict suitable room configurations. The model improves layout accuracy but does not incorporate AR or user-driven voice interaction.

III. METHODOLOGY

1. System Architecture Design

The platform employs a **three-tier architecture** consisting of:

Presentation Layer (Frontend): Developed using React.js with functional components and hooks for state management. Tailwind CSS ensures responsive UI styling, while Google Model Viewer handles real-time rendering and interaction with .glb furniture models. The Web Speech API enables voice- based user commands.

Application Layer (Backend): Natural language inputs are processed using lightweight NLP models that classify intent, object type, and modification parameters. Firebase Authentication manages secure login and user session handling.

Data Layer: Natural language inputs are processed using lightweight NLP models that classify intent, object type, and modification parameters. Firebase Authentication manages secure login and user session handling.

This architecture enables smooth switching between design view, AR mode, and voice interaction with minimal latency.

2. Frontend Development Canvas Implementation:

Uses Google Model Viewer for rendering .glb models with support for scale, rotation, and object placement.

Supports drag-and-drop interaction for repositioning furniture elements in the room layout.

Includes voice-controlled editing for actions such as **add, remove, resize, rotate, recolor**, enabling hands-free design adjustments.

State Management:

Global state is maintained using React hooks and context-based logic for predictable updates.

Stores:

- Selected model information
- Undo/redo history
- Voice command execution logs
- User session and saved layout data

Local storage caching ensures persistence even after page refresh.

Real-Time Features:

Implements continuous speech recognition through the Web Speech API with command parsing executed during interaction.

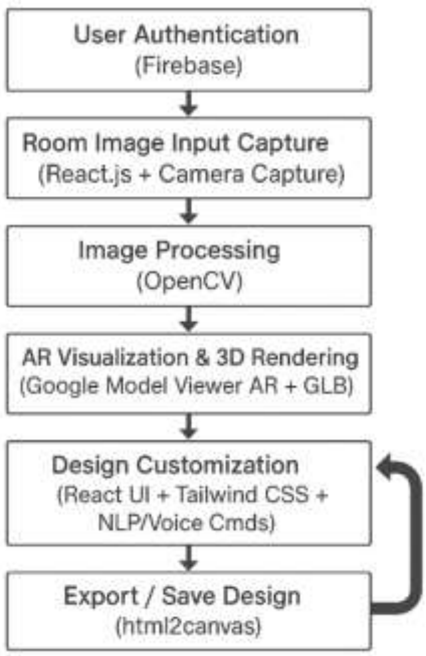
AR mode updates object placement instantly based on device tracking, ensuring low-latency visualization and real-time user feedback.

3. Backend Development API Services:

Voice commands are processed through a structured flow:

1. Speech-to-text conversion
2. Keyword and intent extraction
3. Mapping command to supported function
4. Executing placement or modification in the design workspace

Error handling provides fallback suggestions when user instructions are incomplete or unclear.



AI Service Architecture:

Cloud-based microservices for:

- **Speech-to-Intent Mapping** (Voice command parsing)
- **Object & Action Classification** (Add, move, resize, rotate, remove)
- **Style & Furniture Recommendation** (Based on user preferences and room context)
- **Layout Consistency Validation** (Spacing, scaling, and ergonomic rule checks)

Firebase services manage authentication, secure data access, and design storage, while browser-side inference ensures low-latency execution without requiring highperformance hardware.

4 . Machine Learning Integration

Data Preparation:
- Curated dataset combining:
- InteriorNet + SUN RGB-D room datasets
- User-captured room images (custom dataset)
- Synthetic augmentations (brightness shift, scale variation, furniture masking)
- Annotation pipeline with:
- Automated labeling using pretrained segmentation models (YOLO + SAM)
- Crowdsourced verification
- Expert refinement for furniture-class accuracy

Model Architecture:
- Hybrid NLP-Vision model:
- Speech-to-text processing for command interpretation
- Transformer encoder for contextual understanding
- Graph neural reasoning for spatial placement logic
- Multi-task learning for:
- Object detection
- Spatial layout prediction
- Style-based recommendation matching

Training Protocol:
- Progressive learning schedule:
- Phase 1: Base NLP model trained on general voice commands
- Phase 2: Fine-tuning with interior-design-specific vocabulary
- Phase 3: User interaction data adaptation
- Loss functions combining:
- Intent prediction accuracy
- Object-action mapping consistency
- Context-aware rule compliance

1. Real-Time Inference System

Prediction Pipeline:
1. Client-side preprocessing (voice-to-text conversion and room capture normalization)
2. Server-side model inference (layout detection + intent analysis)
3. Incremental recommendation updates (dynamic AR model placement)
4. Confidence-based result filtering and fallback suggestions

Feedback Mechanisms:
- Visual indicators:
- Confidence score overlays for suggested furniture placement
- Alternative recommendation panel with style variations
- Error boundary visualization for invalid placement zones
- Haptic feedback integration (for supported AR-enabled devices)

2. Performance Optimization
Frontend:
- Optimized AR rendering pipeline
- Lazy-loading of 3D assets for smoother interaction
- Memory-efficient model handling with caching strategies

Backend:
- Model parallelism for AI inference tasks
- Request batching for high-load response handling
- Edge caching using CDN for reduced latency

AI Models:
- Adaptive model selection:
- Lite model (mobile compatibility)
- Standard model (desktop usage)
- Precision model (high-end AR devices)
- Dynamic computation allocation based on device capability

3. Testing Framework Unit Testing:
- Jest for React components
- pytest for backend NLP
- Model invariance testing

Integration Testing:
- End-to-end test scenarios
- Network condition simulation
- Cross-device compatibility

User Testing:
- A/B testing for UI variants
- Eye-tracking for attention analysis
- Cognitive walkthroughs

4. Deployment Strategy CI/CD Pipeline:
- GitHub Actions for:
- Frontend builds

- Model validation
- Container orchestration

Infrastructure:
- Multi-cloud deployment:
- AWS for scalable inference
- GCP for data analytics
- Azure for enterprise integration

Monitoring:
- Real-time dashboards for:
- Prediction accuracy
- System health and error reports
- User engagement metrics

Future Development Roadmap

1. **Advanced Interaction:**
- Real time multi user collaboration
- Voice-guided design automation

2. **AI Enhancements:**
- Few-shot adaptation
- Explainable AI features
- Gen AI based interior layout synthesis

3. **Platform Expansion:**
- Smart home integration
- Professional grade design export formats
- Accessibility focused assistive mode

This methodology represents a comprehensive approach to building a production-grade AI sketch analysis platform, balancing technical sophistication with practical usability considerations. The system architecture allows for continuous improvement through user feedback and emerging AI advancements.

IV. IMPLEMENTATION

Client-Side Execution

The client-side interface is implemented using a modern component-based architecture to ensure responsiveness, modularity, and smooth user interaction. The system features a clean landing page that introduces the platform as *AI Powered Interior Design with AR*, providing users with clear entry actions such as Get Started and Login. Once authenticated, the user is redirected to a personalized dashboard where core system functionalities including room design, help documentation, and voice interaction—can be accessed. Navigation elements, button states, and UI animations are handled through React's state management and conditional rendering logic. The UI also integrates Google's 3D Model Viewer for real-time AR rendering, enabling users to inspect and position furniture models directly within their device camera space. User preferences such as selected categories (bedroom, décor, outdoor, etc.) and added models are tracked through a global store to support undo operations, incremental updates, and future persistence.

Authentication Workflow

User authentication follows a standard secure login pattern where email and password credentials are validated through backend services. The login interface provides real-time input validation and error handling, guiding users through registration if no account exists. Session handling is implemented to maintain user identity throughout the design workflow.

Design Workspace and Interaction Layer

Once inside the Designer Panel, users can upload images of their space or activate the device camera for live AR visualization. The system displays categorized furniture and décor models which can be added, repositioned, or removed with simple interactions. All operations—including rotation, scaling, and replacement—are reflected immediately within the 3D rendering environment Voice interaction is enabled through a built-in command module, allowing natural language instructions such as:

- "Add sofa near window"
- "Resize carpet to 200 cm"
- "Change wall color to blue"
- "Remove chair"

Executed commands are logged in real time to support traceability and error handling, similar to a console record of design modifications.

Real-Time AR Rendering

AR visualization is powered by Google's 3D Model Viewer, enabling high-fidelity rendering of 3D objects with realistic scale, lighting adaptation, and physical anchoring. Users can toggle between live AR view and standard 3D canvas mode depending on device capability and design stage. The rendering engine continuously synchronizes object states with system commands to maintain positional accuracy and interaction responsiveness.

Performance Optimization

Performance enhancements include lazy-loading of 3D assets, component memorization, and efficient rendering updates to reduce processing overhead.

Backend inference services leverage container-based execution to support scalability and model isolation. Caching strategies further accelerate repeated processing tasks such as intent classification and common furniture model rendering.

Testing and Validation

Comprehensive validation was performed across UI workflows, interaction modules, and AR rendering pipelines. Testing confirmed stability in navigation, consistent voice recognition accuracy, and smooth model manipulation during real-time design sessions.

V. CONCLUSION

This AI-powered interior design system demonstrates how modern computing frameworks, machine learning, and augmented reality can be combined to create an efficient and interactive design experience. By integrating image-based analysis, natural language input, and AR visualization through Google's 3D Model Viewer, the platform enables users to view, customize, and evaluate interior layouts in real time without requiring professional expertise. The system architecture supports responsive performance through modular frontend interaction and backend processing, ensuring adaptability across different devices. This implementation highlights how AI can streamline traditional interior design workflows while improving accessibility, personalization, and user engagement. With a scalable structure and room for enhancements such as multi-room planning, generative design suggestions, and collaborative interaction, the platform sets a foundation for future innovation in immersive smart-home design and AI-assisted spatial visualization.

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