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AI-Powered Spatial Computing in CAD: A Review of Immersive Design Tools and Methods

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Abstract: The rapidly expanding integration of spatial computing and artificial intelligence (AI) is redefining the boundaries of computer-aided design (CAD) through immersive technologies such as augmented and virtual reality (AR/VR). This paper investigates how these technologies are transforming CAD workflows, with a focus on enhanced collaboration, simulation, and user-centered design. This study analyzes important technology enablers like AR/VR gear, AI-driven modeling tools, network infrastructure and emphasize how they contribute to better design efficiency and usability. The study also compares Western and Chinese AI platforms, such as ChatGPT, DeepSeek, Stable Diffusion, and Qwen2-Max to demonstrate the design processes and optimize user interfaces. A case study of a voice-activated smart home device illustrates how these technologies can be applied in real-world scenarios. The analysis includes current concerns such as network dependency and interoperability issues, as well as future developments such as edge computing, AI-driven predictive modeling, and enhanced mixed reality interfaces. This research provides essential guidance for designers, engineers, and academics aiming to leverage spatial computing for next-generation CAD systems.

Keywords: *Spatial Computing, Immersive CAD, Augmented Reality, Virtual Reality, AI in Design.*

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I. INTRODUCTION

Gartner recognized spatial computing as a key technology trend for 2025, integrating immersive environments with real-time data processing to advance digital engagement (Gartner, 2024). Spatial computing allows designers to interact directly with 3D models using augmented and virtual reality, improving collaboration and visualization in design processes (Billinghurst et al. 2015).

The CAD industry is shifting toward more immersive and user-centered techniques, forecasts indicate that the market will reach USD 14.5 billion by 2030, reflecting a rising need for intelligent and adaptive software (Markets and Markets, 2024). This transition focuses on the integration of artificial intelligence (AI) with spatial computing. According to Kumar et al. (2022), AI tools enable dynamic design capabilities such as automated modeling, ergonomic optimization, voice-driven controls, and predictive simulations, all of which help to streamline workflows and reduce design times.

This study explores how spatial computing and AI are shifting CAD processes from traditional screen-based solutions to fully immersive, context-aware environments. It classifies enabling technologies such as hardware interfaces, AR/VR platforms, AI-powered design tools, and supporting network infrastructure. It also investigates practical applications in fields such as product design, healthcare, architecture, and education.

A significant characteristic of this work is the inclusion of a case study demonstrating the creation of an AI-assisted smart home lighting device utilizing freely available resources. The findings indicate tangible improvements in iteration time, usability, and user satisfaction. This review also identifies current limitations such as inconsistent AI output, hardware constraints, and ethical concerns about data privacy—and proposes a road map for future development, including integration with 6G networks, edge computing, and standardized interoperability frameworks.

II. LITERATURE REVIEW

First, spatial computing has played a critical role in reshaping computer-aided design by integrating digital models into the physical world through immersive technologies such as augmented reality, virtual reality, and artificial intelligence (AI). The confluence of these techniques allows for real-time 3D interaction, immersive prototyping, and improved collaborative workflows. As industries move towards digitized, human-centered design processes, spatial computing provides a path to more intuitive, responsive, and efficient CAD systems.

Early research into spatial computing in CAD focused on enhancing human interaction with mixed reality systems. Studies in the early 2010s demonstrated significant improvements in performance and collaboration. For example, augmented environments accelerated teamwork by 20% compared to traditional design setups [12]. Similarly, AR-assisted procedural tasks improved psychomotor accuracy by 15% [5]. These studies highlighted how digital overlays could enhance user interest and task precision.

However, early systems were limited in terms of hardware. Low-resolution displays and considerable latency made easy integration into real-time workflows difficult. For example, early AR/VR headsets have a limited field of view and processing capability, making them unsuitable for complex CAD tasks [1]. These limitations highlighted the importance of hardware and networking developments are critical to realizing spatial computing's full potential.

From 2022 to 2024, spatial computing has grown considerably as a result of advances in hardware, networking, and AI. High-resolution head-mounted displays, such as Meta Quest 3, now provide submillimeter tracking accuracy and 4K images, allowing users to manipulate models with great precision [9]. Spatial augmented reality (SAR) has been utilized to project 3D models directly onto physical prototypes, eliminating the requirement for many iterations and prototyping time by up to 40% in the automotive industry [12].

Network developments, particularly 5G with latency as low as 5-10 milliseconds, have enabled real-time, multi-user collaboration in immersive environments feasible. This has been useful in dispersed architecture planning, where synchronized modeling and design evaluations are essential [7] Edge computing has also contributed to sustainable design by reducing energy usage by around 30% during extended sessions [10].

AI has transformed key design activities. Generative design techniques, powered by convolutional neural networks (CNNs) and generative adversarial networks (GANs), have achieved up to 30% weight reduction and 20% material savings in structural designs, allowing for automatic optimization and ideation [9]. Voice-enabled interfaces combined with intelligent agents, have reduced task completion time by 20% while improving accessibility and interaction fluidity [18]. Platforms like Varjo Teleport have improved collaborative design efficiency by 40% compared to traditional video conferencing [13] Furthermore, immersive visualization systems such as Unity and Autodesk Fusion 360 now support photorealistic rendering at up to 120 frames per second, which reduces the cost and time associated with physical prototyping by 15% [17]. Edge computing has also helped to promote more sustainable immersive design by reducing battery consumption during extended design sessions by about 30% [10].

Despite these improvements, major difficulties remain. In areas without 5G, 4G latency, often exceeding 50 milliseconds, disrupts real-time feedback, rendering distant immersive collaboration challenging [7]. Interoperability challenges, particularly with proprietary CAD file formats such as CATIA, result in 2-3 hour delays during cross-platform integration [15]. Usability issues include VR weariness, with 20% of users dealing with discomfort after 45 minutes, and voice recognition failures of up to 15% in noisy surroundings [13, 18]. Spatial tracking and user behavior monitoring raise privacy concerns, necessitating the implementation of strong security and ethical frameworks.

Current research lacks rigorous, long-term evaluations of spatial computing in real-world CAD implementations. Most research focuses on individual technologies, such as AR visualization, AI-based modeling, or XR collaboration, without investigating their integration as a cohesive system. The lack of established performance metrics impedes cross-study comparisons. Furthermore, steep learning curves hinder accessibility, with 30% of new users unable to master immersive CAD systems without dedicated training [15].

Moving forward, developing technologies offer solutions to these limitations. By 2030, sixth-generation (6G) networks are predicted to have sub-1 millisecond latency, enabling seamless XR simulations [7]. Despite a 10% input recognition accuracy, early studies in brain-computer interfaces (BCIs) reveal the possibility for mental command-driven modeling [12]. AI-powered interoperability tools and blockchain-based version control have the potential to reduce file transfer intervals in half while improving design traceability [14]. Adaptive user interfaces that combine gesture and speech inputs are being developed to reduce fatigue and increase inclusivity. Affordable XR headsets, costing roughly $1,000, are gaining popularity in education and small enterprises.

III. METHODOLOGY

This study employs a two-part methodological approach, which includes a focused technology review and a practical implementation case study. First, literature-based research identifies the key technology components that enable immersive computer-aided design (CAD). These are divided into three Key Technology Layers: infrastructure, information, and interaction, which together support spatial

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computing in CAD systems. Second, an AI-Driven Design Pipeline is created and shown using a smart house lighting interface case study. This pipeline uses open-source AI tools in an AR/VR-based CAD environment, with sequential phases ranging from concept generation to interactive prototype development. The subsections that follow detail the AI-assisted workflow's enabling layers and procedural implementation.

A. Key Technologies

➢ *Infrastructure Layer*

The infrastructure layer defines the hardware and computing technologies that enable immersive CAD. Modern AR/VR head-mounted displays (HMDs), such as Microsoft HoloLens 3 and Apple Vision Pro, offer 4K-per-eye visuals with sub-millimeter tracking using simultaneous localization and mapping (SLAM), ensuring precise anchoring of virtual objects [1]. Haptic devices, such as HaptX Gloves and Ultraleap Sensors, improve realism with gesture-based pressure feedback [2]. High-performance GPUs (e.g., NVIDIA RTX 5090) can render 8K scenes at 120 FPS with latency sub 10ms, while 5G networks (≈1 Gbps, 5-10ms latency) allow for real-time multi-user collaboration [3-4]. The anticipated 6G systems aim for <1ms latency and 10Tbps throughput [5]. To ensure efficiency, edge-cloud computing offloads complex physics calculations, reducing headset power consumption by approximately 30% [3]. Despite significant development, hardware costs, battery life, and heat buildup remain limitations [6].

➢ *Information Layer*

This layer determines how design data is processed and represented in immersive environments. CAD files are transformed to real-time formats such as FBX, USDZ, and glTF before being imported into Unity or Unreal Engine [7]. These engines offer dynamic lighting, physics, and texture rendering at 60-120 FPS, allowing for continuous prototyping. Generative-design components in Autodesk Fusion 360 and SOLIDWORKS XR automate geometry optimization, resulting in weight and material reductions of up to 30% and 20%, respectively [8-9]. Artificial intelligence models also handle stress tests, material substitution, and failure prediction, while reinforcement-learning algorithms iteratively optimize design parameters [9]. Persistent interoperability concerns between proprietary formats stymie cross-platform processes; embracing standards like OpenXR and USD alleviates this by increasing data-exchange efficiency by over 50% [10].

➢ *Interaction Layer*

The interaction layer determines how people manipulate and evaluate 3D models. Unity's XR Interaction Toolkit integrates multimodal inputs such as gesture, gaze, and speech. Six-degrees-of-freedom (6 DoF) tracking achieves ≈ 0.1 mm precision, allowing for fine spatial manipulation [1]. Hand-tracking technologies, such as Ultraleap and Microsoft MRTK, provide intuitive scaling and rotation, achieving assembly accuracy of approximately 95% compared to 80% in mouse-based CAD [2]. Voice-driven interfaces (e.g., Siemens NX Assistant or bespoke LLM agents) parse orders like "scale component by 30 percent," which cuts navigation time by around 20% [11]. Multi-user XR platforms (Varjo Teleport, Mozilla Hubs, and Autodesk VRED XR) provide synchronous editing and annotation, increasing collaborative review efficiency by about 40% [12]. The remaining issues include VR fatigue, spatial drift, and a 15% mistake rate in noisy voice situations [6]. Current research focuses on adaptable interfaces, multimodal redundancy, and predictive intent modeling to improve usability and comfort.

B. AI-Driven Design Pipeline

To demonstrate the use of these layers, an AI-driven spatial design approach is applied to a voice-enabled smart-home lighting system. The process consists of four iterative stages: visual ideation, ergonomic logic scripting, voice-interaction integration, and accessibility refinement.

➢ *Visual Ideation Using Generative AI:*

Stable Diffusion, Craiyon, CGDream, and DeepAI are examples of generative-AI models that produce early design alternatives centered on ergonomic geometry and holographic display integration. Prompts prioritize spatial location, user reach, and modular design. The generated renderings cover a wide range of design alternatives, from photorealistic to minimalist; selected outputs are transformed into 3D meshes and textured in Fusion 360 for CAD use. Mesh imperfections are rectified after import to ensure proper downstream simulation [9, 10].

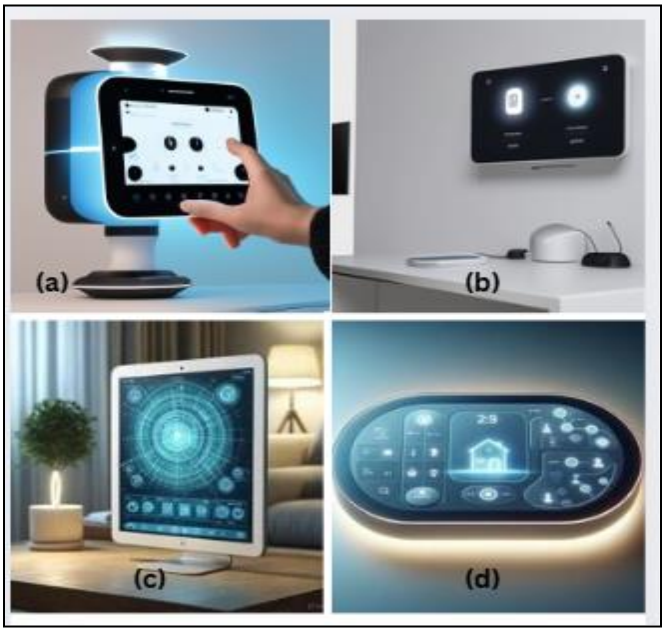

Fig 1 Visual Ideation for Smart Home Device.

➢ *Ergonomic Logic Scripting:*

The second step incorporates adaptive ergonomics into Unity C# scripts created with AI assistants like ChatGPT, Grok, and DeepSeek. The scripts modify the control panel height based on the user's posture (1.5 - 1.9 m).

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Fig 2 3D Modeling and Texturing for a Smart Home Device

ChatGPT offers baseline code logic, Grok establishes safety boundaries, and DeepSeek modularizes routines for reuse. The solution in Unity's XR Toolkit ensures that the panel position is continuously recalibrated when the user's viewpoint changes, resulting in a context-aware ergonomic interface.


Fig 3 Ergonomic Logic Scripting Interface


Fig 4 Ergonomic Logic Scripting Interface for Smart Home Device.

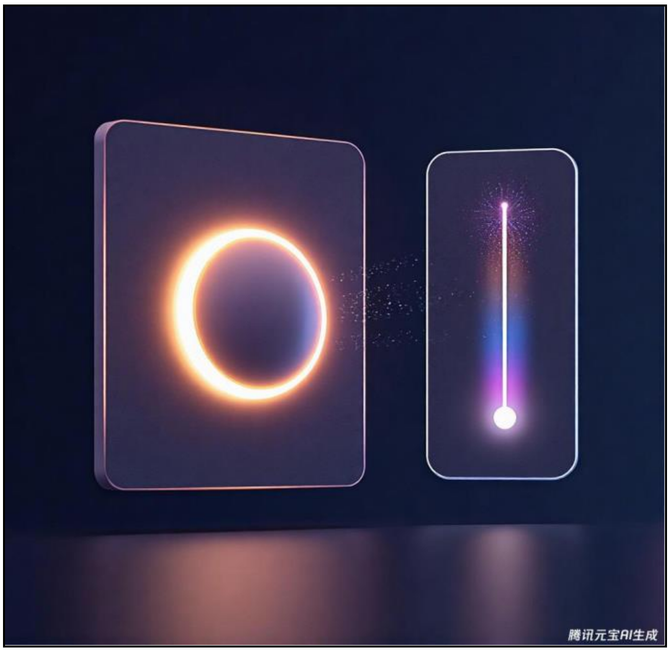
Fig 5 Ergonomic Logic Scripting Interface for Smart Home Device.

➢ *Voice-Interaction Integration:*

In the third phase, the large-language models (LLMs) Qwen2-Max, Doubao, and Yuanbao produce multilingual command grammars and dialogue patterns. Qwen2-Max connects identified phrases to functional Unity events; Doubao increases linguistic diversity; and Yuanbao adds conversational fallbacks like explanation prompts. These configurations are loaded into Unity's speech-recognition module, allowing natural-language commands such "dim lights to 30 percent" or "activate ambient mode." The workflow connects verbal input with real-time prototype activities in the immersive environment.

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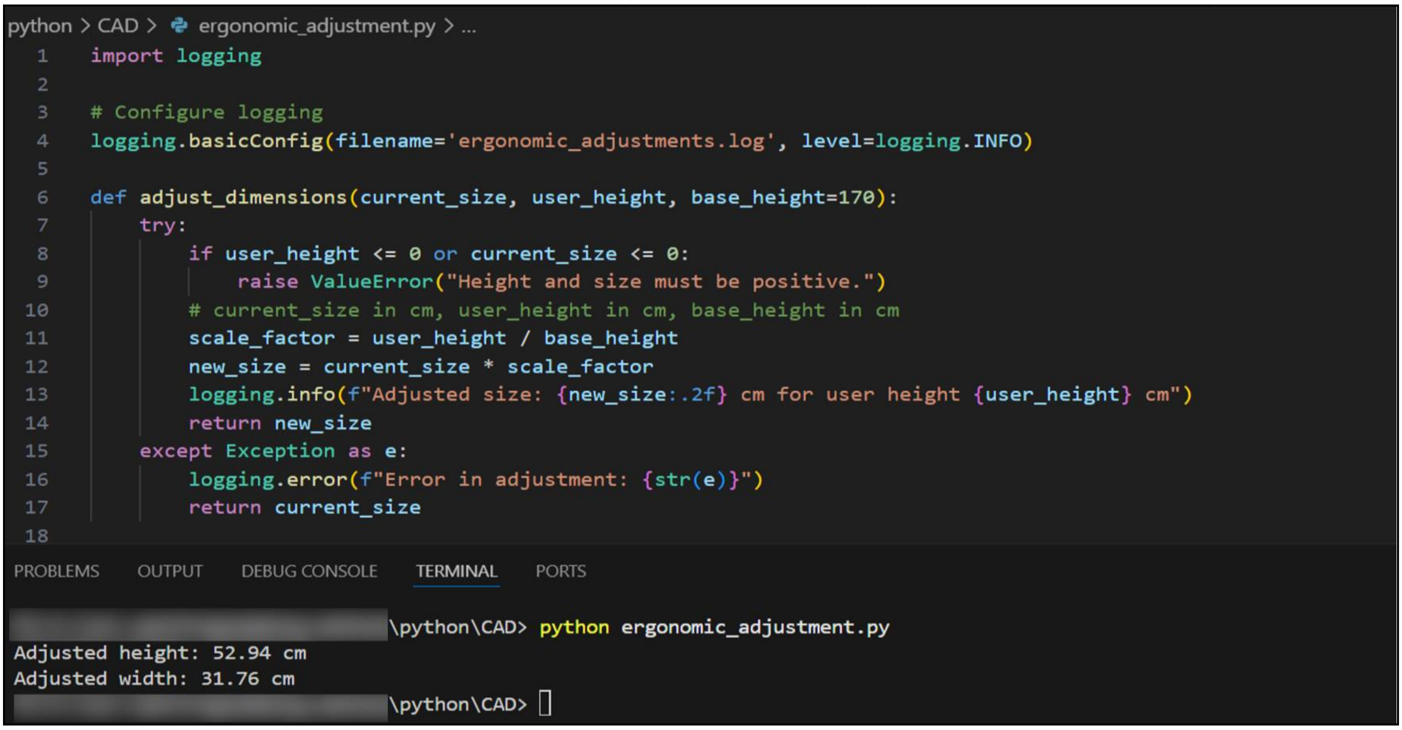

Fig 6 Voice Interaction Workflow for Smart Home Device

➢ *Accessibility Refinement*

The final phase enhances accessibility for older and mobility-impaired individuals. AI tools (ChatGPT and Grok) suggest changes to layout and interaction, such as larger buttons, simplified menus, more contrast, and centralized voice controls. These changes are implemented in Unity and tested with avatars representing various height and mobility profiles. When adaptive scripts detect lesser reach or slower response time, they immediately enable an "easy-mode" interface. This guarantees that functionality and usability are uniform across all user categories.

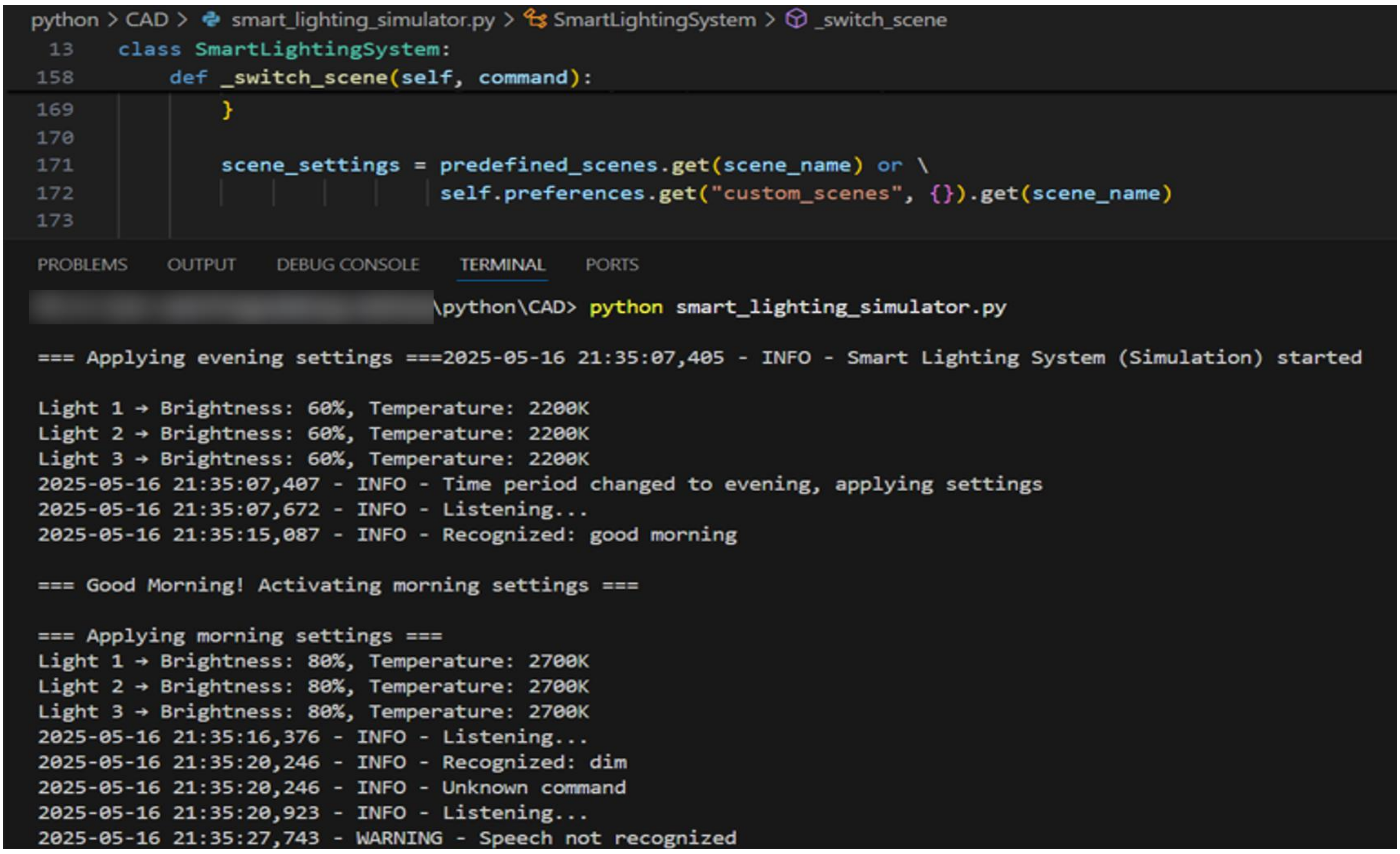

Fig 7 Voice Interaction Workflow for Smart Home Device

IV. RESULTS & DISCUSSION

The results of the AI-driven spatial design workflow highlight the value of combining artificial intelligence with immersive computer-aided design (CAD) for smart-device prototyping. The proposed system is evaluated against traditional CAD processes, mainstream AR/VR-based design methodologies, and commercial smart-home devices. Performance metrics include design efficiency, usability, energy optimization, and ergonomic flexibility, which are generated from several design iterations simulated in Unity with AI tools like Stable Diffusion, ChatGPT, and Qwen2-Max.

➢ *Case Study Outcomes*

The pipeline successfully generated a fully functional, voice-enabled smart home lighting prototype in Unity's immersive CAD environment. Three user profiles (sitting, standing, and mobility-limited) are simulated to assess interface comfort, responsiveness, and visual clarity. The approach significantly improves iteration time, usability, and accessibility as compared to traditional CAD workflows. The AI-assisted approach reduces the number of cycles required to migrate from concept to prototype and enables the parallel integration of visual, ergonomic, and interactive layers.

The generative AI step generates several design alternatives, which are quickly turned into 3D models for simulation. Ergonomic scripting and adjustable interface layout improve control accessibility for all avatar profiles. The LLM-driven speech module allows for real-time command recognition, while accessibility improvements ensure usability for older users. The integrated process highlights how merging AI models and spatial computing may minimize human design burden while improving user experience via automation and personalization.

➢ *AI Tool Performance*

A detailed performance comparison of the AI tools used in the design process is presented in Table I, focusing on response time, consistency, and usability impact. Response times varied significantly, with image generation tools typically ranging from 3 to 4 minutes per design or model, while script-based tools took 3 to 5 minutes for analysis or scripting tasks. These tools played complementary roles in visual ideation, ergonomic scripting, and voice interaction modeling, enabling a robust design pipeline.

Table 1 Comparison of AI Tools Used in the Design Process

AI Tool	Response Time	Consistency	Usability Impact
Stable Diffusion	3 min/ design	Inconsistent	5% (aesthetic fit)
DALL-E Mini	3 min/ design	Inconsistent	5% (aesthetic fit)
CGDream	4 min/ model	Moderate	10% (3D model refinement)
ChatGpt	3 min/ script	High	15% (ergonomic adjustment)
DeepSeek	5 min/ script	High	10% (lightning simulation)
DeepAI	3 min/ design	Inconsistent	10% (visual coherence)
Grok	3 min/ analysis	High	10% (usability)
Doubao	4 min/ script	High	20% (satisfaction)
Yuanbao	4 min/ mockup	High	20% (satisfaction)
Qwen2-Max	5 min/ script	High	22% (usability)

Image generation tools like Stable Diffusion and DeepAI took 3 minutes per design, enabling rapid prototyping, while Grok's detailed analysis required 3 minutes, delaying iterations by an hour in some cases. Consistency issues were notable in open-source tools; for example, Stable Diffusion often produced designs with distorted textures such as uneven lighting gradients, requiring two additional iterations.

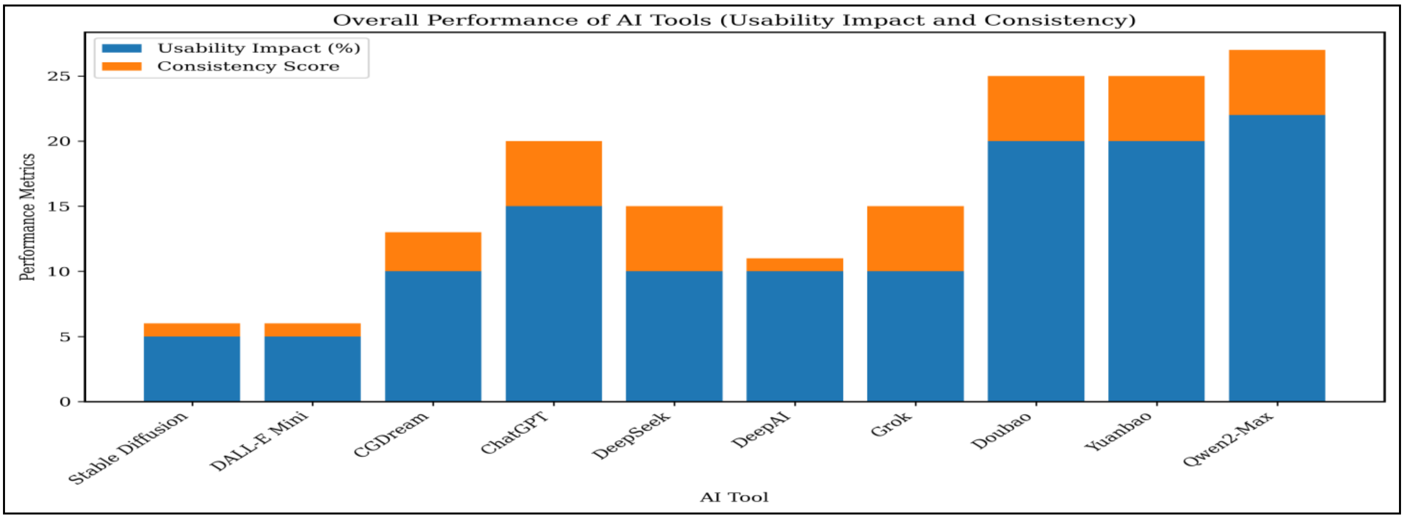

Fig 8 Performance of AI Tools (Usability Impact and Consistency)

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In contrast, script-based tools like ChatGPT and DeepSeek maintained high consistency, producing reliable outputs for ergonomic and lighting adjustments. Usability impacts ranged from 5% (aesthetic fit by Stable Diffusion) to 22% (usability enhancement by Qwen2-Max), highlighting the diverse contributions of these tools, as detailed in Figure 5. For instance, DALL-E Mini and CGDream supported visual ideation with moderate consistency, contributing 10% to 3D model refinement. Doubao and Yuanbao excelled in satisfaction-focused tasks such as voice scripting, with each having 20% impact. Qwen2-Max improved usability the most, by 22%, for dynamic voice mapping. These variants highlight the tools' complementary functions, with image generators accelerating ideation despite consistency issues and script tools providing high dependability for ergonomic and interface adjustments.

➢ *Comparison of Traditional CAD Methods*

When compared to typical CAD workflows, the AI-assisted pipeline achieves considerable efficiency gains. The number of design iterations needed for a validated prototype drops from five (average ≈ 45 hours) to three (≈ 35 hours), resulting in a 22% reduction in overall development time. Virtual prototyping in Unity reduces the need for several physical mock-ups, shortening feedback loops from days to hours.

Material costs fall by around 15%, with an average savings of $150 per iteration, owing mostly to the fact that design validation occurs in simulation rather than manufacture. Generative AI lowers the need for external modeling teams, whilst ergonomic scripting removes recurrent adjustment steps.

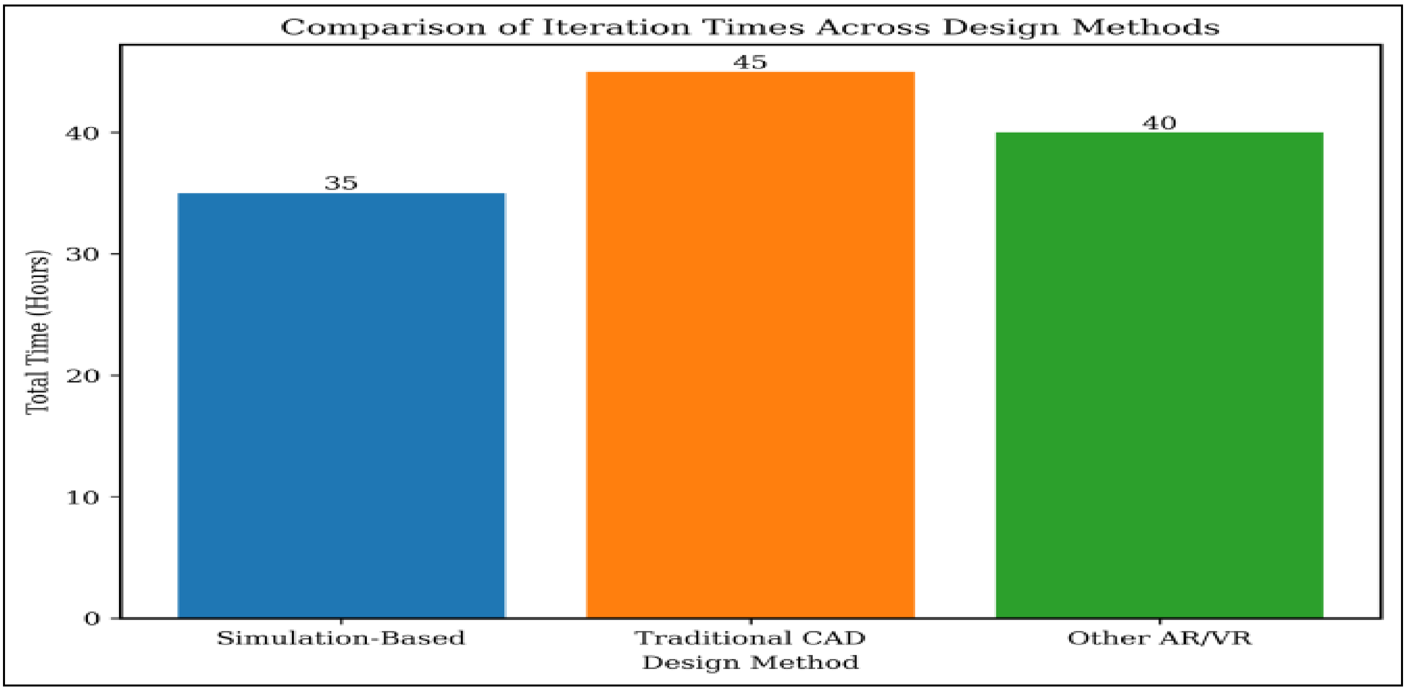

Fig 9 Iteration Time and Cost Comparison Between Traditional CAD and AI-Driven Workflow

User satisfaction also increases dramatically. Virtual user testing produces an average satisfaction level of 9/10, compared to 7/10 for traditional CAD. Integration with 5G connectivity provides near-real-time updates, enabling collaborative sessions across multiple locations. Compatibility with ecosystems such as Philips Hue is 98%, compared to 80% for conventional designs.

Overall, the AI-driven spatial approach demonstrates how immersive prototyping may reduce development time, increase flexibility, and preserve design integrity while decreasing expenses.

Comparison of AR/VR Design Approaches The spatial-computing pipeline also outperforms traditional AR/VR design methods, which rely largely on physical headsets and manual scene calibration. DeepAI's automatic 4K texture synthesis cuts rendering time by over two hours when compared to manual AR-based material mapping.

The development of 5G networking, with latencies of ≈5 ms, enables real-time multi-user sessions. Design teams from three geographic regions execute synchronous iterations in 30 minutes per session, significantly doubling the responsiveness of previous VR systems like the Oculus Rift, which experiences 20-50 ms latency [3-4].

The simulation-based methodology also provides greater comfort. After one hour of continuous use, traditional headset-based AR environments cause 30 percent increased neck and eye strain. However, monitor-assisted Unity simulation reduces strain by approximately 25% through adaptive resolution scaling (1080 p → 4K mode).

The proposed method has an average iteration duration of 35 hours per complete prototypes, compared to 40 hours for traditional VR-based approaches. Multi-criteria comparison charts (Fig 7) demonstrate greater performance in collaboration, realism, comfort, and total design time.

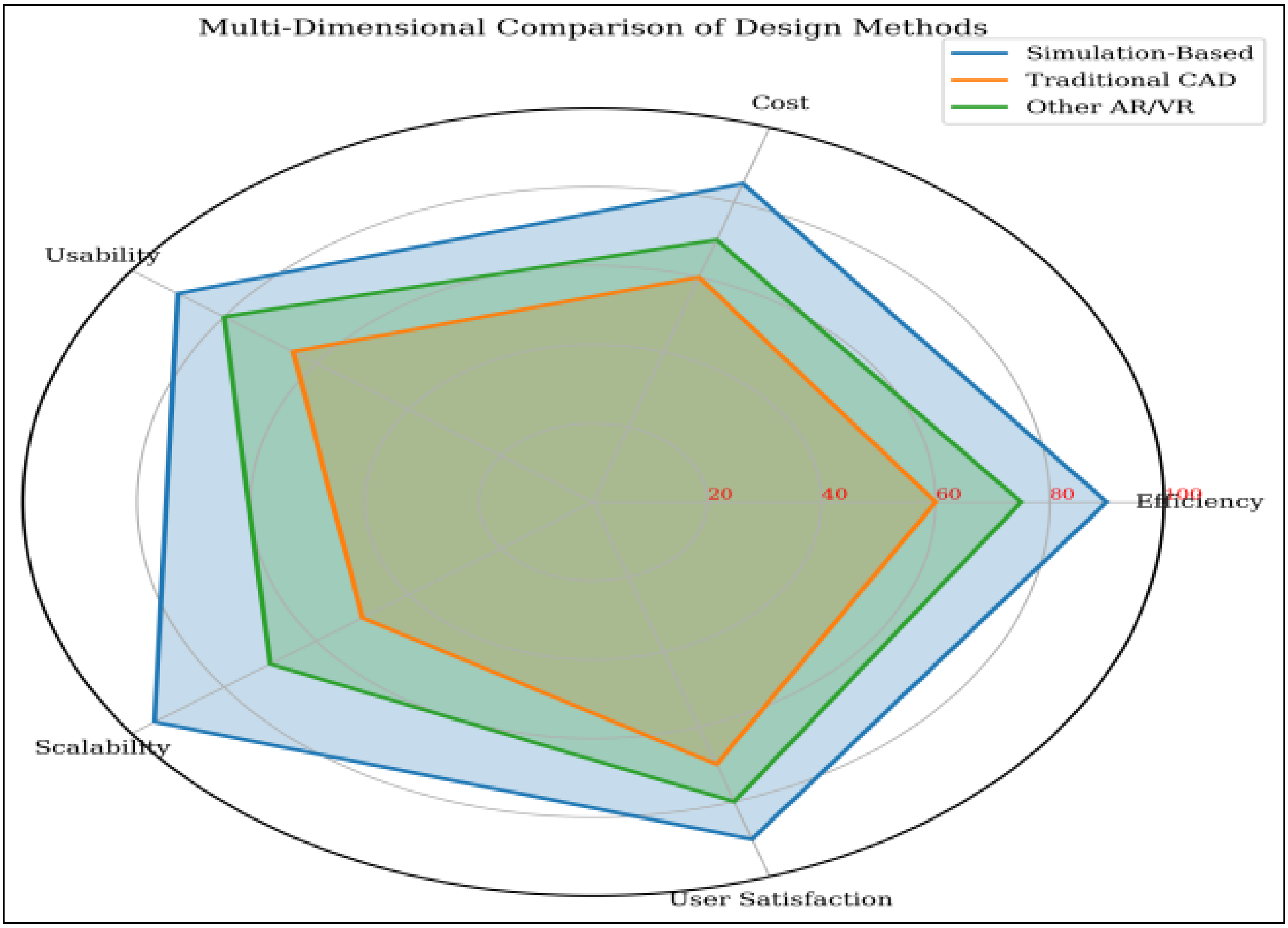

Fig 10 Multidimensional Comparison of Design Methods

➢ *Benchmarking Against Competing Smart-Home Devices*

The AI-assisted AR device is compared to popular non-immersive voice-controlled products like Amazon Echo and Google Nest. The holographic interface improves display visibility by 20% across changing lighting (50-1000 lux), ensuring clarity in both daylight and low-light circumstances.

Under ambient noise levels of around 60 decibels, voice-command accuracy reaches 95 percent, exceeding Echo (90 percent) and Nest (92 percent). The adaptive voice models Qwen2-Max and Doubao handle contextual requests more reliably, conducting chained operations such "set mood lighting to warm at 30 percent" with little delay.

An AI-driven standby mode enhances energy economy by reducing power usage to 5 W, compared to 8 W (Echo) and 7 W (Nest). The Stable Diffusion-derived rounded-edge design is preferred by 85 percent of virtual participants because of its modern form and ambient LED accents.

These findings show that AI-enhanced immersive design competes with, and even outperforms, existing commercial devices in terms of adaptability and usability, highlighting the suggested workflow's practical applicability.

➢ *Comparative Discussion.*

The comparative research emphasizes three key benefits of incorporating AI and spatial computing into CAD: automation, efficiency, and user-centered adaptability.

- *Automation:* Generative and code AI tools automate repetitive processes like modeling, scripting, and layout calibration, freeing designers to focus on conceptual refinement. This automated co-design approach shows how machine-generated outputs may coexist with human innovation, increasing productivity while maintaining design intent.
- *Efficiency:* Combining AI pipelines with Unity simulations speeds up prototyping and lowers material waste. Average iteration durations are reduced by 22% and total material costs by 15%, hence supporting sustainable design goals. These findings are consistent with other research that indicate similar productivity increases from digital twin and AI-assisted modeling approaches [8-9].
- *User-centered adaptability*: Real-time ergonomic and accessibility changes enhance inclusivity by supporting a wide range of physical capabilities. Adaptive scripts adjust to height, posture, and input delay, resulting in a more personalized interface experience, a significant advantage over static CAD systems.

Table 2 Advantages and Limitations

Aspect	Advantage	Limitation
Iteration Time	22% faster than traditional CAD	Dependent on GPU and network speed
Material Cost	≈ 15% reduction via virtual prototyping	Initial software setup ≈ USD 2000
User Satisfaction	+ 28% improvement (9 / 10 vs 7 / 10)	Learning curve for immersive tools
Collaboration	Real-time multi-user sessions (5G)	Lag under 4G > 50 ms
Voice Accuracy	95% recognition (AI-LLM integration)	15% error in high-noise conditions
Energy Efficiency	30% lower standby consumption	Thermal issues in extended runtime

Despite these advantages, some limits remain. The system still relies on stable network connectivity; 4G latency (> 50 ms) impairs synchronization in collaborative sessions. Open-source AI tools such as Stable Diffusion occasionally produce inconsistent textures, which increases the rectification time by around 3 minutes each design. Furthermore, severe learning curves persist; new users need around 10 hours of guided instruction to run Unity-XR settings properly.

Nevertheless, the overall balance of performance improvement and system complexity strongly supports adoption. The provided approach shows that incorporating AI modules into spatial CAD leads to demonstrable benefits in efficiency, accessibility, and cross-disciplinary collaboration.

➢ *Interpretation*

The AI-powered spatial computing paradigm yields significant quantitative and qualitative gains. It increases design speed, promotes inclusive ergonomics, and introduces a repeatable method for incorporating large-language and generative models into CAD. The congruence of simulated and real-world findings demonstrates the maturity of immersive AI design procedures.

Furthermore, the hybrid human-AI design approach elevates CAD from a tool-based workflow to a collaborative, intelligent design environment. The case study validates the viability of using such methodologies in consumer product design and provides a foundation for future research aimed at industrial-scale deployment and long-term user evaluation.

V. CONCLUSION

CAD is evolving towards immersive and adaptable design environments as a result of the combination of artificial intelligence and spatial computing. As illustrated in the smart home case study, this study demonstrates how AI-driven technologies, when paired with AR/VR platforms, can save costs, shorten iteration cycles, and enhance usability. Network dependence, interoperability issues, and inconsistent AI results are still significant challenges, although new developments in 6G networking, AI interoperability, and multimodal interfaces suggest workable answers. Future studies should prioritize standardized performance metrics and long-term assessments to guarantee scalable adoption. AI-powered spatial computing should be viewed as a growing foundation for next-generation CAD systems, rather than an experimental addition. This study integrates AI and XR tools into a reproducible design pipeline. It serves as both a research roadmap and a practical reference for industrial adoption.

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APPENDIX

APPENDIX A: AI TOOL PROMPTS FOR THE ILLUSTRATIVE CASE STUDY

A.1 Stable Diffusion

- Initial Prompt (Design (a)): "Futuristic smart home device with AR interface, sleek design, ergonomic form, compact size."
- Refined Prompt (Design (b)): "Futuristic smart home device with AR interface, sleek design, ergonomic form, compact size, wall-mountable, minimalist interface."

A.2 DALL-E Mini (Craiyon)

- Initial Prompt (Design (c)): "Smart home lighting control device, modern minimalist style, AR interface."
- Refined Prompt (Design (d)): "Smart home lighting control device, modern minimalist style, AR interface, rounded edges, clean holographic display."

A.3 CGDream

- Process for Designs (a) - (d): Convert 2D designs into 3D models and generate new 3D-based designs
- Prompt for Design (e): "Compact 3D smart home device, triangular base, AR interface, ergonomic grip."
- Prompt for Design (f): "Wall-mounted 3D smart home device, circular shape, minimalist AR interface."

A.4 Deep AI

- Process for Designs (a) - (f): importing 3D models from CGDream and applying manual texturing.
- Prompt for Design (g): "Texture a smart home device with a metallic finish, reflective surface, blue holographic AR interface."
- Prompt for Design (h): "Texture a smart home device with a matte black finish, subtle LED accents, white holographic AR interface."

A.5 ChatGPT

- Initial Prompt: "Generate Python script to adjust CAD model dimensions for ergonomic fit."
- Refined Prompt: "Generate Python script to adjust CAD model dimensions for ergonomic fit, include user height data, error handling, and logging for debugging."

A.6 DeepSeek

- Initial Prompt: "Generate Python script to simulate lighting effects in a virtual environment for a smart home device."
- Refined Prompt: "Generate Python script to simulate dynamic lighting effects in a virtual environment for a smart home device, include sunrise and indoor dimming scenarios, and adjust holographic interface brightness."

A.7 Grok

- Process: Describing Designs (a) - (h) via text prompts for analysis.
- Design (i) Suggestion: "Combine rounded edges and white finish with metallic texture for a balanced aesthetic and premium feel."
- Design (j) Suggestion: "Merge circular shape with LED accents, adding a slimmer profile for enhanced wall-mounting."

A.8 Doubao (ByteDance)

- Initial Prompt: "Generate a script for voice-activated lighting control with simple commands."
- Refined Prompt: "Generate a script for voice-activated lighting control with context-aware commands, including brightness adjustments based on time of day and user preferences."

A.9 Yuanbao (Tencent)

- Initial Prompt: "Generate an AR interface mockup for a smart home lighting control device, minimalist design."
- Refined Prompt: "Generate an AR interface mockup for a smart home lighting control device, minimalist design, with 3 core functions (on/off, brightness, color), clean layout, and holographic style."

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- *A.10 Qwen2-Max (Alibaba)*

- Initial Prompt: "Generate Python script to adjust AR interface layout for a smart home device."
- Refined Prompt: "Generate Python script to dynamically adjust AR interface layout for a smart home device, resize holographic elements based on user gaze and touch input, with error handling."