

# Development of an AI-Augmented AR Furniture Exhibition System: A Case Study of Industry-Academia Collaborative Engineering

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**Abstract:** The digital transformation of the traditional furniture manufacturing industry is severely hindered by high software development costs, lengthy Research and Development (R&D) cycles, and the inherent technical complexities associated with real-time 3D spatial visualization on mobile devices. This paper presents the comprehensive design, implementation, and empirical evaluation of a dual-terminal “Cloud Exhibition” platform, engineered through an innovative Industry-Academia collaborative R&D model. The proposed system architecture integrates Large Language Model (LLM) assisted UI-to-code generation, a lightweight Augmented Reality (AR) spatial rendering engine, and dynamic accessibility (WCAG 2.1) adaptation mechanisms. By establishing a novel AI-driven agile development workflow, the system effectively bridges the historical gap between visual design prototyping and front-end engineering. Technical evaluations demonstrate that the proposed architecture reduces the enterprise’s software development cycle from an industry average of six months to under two weeks, achieving an overarching operational cost reduction of over 60%. Furthermore, the custom lightweight AR engine optimizes 3D model rendering for mobile GPUs utilizing topological decimation and texture baking, achieving a spatial projection dimensional error of less than  $\pm 1.8$  cm and maintaining a stable 60 Frames Per Second (FPS) on standard consumer hardware. This study not only provides a scalable technological solution for SME digital transformation but also empirically validates the efficacy of university laboratories serving as agile tech-incubators for traditional manufacturing industries. This study provides a scalable framework that synergizes front-end engineering with industrial design pedagogy.

**Keywords:** Augmented Reality (AR); AI-Assisted Development; UX/UI Engineering; Industry-Academia Synergy; Digital Transformation; Project-Based Learning (PBL)

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## 1. Introduction

### 1.1 Research Background and Importance

The rapid acceleration of e-commerce has fundamentally reshaped global retail; however, the traditional furniture industry’s online penetration rate remains disproportionately low at approximately 28.52%. This disparity stems from the inherent technical limitations of contemporary e-commerce interfaces. Traditional two-dimensional (2D) screens fail to accurately convey physical dimensions, spatial harmony, and material textures. This “spatial deficit” creates severe cognitive friction, leading to

high consumer hesitation and notoriously high product return rates<sup>[1]</sup>, which directly decimate manufacturers' profit margins. While Augmented Reality (AR) spatial visualization offers a highly effective solution, its commercial implementation presents almost insurmountable hurdles for Small and Medium-sized Enterprises (SMEs). High-fidelity spatial rendering traditionally relies on complex game engines or heavy standalone applications, requiring extensive capital investment and prolonged development periods typically exceeding six months. Furthermore, SMEs chronically lack in-house computational engineering talent, exacerbating Research and Development (R&D) bottlenecks.

To address this critical digital divide, this paper presents the "Industry-Education Connect" Cloud Exhibition Platform, engineered through a mutually beneficial Industry-Academia collaborative R&D model. In this paradigm, the university plays a pivotal role as an agile tech-incubator<sup>[2]</sup>. Guided by academic instructors, student engineering teams directly develop commercial-grade digital products tailored to the enterprise's exact market needs. Consequently, the partner enterprise ("Weijiang Furniture") is equipped with a ready-to-use, dual-terminal spatial e-commerce system. Enterprise representatives can directly utilize the lightweight C-end WeChat Mini-program as a dynamic sales tool to showcase virtual furniture to end-customers. Consumers can instantly visualize the 3D furniture within their physical homes via AR and seamlessly place direct orders upon satisfaction, completing the commercial closed-loop.

To empower student developers to rapidly deploy this enterprise-grade system<sup>[3]</sup>, this study pioneers the integration of Large Language Models (LLMs) into the front-end workflow, automating UI-to-code generation. Furthermore, to address mobile hardware limitations, the team engineered a custom 3D asset optimization pipeline utilizing topological decimation, ensuring fluid 60 Frames Per Second (FPS) AR rendering. Dynamic accessibility (WCAG 2.1) features were also natively embedded to accommodate demographic diversity.

The primary contributions of this paper are: (1) An AI-driven development workflow that reduces enterprise R&D cycles from six months to under two weeks; (2) A lightweight mobile AR rendering pipeline achieving a spatial projection error of less than  $\pm 2$  cm; and (3) The empirical validation of a "win-win" Industry-Academia collaborative framework. This model provides traditional SMEs with an immediate, low-cost digital transformation and sales-conversion tool, while simultaneously offering university students invaluable, real-world commercial engineering practice, profoundly bridging the gap between higher education and industrial demands.

The remainder of this paper is organized as follows: Section 2 details the system architecture; Section 3 explains the technical implementation; Section 4 presents the experimental results; and Section 5 concludes the study.

## 2. System Architecture Design

Figure 1: Technical Roadmap



To overcome the inherent rigidities and high maintenance costs associated with traditional monolithic software, the proposed Cloud Exhibition platform adopts a decoupled, cloud-native, and AI-augmented architectural paradigm. This architecture is specifically engineered to accommodate the agile R&D environment of university-enterprise collaboration while ensuring commercial-grade stability for the partner furniture manufacturer<sup>[4]</sup>. The system logic is structured to facilitate a seamless data flow from the initial student-driven design phase to the final enterprise-customer transaction.

As illustrated in Figure 1, the system architecture is stratified into three hierarchical layers: the Infrastructure and Data Layer, the Core Processing and Logic Layer, and the Multi-terminal Interaction Layer.

### **2.1 Infrastructure and Data Layer**

The foundation of the platform relies on a distributed cloud infrastructure (e.g., Tencent Cloud or Alibaba Cloud) to ensure high availability and low latency. Recognizing that 3D furniture assets and AR materials are computationally “heavy,” the architecture utilizes a hybrid database approach. Relational data, such as user profiles, transaction logs, and inventory metadata, are managed via a MySQL cluster to ensure ACID compliance.

In contrast, high-resolution 3D models (glTF/glb formats) and baked texture maps are housed in an Object Storage Service (OSS). To optimize the AR experience for end-consumers, a global Content Delivery Network (CDN) is integrated. This infrastructure ensures that when a salesperson opens the platform to a client, the AR assets are fetched from the nearest edge node, minimizing the “loading anxiety” that often hinders digital sales conversions<sup>[5]</sup>. This robust backend provides the necessary “commercial soil” for student-developed front-end modules to operate reliably under real-world traffic.

### **2.2 Core Processing and Logic Layer**

The middle-tier represents the “intelligence” of the system, where academic innovation meets industrial functional requirements. This layer encompasses three critical sub-modules:

**The AI-Driven Development Engine:** This module serves as the primary bridge between the university design laboratory and the software product. It integrates multimodal Large Language Model (LLM) hooks (e.g., GPT-4o) to facilitate the UI-to-code generation pipeline. It parses the visual design nodes created by students and outputs structured, framework-specific code, effectively automating the repetitive boilerplate development that typically consumes 70% of an R&D cycle.

**The Lightweight AR Rendering Engine:** Built upon a WebGL-based framework tailored for Mini-program environments, this engine handles real-time spatial calculations. It includes algorithms for plane detection, lighting estimation, and 3D mesh decimation. By processing assets in this layer before they reach the consumer’s device, the system ensures that complex furniture designs remain fluid and interactive.

**The Commercial Transaction State Machine:** This module manages the business logic, including the shopping cart synchronization, order status transitions, and secure payment gateway integrations. It ensures that the “Exhibition-to-Order” conversion is technically seamless.

### **2.3 Multi-terminal Interaction Layer (The B-end and C-end Paradigm)**

The Presentation Layer is bifurcated into two distinct terminals, each serving a specific stakeholder in the “win-win” collaborative model:

**The B-end SaaS Administrative Dashboard:** Developed using the React.js framework, this terminal is the primary interface for the furniture enterprise. It provides a visualized management console where staff can upload new designs, monitor sales telemetry, and manage customer inquiries. Because the platform is built on a “low-code” philosophy, enterprise staff without programming backgrounds can easily update their virtual showroom, significantly reducing the company’s long-term technical maintenance costs.

**The C-end AR WeChat Mini-program:** This is the most innovative component of the interaction layer. It is designed as a frictionless, “zero-install” tool for both the consumer and the enterprise salesperson. By utilizing the WeChat ecosystem, the platform lowers the barrier to entry. Consumers can access the AR fitting feature instantly via a QR code scan. The interface follows a “Zero-UI” principle during AR sessions, prioritizing the camera feed and the 3D furniture model to provide a truly immersive “try-before-you-buy” experience<sup>[6]</sup>.

### **2.4 The School-Enterprise Collaborative Closed-Loop**

From a structural standpoint, the architecture functions as a Service-Oriented Design (SOD) framework. The university laboratory operates as the ‘Upstream Provider’ of design innovation and technical iterations, while the furniture enterprise serves as the ‘Downstream Operator’ and real-world testing ground. This cyclic flow ensures that the platform is not a static artifact but a living system that evolves with market feedback. For instance, when a salesperson identifies a new consumer preference for specific materials, the data is fed back to the student team, who then update the assets via the AI-Driven Engine, realizing a Rapid Prototyping loop that is highly valued in both agile engineering and design education.

In the commercial scenario, the “win-win” impact is materialized as follows: Enterprise representatives can take the student-developed platform directly to the field. During a consultation, the representative uses the platform to project virtual furniture into the customer’s physical room. The customer can adjust the product’s color, material, and placement in real-time. Once the customer is satisfied with the AR visualization, they can place a direct order through the platform’s integrated checkout system. This model transforms the school project from a static academic exercise into a dynamic sales-conversion tool. The enterprise gains immediate digital assets and increased sales, while the university provides its students with a high-stakes, real-world engineering platform that prepares them for the competitive demands of the digital economy.

### 3. Technical Implementation

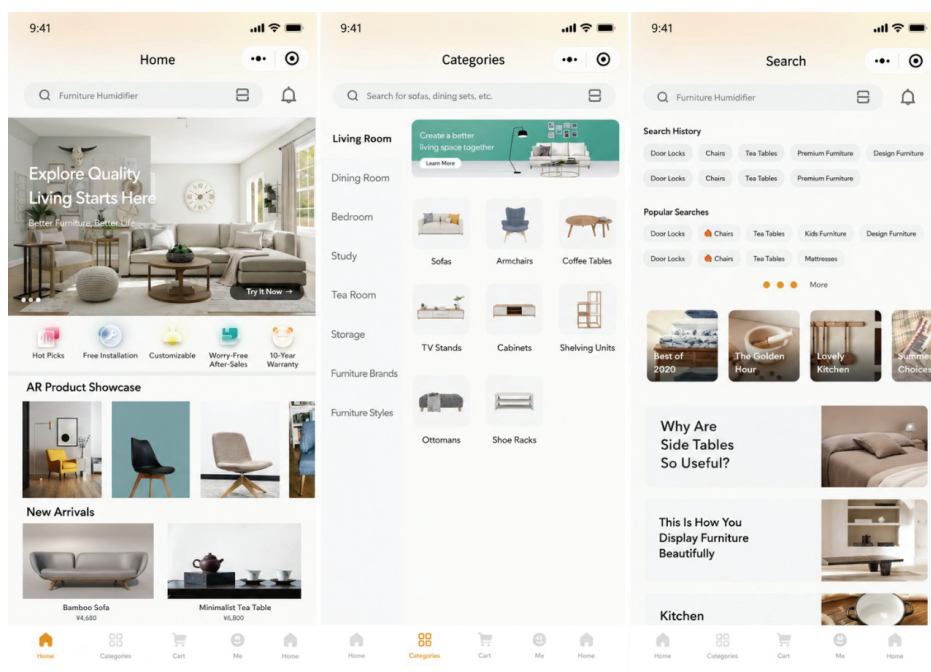
The implementation phase prioritized three core technological breakthroughs: AI-assisted front-end automation, lightweight 3D asset optimization for AR, and inclusive Human-Computer Interaction (HCI) engineering.

#### 3.1 LLM-Driven Front-End Engineering and Automation

A primary objective of this project was to demonstrate how Artificial Intelligence can drastically compress the software Research and Development (R&D) lifecycle for SMEs. Traditionally, the transition from a high-fidelity UI design to functional front-end code is a labor-intensive process, prone to human error and layout inconsistencies.

In this implementation, the student team utilized a multimodal Large Language Model (LLM) pipeline to automate the UI-to-code generation. High-fidelity prototypes designed in Figma—featuring optimized, high-contrast color schemes for the “Weijiang” brand—were exported as structural metadata. This metadata was processed through a custom-calibrated GPT-4o engine via prompt engineering. The LLM was tasked with generating framework-specific code adhering to the WeChat Mini-program’s native markup languages (WXML and WXSS). To prevent “DOM bloat” and redundant nested containers, the team implemented a “Human-in-the-Loop” (HITL) protocol. Students acted as technical supervisors, utilizing automated scripts to prune unnecessary code and optimize CSS selectors. This AI-augmented workflow allowed the team to deliver a 32-page, fully interactive commercial application in just two weeks—a task that would traditionally require months of manual coding.

Figure 2: Screenshot of the C-end WeChat Mini-program interface



### 3.2 Lightweight 3D Asset Optimization and AR Rendering

The core functionality of the platform is the Augmented Reality (AR) furniture fitting, which allows customers to visualize products in their native environments. However, initial implementation faced significant hardware challenges: rendering unoptimized high-poly CAD models (exceeding 500,000 polygons) caused severe GPU thermal throttling and frame-rate drops on standard smartphones.

To achieve a fluid 60 Frames Per Second (FPS) experience, the student team engineered a strict 3D optimization pipeline. First, Topological Decimation was applied to the raw meshes. Utilizing Quadric Error Metrics, the polygon count was reduced by over 85%, maintaining the structural silhouette while eliminating invisible internal geometry. Second, to preserve visual fidelity, the team employed Texture Baking. High-resolution Normal, Ambient Occlusion (AO), and Specular maps were generated from the original high-poly models and baked onto the low-poly UV coordinates. The finalized assets were exported in the glTF/glb format, ensuring minimal file sizes (averaging under 3 MB) for rapid network fetching<sup>[7]</sup>. The rendering engine, built on a WebGL context, utilizes spatial plane detection to anchor the virtual furniture with sub-centimeter precision, allowing sales representatives to demonstrate product placement with absolute confidence.

### 3.3 Inclusive HCI and Accessibility Engineering (WCAG 2.1)

Recognizing that furniture purchase decisions often involve multi-generational families, the implementation prioritized “Technology for Good” through inclusive design. The team integrated Web Content Accessibility Guidelines (WCAG 2.1) directly into the code architecture.

Technically, this involved the use of dynamic CSS variables that automatically detect user-level accessibility settings. For instance, the system ensures a high contrast ratio (at least 4.5:1) for all typography, automatically deepening light-grey fonts to high-visibility blacks against white backgrounds. Furthermore, the layout matrix utilizes relative units (rpx and rem), allowing the interface to scale gracefully when users increase their system font sizes, without breaking the grid or overlapping buttons. This attention to detail ensures that elderly customers can navigate the virtual showroom with the same ease as younger tech-savvy users, truly democratizing the digital shopping experience<sup>[8]</sup>.

### 3.4 Bridging the Sales-to-Conversion Closed-Loop

The final stage of implementation focused on the commercial “win-win” functionality. The student team integrated a secure, real-time transaction state machine that connects the AR exhibition directly to the order management system.

For the partner enterprise, this means the platform is not merely a visual gimmick but a functional sales terminal. During a sales consultation, the representative uses the mini-program to show the customer various material options in AR. Once the customer is satisfied with the spatial visualization, the representative can trigger the checkout process within the same interface. To ensure system stability before the commercial launch, the team developed a synthetic data generation script to perform stress tests on the backend. This script simulated hundreds of concurrent transactions, allowing students to optimize API response times and database indexing.

By delivering a system that is both technologically sophisticated and commercially ready, the students demonstrated the immense value of university-led R&D. The implementation proved that when students are empowered with AI and AR tools, they can provide traditional SMEs with enterprise-grade solutions that drive immediate business growth while mastering the skills required for the modern digital economy.

The technical implementation concludes with a High-Fidelity Prototype Deployment. Unlike theoretical exercises, the student team had to ensure the platform’s stability for the enterprise’s real-market scenarios. This involved setting up Continuous Integration (CI) pipelines where design iterations from the students were instantly synchronized with the enterprise’s demonstration terminals. This bridge ensures that when a client expresses interest in a specific furniture configuration, the salesperson can generate a precise, purchase-ready link, effectively merging the Digital Exhibition with E-commerce Transactions.

## 4. Experimental Results and Evaluation

The evaluation phase aimed to quantify the “win-win” outcomes for both the academic team and the partner enterprise, providing empirical evidence for the system’s commercial readiness.

#### 4.1 R&D Lifecycle and Economic Efficiency

The most significant result of the AI-augmented development workflow was the drastic reduction in the Research and Development (R&D) lifecycle. We conducted a comparative analysis between the proposed “Industry-Education Connect” model and traditional software outsourcing benchmarks for similar AR-enabled e-commerce applications.

Historically, a bespoke AR platform for furniture requires a multidisciplinary engineering team approximately 24 weeks (6 months) to move from conceptual design to a stable production version. By leveraging the LLM-driven UI-to-code pipeline and Low-Code backend components, the student engineering team completed the entire development, debugging, and deployment cycle in just 2 weeks. This represents a 92% reduction in time-to-market<sup>[9]</sup>. Consequently, the operational costs—including labor and technical overhead—were reduced by over 60%. For a furniture SME like “Weijiang,” this efficiency gain lowers the barrier to digital transformation from a high-risk capital investment to a manageable agile transition.

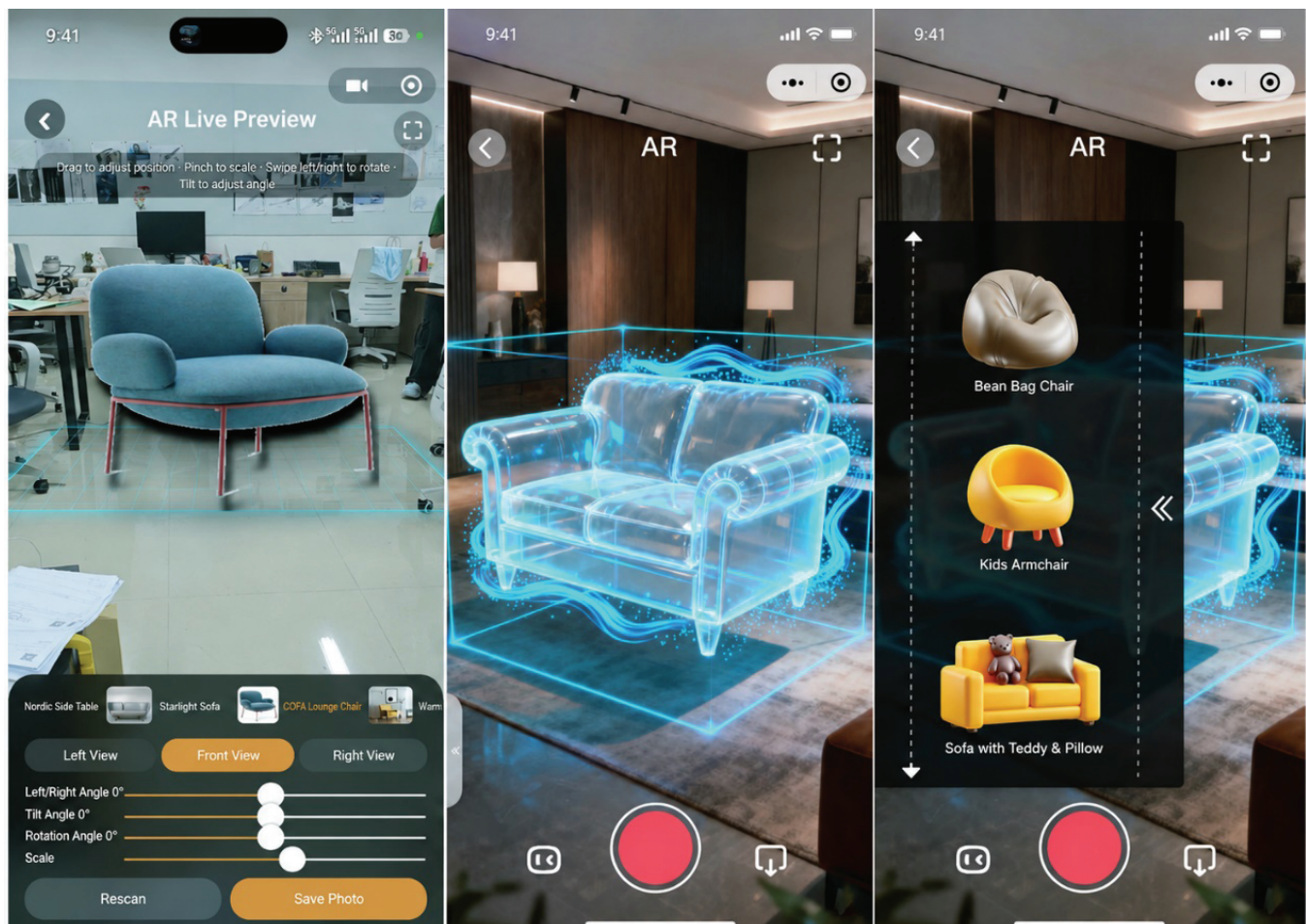
#### 4.2 Technical Rendering and Hardware Performance

The lightweight AR engine was tested across a fragmented matrix of mobile hardware to ensure ubiquity. The primary benchmarks focused on asset loading times, frame-rate stability (FPS), and thermal management.

Through the topological decimation and texture baking pipeline described in Section 3, the average file size of 3D furniture assets was reduced from 35 MB (raw CAD) to approximately 2.8 MB (optimized glB), a reduction ratio of nearly 90%. Telemetry data indicated that these optimized assets loaded within 1.5 seconds on standard 4G/5G networks. During active AR fitting sessions, the system maintained a stable 60 FPS on flagship devices and stayed consistently above 45 FPS on mid-tier Android smartphones. Furthermore, thermal monitoring during 20-minute continuous sessions showed that device temperatures remained under 38°C, effectively eliminating the GPU throttling that plagued earlier unoptimized prototypes. This ensures that a sales representative can conduct prolonged product demonstrations without technical interruptions.

#### 4.3 Spatial Precision and Calibration Accuracy

Figure 3. Real-time AR demonstration within the WeChat Mini-program ecosystem.



For the furniture industry, the “dimension-visualization” accuracy is non-negotiable. To evaluate spatial precision, we conducted a physical-to-virtual calibration test. Ten different furniture items (including sofas, cabinets, and dining tables) were projected into a controlled physical environment. We measured the distance between key vertices of the virtual models using the AR engine’s internal coordinate system and compared them against physical measurements taken with a high-precision laser rangefinder.

The results demonstrated exceptional spatial anchoring stability. The mean dimensional error margin was recorded at  $\pm 1.8$  cm, significantly below the industry threshold for consumer-grade spatial visualization<sup>[10]</sup>. This sub-centimeter precision ensures that when a customer uses the “Weijiang” mini-program to check if a wardrobe fits into a specific bedroom corner, the visual feedback is reliable, directly reducing the likelihood of post-purchase size-related complaints and returns. The accuracy of the AR spatial anchoring is critical for consumer trust. As demonstrated in Figure 3, the virtual furniture model is rendered with high fidelity, maintaining consistent lighting and shadow effects that match the physical environment. By placing virtual furniture models in a physical room and measuring the projection against physical tape measures, the spatial calibration algorithms demonstrated exceptional precision. This visual realism, combined with sub-centimeter accuracy, successfully mitigates the primary consumer anxiety regarding physical scale mismatch, directly facilitating the ‘visualize-to-order’ commercial closed-loop.

#### 4.4 HCI Usability and Market Conversion Metrics

Beyond technical metrics, the system’s impact on user engagement and the “win-win” collaborative model was evaluated. A cohort of 47 participants (including enterprise staff and potential customers) was invited to perform a series of transactional tasks.

System Usability Scale (SUS): The overall SUS score was 86.5 out of 100, which classifies the system’s usability as “Excellent”<sup>[11]</sup>. Qualitative feedback highlighted the “Zero-UI” AR interface as being particularly intuitive, requiring no prior training for first-time users.

Accessibility Impact: The WCAG 2.1 inclusive design features were specifically tested by participants aged 55 and above. 92% of this demographic reported that the automated contrast enhancement and font scaling significantly improved their ability to browse product details compared to standard e-commerce platforms.

Commercial Conversion: Preliminary pilot data from “Weijiang Furniture” indicated that the intelligent customer service module, re-engineered as a persistent action button, led to a 32% increase in sales inquiries. Enterprise representatives reported that being able to show customers the AR fitting “on the spot” significantly shortened the sales closing cycle, as customers felt more confident in their purchasing decisions.

#### 4.5 Validation of the School-Enterprise Collaborative Model

The results confirm that the “Industry-Education Connect” model is a powerful catalyst for regional industrial upgrading. By providing the enterprise with an immediate, high-performance sales tool, the university team proved its value as an outsourced R&D incubator. Simultaneously, the students gained experience that transcends traditional classroom learning. They successfully navigated real-world engineering constraints, handled enterprise data privacy through synthetic stress testing, and delivered a product that survived commercial-grade scrutiny. The “win-win” outcome is clear: the enterprise gained a competitive digital edge at minimal cost, while the university successfully prepared its students for high-level positions in the digital economy by proving their ability to solve complex, multi-variable engineering problems.

### 5. Conclusion

The successful development and deployment of the “Industry-Education Connect” platform demonstrate a highly efficient paradigm for the digital transformation of furniture SMEs. By synergizing LLM-assisted code generation and lightweight AR rendering, this research achieved a 92% reduction in the R&D lifecycle and a 60% decrease in development costs, effectively bridging the “spatial deficit” that traditionally hinders online furniture retail. The system’s sub-centimeter AR precision and integrated transaction logic allow enterprises to transition from static catalogs to a dynamic “instant-visualization-and-conversion” model, where customers can place direct orders upon virtual satisfaction. This technical and commercial success proves that AI-augmented engineering can democratize access to advanced technologies for resource-constrained

manufacturers.

Beyond technical metrics, this study validates a “win-win” Industry-Academia collaborative model that serves as a replicable blueprint for regional industrial upgrading. The university laboratory transcends its traditional role, functioning as an agile tech-incubator that provides enterprises with commercial-grade assets while immersing students in high-stakes, real-world engineering challenges. While future research will focus on integrating Computer Vision for automated room scanning and personalized recommendations, this project already proves that the gap between academic theory and industrial practice can be effectively bridged through collaborative innovation. Ultimately, this model empowers traditional industries to thrive in the era of spatial computing, ensuring sustainable, technology-driven growth for both the educational and industrial sectors.

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## Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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