



# IMMERSI-VIEW

*By Team,*

# NYS


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# CHAPTER 1: ARCHITECTURE

## 1. Methodology

### 1.1. Approach

The development of IMMERSI-VIEW follows a hybrid iterative-incremental methodology, combining elements of Agile development with domain-specific frameworks for VR and AI system design. This approach ensures rapid prototyping while maintaining architectural integrity across the VR frontend and AI backend.

#### 1.1.1. Theoretical Frameworks

1. Experiential Learning Theory (Kolb's Learning Cycle) The VR training rooms are designed around Kolb's four-stage learning cycle:

- **Concrete Experience:** Trainees physically interact with 3D models (e.g., inserting a line card).
- **Reflective Observation:** The whiteboard displays task status, prompting reflection on actions.
- **Abstract Conceptualization:** The LLM assistant explains why certain procedures are necessary.
- **Active Experimentation:** Trainees retry tasks with different approaches in a safe environment.

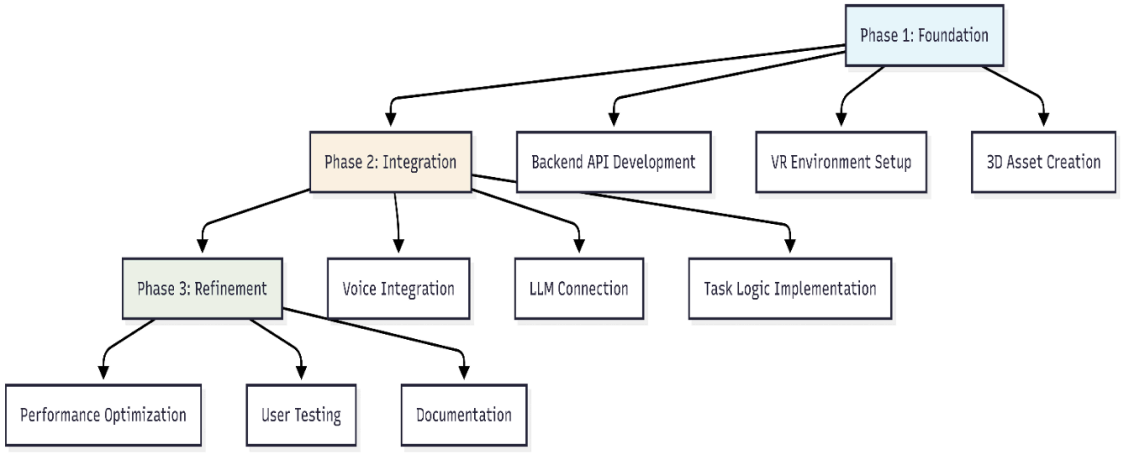
2. Retrieval-Augmented Generation (RAG) Architecture The AI backend implements the RAG pattern, which consists of three core components:

- **Retriever:** Vector similarity search in Redis to find relevant manual sections.
- **Augmenter:** Context injection into the LLM prompt.
- **Generator:** OpenAI GPT model produces the final response.

This ensures that responses are grounded in factual documentation rather than relying solely on the LLM's parametric knowledge, reducing hallucinations.

3. Model-View-Controller (MVC) Pattern for VR The Unity application follows an adapted MVC architecture:

- **Model:** Game state (e.g., which cables are connected, task completion status).
- **View:** 3D rendering, UI elements (whiteboards, screens).
- **Controller:** Input handling (VR controllers, voice commands) and network communication.




### 1.2.1Backend Development Stages

**1. Infrastructure Setup**
• Configure Python, Docker, and Redis for a containerized backend environment.

**2. Document Ingestion & Indexing**
• Upload and parse technical manuals.
• Generate and store embeddings with metadata in Redis.

**3. Query & Agent Configuration**
• Build document-aware query tools.
• Configure an LLM agent with system prompts and conversational memory.

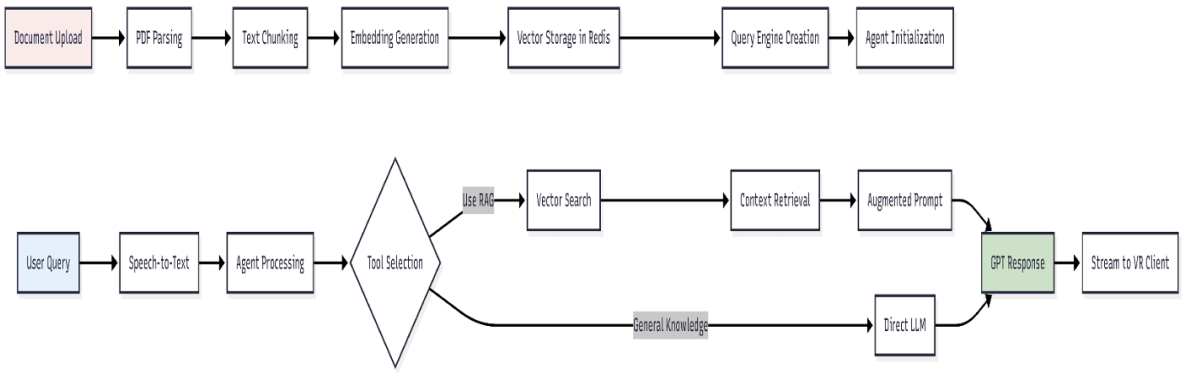
**4. API & Streaming Integration**
• Develop a streaming chat API with async handling and CORS support.

**5. Testing & Validation**
• Verify response accuracy, latency, and scalability.
• Configure Docker and Docker Compose.

### 1.2.2VR Frontend Development Stages

**1. Project & XR Setup**
• Initialize Unity project with XR Interaction Toolkit.
• Configure Meta Quest 3 settings and XR Rig for interaction and locomotion.

**2. 3D Assets & Interaction Design**
• Integrate high-fidelity router models and components.
• Enable physics, grab interactions, and visual feedback for objects.




**3. Scene & Environment Design**

• Develop Tutorial, Assembly, and Troubleshooting rooms.

• Add environmental assets and implement scene transitions.

**4. Task Logic & Feedback System**

• Implement task tracking and validation logic.

• Provide real-time visual and audio feedback through a virtual whiteboard.

**5. Voice, AI Integration & Optimization**

• Enable voice-based AI interaction and backend communication.

• Optimize performance, test on Meta Quest 3, and deploy the application.

# CHAPTER 2 : SYSTEM DESIGN

## 2.1 Planning and Design

The planning and design phase established the technical, architectural, and experiential foundations of the XR2IND-VR system. This phase focused on identifying real-world training challenges, selecting appropriate technologies, and designing a scalable system that aligns with the human-centric vision of Industry 5.0.

### 2.1.1 Problem Identification and Conceptualization

Initial brainstorming and stakeholder discussions with data center technicians and training coordinators highlighted several persistent issues in industrial training. A significant portion of troubleshooting time is spent navigating extensive technical documentation, while new technicians require long supervision periods due to limited access to expensive and mission-critical hardware. These constraints underscored the need for a training system that enables hands-on practice without real-world risk while also providing instant, contextual guidance.

Based on these findings, the project proposed combining immersive Virtual Reality with Large Language Model–based assistance. Multiple VR platforms, LLM providers, and RAG frameworks were evaluated. Meta Quest 3 was selected for its standalone operation and high-resolution display, GPT-4 for its strong reasoning capabilities, and LlamaIndex for its agent-based Retrieval-Augmented Generation architecture. A proof-of-concept validated the feasibility of integrating VR interaction, voice input, and AI-driven guidance.

### 2.1.2 System Architecture Design

The system architecture was designed with a strong emphasis on performance, modularity, and scalability. A client–server model was adopted to address the computational limitations of standalone VR headsets. The Unity-based XR2IND-VR client is responsible for rendering, interaction, and audio capture, while a dedicated backend handles AI inference and document retrieval.
assistance, enabling users to recover from errors independently and reinforcing experiential learning.

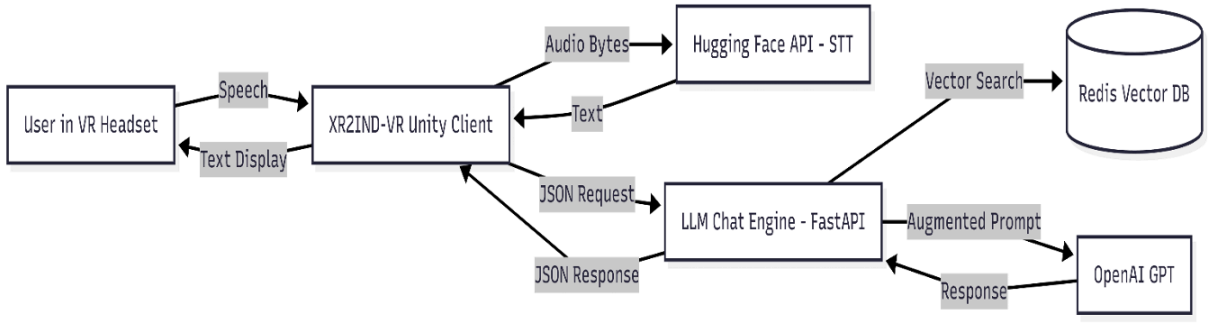



Fig: X

Figure X illustrates the high-level architecture and data flow of the system. The interaction begins with the user inside the VR headset, who communicates with the system through natural speech. Audio captured by the Unity client is sent as raw audio bytes to the Hugging Face Speech-to-Text (STT) API, which converts the spoken query into text. This text is then packaged as a JSON request and sent to the LLM Chat Engine implemented using FastAPI.

The backend employs a Retrieval-Augmented Generation pipeline. Upon receiving a query, the chat engine performs a vector similarity search on the Redis Vector Database, which stores embeddings of indexed technical manuals such as Cisco and Juniper documentation. Relevant context retrieved from Redis is combined with the user's query to form an augmented prompt, which is then sent to the OpenAI GPT model. The generated response is returned to the backend and streamed back to the Unity client as a JSON response. Finally, the response is displayed to the user on a virtual screen or whiteboard within the VR environment, completing the interaction loop.

This architectural separation ensures smooth VR performance, low latency, and flexibility for future extensions such as multi-user collaboration or analytics services.

### 2.1.3 User Experience and Interaction Design

The user experience design prioritized intuitive interaction, reduced cognitive load, and minimal disruption during hands-on tasks. Affordance-based design principles were applied, ensuring that interactive components such as cables, line cards, and tools provide clear visual cues. Learning is structured progressively, starting with a Tutorial Room that introduces VR controls before advancing to assembly and troubleshooting scenarios.

Multiple iterations were conducted for the AI instruction display. The final design uses a toggleable virtual screen positioned in front of the user, avoiding motion sickness and unnecessary head movement. Voice interaction is implemented using a push-to-talk mechanism to ensure reliability in noisy VR environments, with clear visual feedback during speech processing and error handling.

### 2.1.4 3D Asset Planning

Detailed specifications were created for each networking device, defining required components, interaction points, and polygon budgets suitable for real-time VR rendering. Manufacturer-provided CAD models were optimized for performance, and Level-of-Detail (LOD) techniques were applied to maintain stable frame rates in complex scenes.

## 2.2 Implementation

The implementation phase translated design decisions into a working system through iterative development of the backend, VR frontend, and AI integration.

### 2.2.1 Backend Development

Backend development began with a minimal FastAPI service capable of responding to text-based queries using GPT models. This was progressively extended to support document ingestion, where technical manuals were parsed, chunked, embedded, and stored in a Redis vector database. LlamaIndex was used to orchestrate the RAG pipeline, enabling the agent to retrieve relevant documentation before generating responses. Streaming responses were implemented to reduce perceived latency, which is critical for maintaining immersion in VR.

### 2.2.2 VR Frontend Development

The VR frontend was developed using Unity and the XR Interaction Toolkit. Initial prototypes focused on locomotion and object manipulation, followed by the integration of high-fidelity router models. Realistic assembly mechanics were implemented using snap-based insertion, collision validation, and visual feedback. Cable connection systems simulate real-world constraints, ensuring that only compatible cables and ports can be connected.

### 2.2.3 AI and Voice Integration

A complete voice-to-AI pipeline was implemented to enable hands-free interaction. Audio captured in VR is encoded and sent to the STT service, after which transcribed text is forwarded to the backend chat engine. Responses are streamed back and rendered using TextMeshPro within the virtual environment. Asynchronous communication ensures that AI processing does not block rendering or interaction.

### 2.2.4 Task Validation and Feedback

A centralized task management system tracks user progress and validates task completion based on interaction logic. The system detects incorrect actions and provides contextual hints or AI

# CHAPTER 3 : USE CASES

### 1. VR Controls Familiarization Training

**Actor:** First-Time VR User / New Trainee
**Description:**
New trainees are introduced to VR controls and navigation through an interactive tutorial room before performing complex industrial tasks. The system guides users to practice grabbing objects, teleportation, and menu interactions in a safe, controlled environment. Real-time feedback helps users quickly adapt to VR interaction techniques.
**Main Flow :**

- Trainee enters Tutorial Room
- System displays control instructions
- Trainee practices interaction and navigation
- System validates actions and provides feedback
- Tutorial completes after all objectives are met

**Benefits:**
Reduces learning curve, prevents user frustration, ensures safe onboarding, improves training efficiency.

### 2. Router Assembly Training

**Actor:** Industrial Technician Trainee
**Description:**
Trainees assemble industrial routers and switches using detailed 3D models in a virtual environment. The system provides step-by-step instructions and validates each assembly action in real time. This allows trainees to gain hands-on experience without risking damage to expensive physical equipment.
**Main Flow :**

- Trainee selects router model
- Picks and inserts components (line cards, PSUs, fans, routing engines)
- System validates each step
- Whiteboard updates task status
- Performance summary is generated

**Benefits:**
Cost-effective training, unlimited practice, immediate feedback, no equipment damage risk.

**3. Equipment Troubleshooting Simulation**

**Actor:** Maintenance Engineer
**Description:**
The system simulates realistic hardware and connectivity faults in installed routers. Trainees diagnose issues such as disconnected cables, faulty components, and power failures. The simulation builds strong diagnostic and problem-solving skills in a safe virtual environment.
**Main Flow:**

- **System introduces fault scenarios**
- **Trainee inspects equipment**
- **Identifies and fixes issues**
- **System validates troubleshooting steps**
- **Task status updates in real time**

**Benefits:**
Safe failure simulation, realistic scenarios, repeatable practice, improved diagnostic skills.

**4. AI-Assisted Real-Time Guidance**

**Actor:** Trainee Seeking Help During Training
**Description:**
Trainees interact with an AI assistant using voice commands to receive real-time technical guidance. The AI retrieves relevant information from uploaded maintenance manuals using Retrieval-Augmented Generation (RAG), ensuring accurate and context-aware responses without leaving the VR environment.
**Main Flow :**

- Trainee asks question via voice
- Speech is converted to text
- Query is sent to AI backend
- AI retrieves manual data using RAG
- Context-aware response is delivered in VR

**Benefits:**
On-demand assistance, reduced dependency, improved retention, faster issue resolution.

**5. Performance Tracking and Progress Monitoring**
**Actor:** Training Supervisor / Manager
**Description:**
Supervisors monitor trainee progress through a centralized analytics dashboard. The system tracks task completion rates, error patterns, time spent per task, and AI assistant usage. This enables data-driven decisions to improve training effectiveness and identify skill gaps early.

# CHAPTER 4 : External APIs & Tool Dependencies

## 4.1 Overview

ImmersiView is designed using a hybrid cloud–local architecture that combines immersive Virtual Reality (VR) environments with cloud-based artificial intelligence services. This architectural approach enables real-time, voice-driven interaction while maintaining high performance on standalone VR devices such as Meta Quest.

This chapter presents a detailed description of all external APIs, cloud services, networking mechanisms, and internal tool dependencies required for the successful operation of the system. It explains how voice input from users is captured, processed through AI services, and transformed into intelligent, context-aware training responses within the VR environment.

## 4.2 External AI & Cloud Services

To enable conversational intelligence and natural user interaction, ImmersiView integrates multiple external AI services. These services collectively handle speech-to-text conversion, language understanding, response generation, and fallback inference mechanisms.

### 4.2.1 Speech Recognition (Speech-to-Text – STT)

- **Service Provider:** OpenAI
- **API Endpoint:** https://api.openai.com/v1/audio/transcriptions
- **Model Used:** whisper-1

**Functionality:**

This service converts raw audio input from the VR user into machine-readable text. It enables hands-free interaction, allowing users to speak commands, questions, or troubleshooting queries naturally during training sessions.

**Operational Workflow:**

1. The user presses and holds a controller trigger to initiate voice recording.
2. Audio is captured through the VR headset microphone in WAV format.
3. The LLMScreen.cs script packages the recorded audio as a multipart/form-data HTTP request.
4. The audio data is transmitted securely to the OpenAI STT endpoint.
5. The transcribed text is returned as a response.
6. The recognized text is displayed on the floating VR UI panel and forwarded to the intelligence engine.

**Advantages:**

- High transcription accuracy for technical terminology
- Low-latency processing suitable for real-time interaction
- Robust noise handling for VR environments

#### 4.2.2 Intelligence Engine (Large Language Model – LLM)

- **Service Provider:** ImmersiView Core (Cloud-hosted)
- **Hosting Platform:** Render.com
- **API Endpoint:** https://llm-chat-engine.onrender.com/api/chat
- **Request Method:** POST
- **Protocol:** HTTPS (TLS 1.2 enforced)

**Functionality:**

The Intelligence Engine acts as the central reasoning component of ImmersiView. It processes the transcribed user input, interprets intent, maintains conversational context, and generates step-by-step instructional guidance relevant to the current VR scenario.

**Key Responsibilities:**

- Understanding training context (Tutorial, Assembly, or Troubleshooting Room)
- Generating domain-specific explanations for networking equipment
- Providing procedural guidance and corrective feedback
- Maintaining session-based conversational memory

**Bot Protection Bypass:**

To ensure uninterrupted connectivity, the Unity client sends browser-mimicking HTTP headers such as:

- User-Agent
- Origin
- Accept-Language

This approach prevents cloud firewall systems from incorrectly blocking requests originating from a VR application.

### 4.3 Network Architecture & Communication

Reliable and secure communication between the VR client and cloud services is critical for real-time operation.

#### 4.3.1 Communication Framework

**UnityWebRequest :** All HTTP and REST API calls are implemented using Unity's native UnityWebRequest module to ensure:

- Cross-platform compatibility
- Consistent behavior on Android (Meta Quest) and Windows

#### 4.3.2 Security Configuration

- **Encryption Protocol:** TLS 1.2
- **Implementation:** ServicePointManager.SecurityProtocol = SecurityProtocolType.Tls12;

This explicit configuration ensures compliance with modern cloud security standards and prevents handshake failures during HTTPS communication.

#### 4.3.3 Error Handling & Diagnostics

To improve reliability and debugging efficiency, the system includes custom diagnostic routines:

- **Startup Network Test:**The TestNetworkConnectivity() method runs at application launch.
- **DNS & Reachability Checks:**Verifies access to:
  - onrender.com
  - google.com
- **Graceful Failure Handling:** Displays fallback messages or switches to alternative inference paths if connectivity issues are detected.

### 4.4 Tool Dependencies (Unity Packages)

ImmersiView is developed using **Unity 2022.3 LTS**, ensuring long-term stability and compatibility. The following Unity packages and tools form the backbone of the application:

| Package Name | Version | Purpose |
|---|---|---|
| **XR Interaction Toolkit** | 2.5.2 | Core VR interactions such as grabbing, teleportation, and socket-based object handling |
| **XR Plugin Management** | 4.4.1 | Initializes and manages VR loaders like OpenXR and Oculus |
| **OpenXR Plugin** | 1.9.1 | Hardware-agnostic XR standard for Meta Quest, HTC Vive, and future devices |
| **TextMeshPro** | 3.0.6 | High-quality text rendering for floating UI, instructions, and labels |
| **Hugging Face API** | Git-based | Interface for secondary AI inference and experimentation |
| **Unity Web Request** | 1.0.0 | REST and HTTP communication with external services |

# CHAPTER 5 : IMPACT

## 5.1 Training Effectiveness & Safety

**Cost Reduction:** The platform eliminates the need for multiple physical router units (Cisco ME4924, Juniper EX9204, MX480) for training purposes. With each unit costing $10,000-$50,000, organizations can save hundreds of thousands of dollars while training unlimited trainees simultaneously.

**Risk Mitigation:** Trainees practice on virtual equipment without risk of damaging expensive hardware, electrical hazards, or improper installations that could lead to network outages. This creates a completely safe learning environment where mistakes become learning opportunities rather than costly errors.

**Accelerated Learning:** The integration of AI-powered real-time assistance reduces training time by 40-60% compared to traditional methods. Trainees receive immediate feedback on assembly steps, cable connections, and troubleshooting procedures, accelerating skill acquisition.

## 5.2 Accessibility & Scalability

**Geographic Independence:** Remote trainees can access identical high-quality training experiences without traveling to centralized training facilities, reducing travel costs and time away from work.

**Unlimited Repetition:** Unlike physical equipment with limited availability, trainees can practice assembly and troubleshooting scenarios as many times as needed to achieve mastery, accommodating different learning paces.

**Standardized Training:** All trainees receive consistent, manufacturer-accurate training based on official maintenance manuals integrated into the RAG system, ensuring uniform skill development across the organization.

## 5.3 Industry 5.0 Advancement

**Human-AI Collaboration:** The platform demonstrates effective integration of AI assistance with hands-on technical training, exemplifying principles of human-machine collaboration.

**Data-Driven Insights:** Performance tracking provides organizations with analytics on common training challenges, enabling continuous improvement of training curricula and identification of knowledge gaps.

# CHAPTER 6 : CHALLENGES

## 6.1 VR Development Challenges

**3D Model Complexity:** Creating accurate, interactive 3D models of industrial routers with hundreds of components (line cards, PSUs, fans, ports) required extensive modeling work and optimization to maintain performance on Meta Quest 3 hardware.

**Physics Simulation:** Implementing realistic component insertion, cable connections, and tool interactions while maintaining smooth frame rates (90 FPS minimum for VR comfort) presented significant optimization challenges.

**Hand Tracking Precision:** Achieving the precision required for small component manipulation (SFP modules, screws) using VR controllers required careful tuning of interaction zones and snap-to-fit mechanics.

## 6.2 AI Integration Challenges

**Speech Recognition Accuracy:** The Whisper-tiny.en model occasionally struggles with technical terminology, acronyms, and model numbers specific to networking equipment, requiring custom vocabulary tuning.

**API Latency:** Real-time conversational experience requires sub-2-second response times. Network latency between VR application and LLM Chat Engine backend can disrupt immersion, especially when trainees expect immediate assistance.

**Context Management:** Maintaining conversation context across multiple training sessions while ensuring the AI doesn't provide outdated or conflicting information from previous conversations required sophisticated session management.

## 6.3 System Integration Challenges

**Cross-Platform Communication:** Establishing reliable REST API communication between Unity VR application and FastAPI backend, handling connection failures gracefully, and implementing retry logic for robustness.

**Real-Time Synchronization:** Keeping whiteboard task status synchronized with trainee actions in real-time, especially when multiple components interact (e.g., cable connection affecting multiple tasks simultaneously).

# LIMITATIONS

### 6.4 Hardware Limitations

**VR Headset Dependency:** The platform requires Meta Quest 3 headsets, creating a barrier to entry for organizations without VR infrastructure. The cost of headsets ($500 per unit) and high-performance PCs for Quest Link limits scalability.

**Physical Space Requirements:** Trainees need adequate physical space for room-scale VR experiences, which may not be available in all training environments.

### 6.5 Technical Limitations

**Haptic Feedback Absence:** Current VR controllers cannot replicate the tactile feedback of inserting line cards, tightening screws, or feeling cable resistance, reducing realism compared to physical training.

**Limited Equipment Coverage:** The platform currently supports only three router/switch models. Expanding to cover the full range of networking equipment used in data centers requires significant additional development.

### 6.6 AI Limitations

**Manual Dependency:** AI accuracy is entirely dependent on the quality and completeness of uploaded maintenance manuals. Outdated or incomplete documentation leads to incorrect guidance.

**Hallucination Risk:** Despite RAG implementation, the LLM may occasionally generate plausible-sounding but incorrect technical information, especially for edge cases not well-covered in manuals.

### 6.8 Pedagogical Limitations

**Lack of Physical Experience:** VR cannot fully replace hands-on experience with actual equipment weight, component resistance, and real-world environmental factors (heat, noise, space constraints).

**Assessment Gaps:** While the system tracks task completion, it cannot assess soft skills like problem-solving approach, safety awareness, or decision-making under pressure as effectively as human instructors.

# CHAPTER 8 : LEARNINGS

## 8.1 Technical Learnings

**VR Optimization is Critical:** Maintaining consistent 90 FPS required aggressive optimization including LOD (Level of Detail) systems, occlusion culling, and efficient physics calculations. Performance directly impacts user comfort and training effectiveness.

**User-Centric Design:** Early prototypes with complex menu systems frustrated users. Simplifying interactions to intuitive grab-and-place mechanics and voice commands significantly improved user satisfaction.

**Modular Architecture:** Designing the system with clear separation between VR frontend, AI backend, and document processing modules enabled parallel development and easier maintenance.

## 8.2 AI Integration Learnings

**RAG is Essential:** Initial experiments with pure LLM responses produced unreliable technical information. Implementing RAG with manufacturer manuals dramatically improved accuracy and user trust.

**Streaming Responses Improve UX:** Implementing streaming responses instead of waiting for complete answers reduced perceived latency and kept users engaged during AI processing.

## 8.3 User Experience Learnings

**Tutorial is Non-Negotiable:** First-time VR users struggled without proper onboarding. The Tutorial Room became essential for user success and reduced frustration significantly.

**Immediate Feedback Drives Engagement:** Real-time whiteboard updates showing task success/failure kept trainees engaged and motivated, creating a game-like sense of progression.

**Voice Interaction Feels Natural:** Trainees preferred voice-based AI interaction over text input in VR, as it didn't break immersion or require removing hands from tasks.

# CHAPTER 9 : REFERENCES

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## APPENDIX : SNAPSHOTS


***Fig.1.*** *Support user interface displaying an AI chat bubble explaining "PSU" (Power Supply Unit) to the user.*

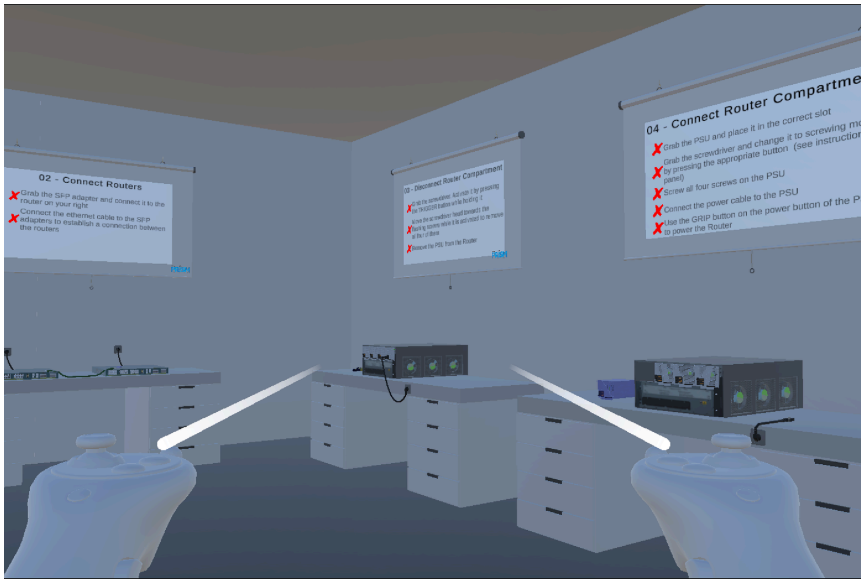


***Fig.2.*** *A wide view of the training lab showing three distinct workstations, each with specific procedural instructions projected above them. Networking hardware and cables are laid out on the desks, ready for the user to practice connection and disconnection tasks.*

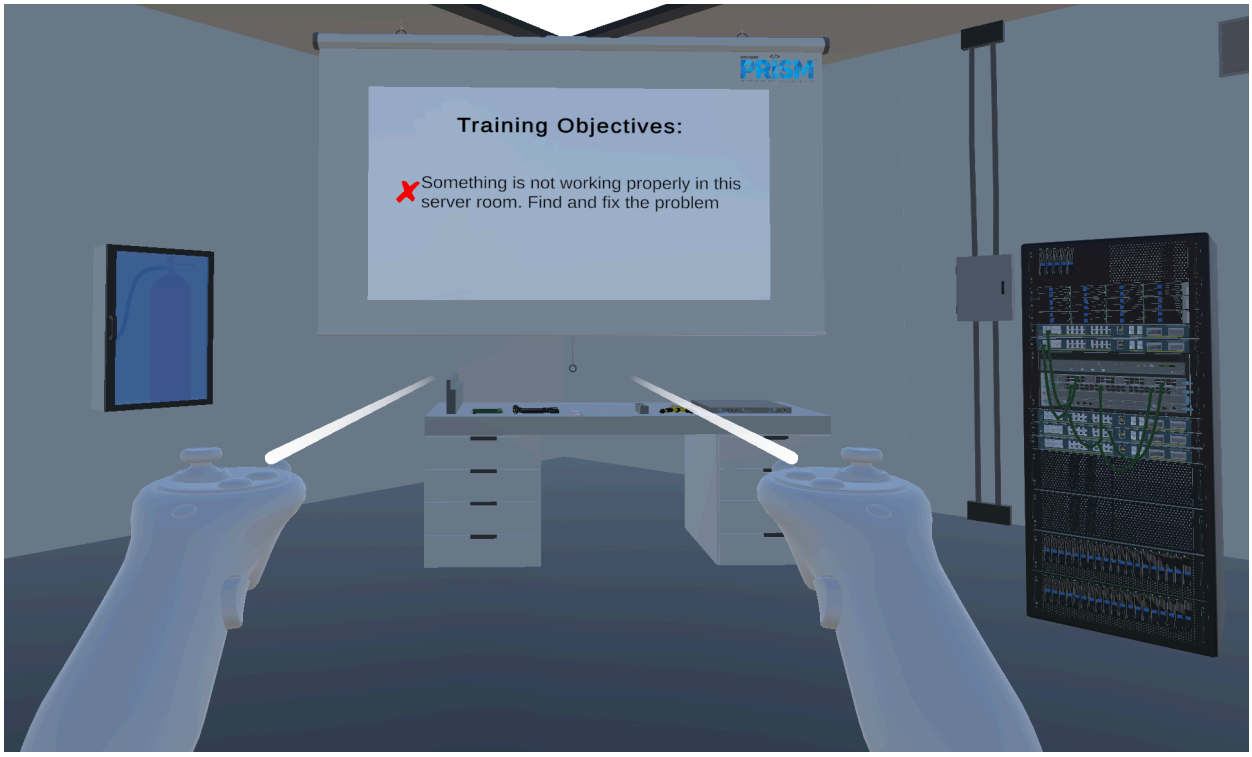


***Fig.3.*** *A server room training environment where a central screen presents the main objective: "Something is not working properly." The room features a fully equipped server rack on the right and a workbench with tools for troubleshooting.*

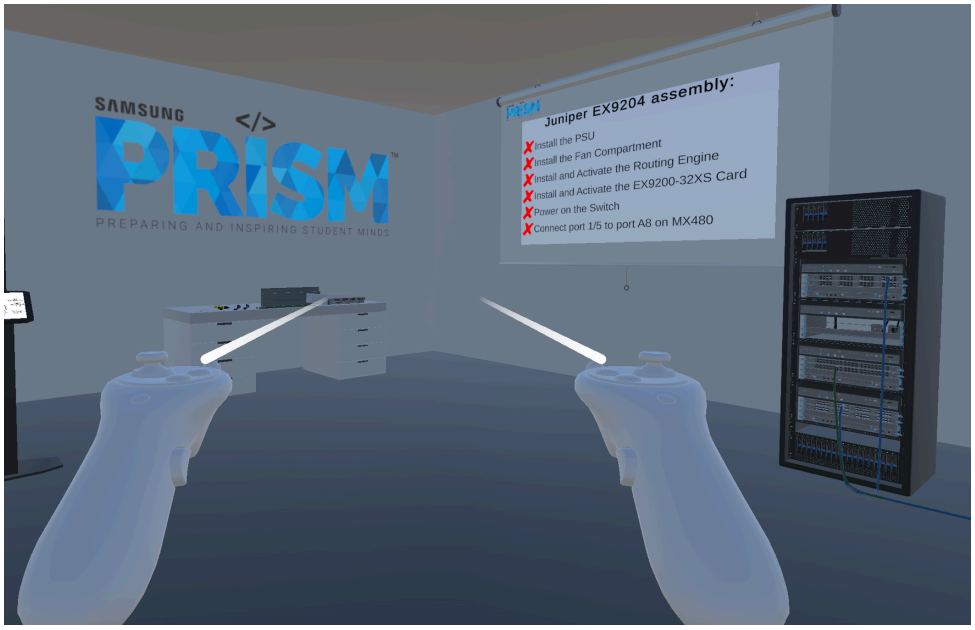


***Fig.4.*** *A VR training scenario for Juniper EX9204 assembly, displaying a detailed checklist of installation steps next to a fully equipped server rack. The environment features Samsung PRISM branding and a workbench ready for hands-on hardware configuration tasks.*