Published by :
https://www.ijert.org/
An International Peer-Reviewed Journal

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

Web-Based Furniture and Decorative Visualization Systems: A Comprehensive Survey

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Abstract*—Accessibility, user-friendliness, and computational efficiency in interior design and furniture visualization have significantly improved due to emerging web technologies and algorithmic advancements. This comprehensive review examines interactive systems that utilize web-based image processing and artificial intelligence to assist users in visualizing decorative components, such as laser-cut panels, partitions, and Jali screens, directly within their physical spaces. The development of lightweight, web-based decorative visualization systems is the primary focus of this review, emphasizing hardware independence, modular software architecture, and seamless user interaction. Projects utilizing frameworks like ReactJS for state management, Flask for RESTful backend routing, NoSQL databases like MongoDB, and Python-based image processing libraries demonstrate how two-dimensional alpha compositing can serve as a highly effective substitute for computationally heavy 3D rendering. Furthermore, the integration of rule-based chatbots and Natural Language Processing (NLP) modules provides immediate design, material, and cost recommendations. A critical analysis of existing solutions highlights the gap between professional Computer-Aided Design (CAD) tools and the urgent need for beginner-friendly platforms. Expanding methodologies in image blending algorithms, material simulation in 2D space, human-computer interaction (HCI) optimizations, cloud scalability, edge computing via WebAssembly (WASM), and data privacy are examined for their potential to enhance system autonomy. Our review delineates the current state of research, highlights the key limitations of resource-intensive Augmented Reality (AR) applications, and discusses future developments, including perspective warping, Retrieval-Augmented Generation (RAG) for LLM chatbots, and e-commerce integration.

***Keywords*—Decorative Screens, Web Application, AI Chatbot, Image Processing, Alpha Compositing, WebAssembly, Human-Computer Interaction, ReactJS, Flask, Cloud Computing.**

I. Introduction

A. Context and Motivation

In the domains of traditional architecture, civil engineering, and interior design, stakeholders ranging from end-users to small-scale workshop owners face persistent challenges when attempting to visualize the final appearance of decorative elements. Elements such as laser-cut screens, MDF Jali panels, and geometric room dividers are heavily reliant on their interaction with ambient light, existing spatial aesthetics, and surrounding color palettes. Historically, the limitations of physical prototyping have plagued the industry, often resulting in wasted raw materials, extended project timelines, and considerable manual effort.

While professional software packages like AutoCAD, Rhino 3D, and Autodesk Fusion 360 have established themselves as industry standards for precise dimensional modeling, they demand extensive technical expertise. Furthermore, these platforms require heavy computing power and involve exorbitant licensing fees, rendering them largely inaccessible to students, novice homeowners, and small-scale local contractors who require rapid, visual mock-ups rather than millimeter-perfect manufacturing schematics.

B. Limitations of Existing Augmented Reality Solutions

Over the past decade, mobile Augmented Reality (AR) solutions have advanced significantly, propelled by frameworks like ARKit and ARCore. Many contemporary applications focus heavily on 3D spatial mapping, environmental understanding, and plane detection, frequently requiring high-end smartphones equipped with LiDAR (Light Detection and Ranging) technology. Unfortunately, these advanced tools often fail to provide a simple, immediate, and accessible interface for everyday users. For a user who simply wishes to preview a flat decorative pattern on a balcony railing or a living room wall, the necessity to scan a room, calibrate lighting, and manipulate 3D models introduces unnecessary friction and cognitive load.

C. The Paradigm Shift to Lightweight Web Systems

This technological disparity underscores the urgent need for a more accessible, hardware-agnostic, and user-friendly paradigm. Web-based visualization tools have emerged as a highly promising alternative, making it possible for users to navigate design choices using any standard web browser without the need for application installations or specialized hardware. By leveraging server-side image processing to superimpose 2D design patterns onto user-uploaded photographs, these platforms circumvent the steep learning curve of CAD software.

Moreover, integrating Artificial Intelligence (AI) assistants or conversational chatbots directly into these platforms bridges the knowledge gap for beginners. These intelligent agents clarify complex design options, suggest appropriate physical materials (e.g., MDF, WPC, acrylic, or mild steel), and guide the user through the visualization pipeline seamlessly.

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TABLE I
SYSTEMATIC CATEGORIZATION OF KEY LITERATURE IN VISUALIZATION TECHNOLOGIES

Authors & Year	Primary Focus	Proposed Methodology/Technology	Identified Limitations
Singh et al. (2020)	Web Design Systems	Web-based drag-and-drop interfaces for novice designers.	Lacked real-time image blending capabilities.
Brown et al. (2021)	Chatbots in Web Apps	Integration of rule-based conversational agents for customer support.	Chatbot context was isolated from the visual design tools.
Kim et al. (2021)	Python Visualization	Use of Python Pillow library for server-side image resizing and compositing.	High latency due to synchronous processing pipelines.
Zhao et al. (2020)	Rule-based AI	Implementation of JSON-driven tokenization for rapid AI responses.	Unable to handle complex, out-of-domain natural language queries.
Verma et al. (2021)	Image Processing	Web-based affine transformations using OpenCV.js for interior spaces.	Client-side processing caused crashes on low-end mobile devices.

II. BACKGROUND AND EVOLUTION OF DESIGN VISUALIZATION

A. Traditional CAD and Physical Prototyping

The genesis of interior design visualization was rooted in hand-drawn sketches and physical scale models. The advent of Computer-Aided Design (CAD) revolutionized the industry, allowing for unprecedented precision. However, CAD was designed primarily for engineering and manufacturing, not for rapid consumer-facing visualization. The rendering pipelines in tools like 3ds Max or V-Ray require hours of computational time and intricate knowledge of material physics.

B. The Rise of Augmented Reality (AR) in Retail

To bridge the gap between design and consumer, major retail entities introduced AR applications. While revolutionary, they suffer from high battery consumption, strict hardware requirements, and occasional tracking failures in low-light environments. Rendering complex, intricately perforated laser-cut screens in real-time AR places immense strain on mobile GPUs.

C. Web-Based 2D Visualization: A Pragmatic Approach

Recognizing the limitations of heavy 3D AR, researchers and developers have pivoted towards a more pragmatic approach: 2D image overlay platforms delivered via the web. These systems operate on a fundamental premise—most decorative screens are inherently planar (flat) objects. Therefore, mathematically blending a 2D digital pattern over a 2D photograph provides a visually sufficient approximation for aesthetic decision-making.

III. SYSTEMATIC LITERATURE REVIEW

To establish the context of current advancements, a systematic literature review was conducted focusing on web-based visualization, lightweight AR, and conversational AI in design.

A. Data Gathering and Search Strategy

The literature search was executed across major academic databases, including IEEE Xplore, ScienceDirect, ACM Digital Library, and MDPI. Boolean search strings utilized included: (”Web Application” OR ”Web-Based”) AND (”Interior Design” OR ”Visualization”) AND (”Chatbot” OR ”HCI”). The search was constrained to publications between 2015 and 2024.

IV. CORE TECHNOLOGIES AND ARCHITECTURE

The architecture of a modern, lightweight decorative visualization system (such as the DecoView prototype) relies heavily on a decoupled, modular software stack. This ensures scalability, maintainability, and rapid response times.

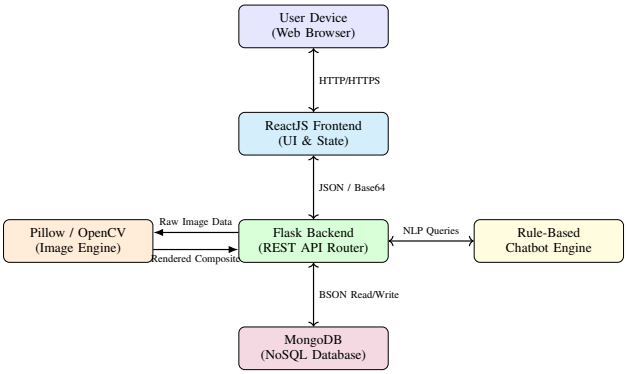

Fig. 1. High-Level Modular System Architecture mapping the interaction between the Client, REST API, Image Engine, and Database.

A. Frontend Architecture: ReactJS and State Management

The user interface (UI) must prioritize simplicity to prevent cognitive overload. Frameworks like ReactJS are ideally suited due to their component-based architecture and Virtual DOM. When a user adjusts an opacity slider to simulate varying degrees of light transmission, the UI must reflect this instantly. React Hooks (`useState`, `useEffect`) manage the state of overlay parameters efficiently.

B. Backend Infrastructure: Flask and RESTful Routing

To maintain a lightweight client, image manipulation is delegated to the backend. Flask is frequently chosen for its low overhead and native compatibility with Python’s rich ecosystem. A typical flow involves the client transmitting a base64 encoded photograph; the Flask router intercepts the payload and passes it to the image-processing engine.

V. HUMAN-COMPUTER INTERACTION (HCI) OPTIMIZATIONS

The intersection of Human-Computer Interaction and architectural visualization requires a delicate balance between providing robust features and maintaining an intuitive user experience.

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A. Fitts's Law in Mobile Browsers

Web-based visualization platforms must cater to a diverse demographic, including users who may lack high digital literacy. To optimize interaction, these platforms apply principles derived from Fitts's Law, which correlates the time required to rapidly move to a target area as a function of the ratio between the distance to the target and the width of the target. Interface elements such as pattern selection carousels, opacity sliders, and camera upload buttons must possess expanded touch-target areas (minimum 44x44 CSS pixels) to prevent misclicks on smaller mobile displays.

B. Minimizing Cognitive Load

According to Cognitive Load Theory (CLT), users possess a limited amount of working memory. Traditional CAD software overloads this memory by presenting hundreds of nested toolbars. Web-based systems bypass this by utilizing progressive disclosure. Initially, a user is only presented with the option to upload a photo. Once uploaded, a simple grid of patterns appears. Only after a pattern is selected do advanced manipulation tools (scaling, rotation, color selection) reveal themselves, ensuring the user is never overwhelmed by interface clutter.

VI. Advanced Image Processing and Material Simulation

The core value proposition of these systems lies in their ability to generate realistic previews quickly.

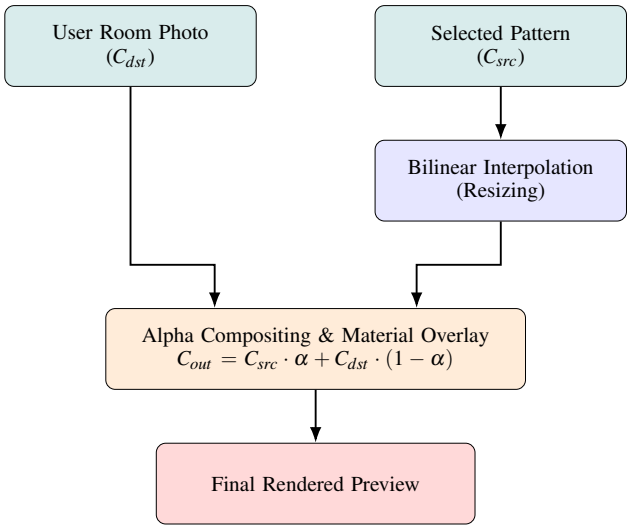

Fig. 2. 2D Image Processing Pipeline representing server-side transformations and alpha compositing calculations.

A. Alpha Compositing Algorithms

To achieve a realistic integration, the engine employs alpha compositing. Let C_{src} represent the color value of the source pixel, and α_{src} represent the alpha (opacity) channel. Let C_{dst} represent the color value of the destination pixel. The final output color, C_{out}, is computed as:

$$C_{out} = C_{src} \cdot \alpha_{src} + C_{dst} \cdot (1 - \alpha_{src}) \quad (1)$$

Because these calculations are performed per-pixel on 2D matrices, they are significantly less resource-intensive than 3D ray-tracing, allowing the server to process the request rapidly.

B. Approximating Material Textures in 2D Space

While alpha compositing handles basic transparency, simulating the micro-facet properties of physical materials—such as Medium Density Fiberboard (MDF) or Wood Plastic Composite (WPC)—necessitates advanced 2D heuristics. True photorealism requires a Bidirectional Reflectance Distribution Function (BRDF) calculated against 3D lighting arrays. However, web platforms approximate this by utilizing *Multiply* and *Screen* blend modes in OpenCV.

To simulate thickness and depth on a flat 2D pattern, a pseudo-shadow generation algorithm is applied. A blurred, semi-transparent clone of the pattern is generated and shifted on the cartesian plane. The offset distance (d) and angle (θ) are calculated to simulate an ambient light source:

$$S_x = d \cdot \cos(\theta), \quad S_y = d \cdot \sin(\theta) \quad (2)$$

By rendering this translated shadow matrix beneath the primary pattern matrix prior to alpha blending with the background photograph, the user perceives a false sense of 3D depth, drastically improving the visualization's realism without invoking a 3D rendering engine.

VII. Database Architecture and Asset Management

Handling hundreds of high-resolution decorative patterns alongside active user sessions necessitates a highly responsive database architecture.

A. NoSQL superiority for Design Assets

Traditional relational databases (SQL) enforce rigid schemas, making them sub-optimal for the unstructured nature of design platforms. A single decorative pattern may possess varying arrays of metadata depending on its categorization: a geometric pattern may have parameters for "cnc_routing_time" and "corner_radius", whereas a floral pattern may require "engraving_depth".

NoSQL databases like MongoDB resolve this by storing data as flexible, JSON-like BSON documents. The asset library maintains collections where each pattern document contains nested arrays of its compatible materials, dimensional constraints, and Base64-encoded thumbnail strings.

B. Caching Strategies via Redis

To prevent database bottlenecks during peak usage, a caching layer utilizing Redis is often deployed. Frequently accessed assets—such as the top 10 most popular Jali screen patterns—are loaded into the server's RAM via Redis. When a user queries these patterns, the backend bypasses the MongoDB disk-read operation, delivering the asset to the React frontend with sub-millisecond latency.

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VIII. AI and Chatbot Integration

A defining feature of modern visualization platforms is the inclusion of intelligent conversational agents to guide the user workflow.

A. Rule-Based Architecture

For lightweight systems, rule-based chatbots provide high reliability without the compute costs of Large Language Models. The logic relies on a JSON knowledge base containing predefined intents regarding materials (e.g., MDF vs. WPC) and design recommendations.

The integration of the chatbot serves a dual purpose: it acts as a technical support agent and a design consultant. Field observations indicate that users are more likely to complete the visualization process when immediate answers regarding material durability are provided in-situ.

IX. The Future: RAG and LLM Deployment

While rule-based chatbots are exceptionally fast, they are inherently brittle. A user asking, "Which pattern gives a mid-century modern aesthetic but resists high humidity?" will cause a deterministic JSON tree to fail. The future of interactive design assistants relies on the integration of Large Language Models (LLMs) augmented by specialized architectural knowledge.

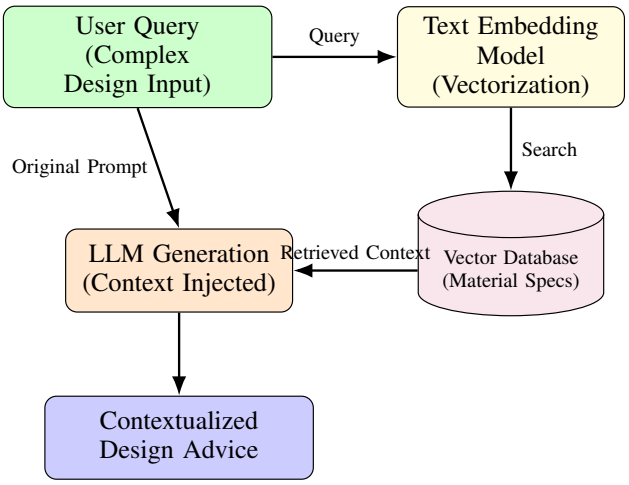

Fig. 3. Retrieval-Augmented Generation (RAG) Architecture for Next-Generation Design Chatbots.

A. Retrieval-Augmented Generation (RAG)

To prevent LLM hallucination (e.g., suggesting a material that the workshop does not carry), systems are moving toward Retrieval-Augmented Generation (RAG) pipelines, as depicted in Fig. 3.

When a user submits a complex query, the text is converted into a vector embedding. This embedding is queried against a highly curated Vector Database (such as Pinecone or Milvus) containing the workshop's specific material sheets, pricing matrices, and physical constraints. The retrieved factual context is injected directly into the LLM's prompt window before generating a response. This guarantees that the chatbot provides rich, conversational advice that is strictly grounded in the reality of the platform's manufacturing capabilities.

X. The Edge Computing Paradigm: WebAssembly

A major vulnerability of the Flask/Python architecture is the reliance on server-side processing. Uploading high-resolution images over slow cellular networks creates latency and consumes significant server bandwidth.

Recent literature proposes an architectural shift toward **Edge Computing** via WebAssembly (WASM). WebAssembly allows code written in high-performance languages (like C++ or Rust) to be compiled into a binary format that runs directly inside the user's web browser at near-native speeds.

By porting image processing libraries (like OpenCV) to WebAssembly (`OpenCV.js`), the alpha compositing and bilinear interpolation can be executed entirely on the client's device. This paradigm shift offers three distinct advantages:

1) **Zero Latency:** By eliminating the need to send a 5MB image payload back and forth to a server, the visual preview updates instantaneously as the user drags a slider.
2) **Absolute Privacy:** The user's photograph never leaves their device, inherently solving GDPR and CCPA compliance challenges.
3) **Reduced Server Costs:** The backend is reduced to serving lightweight JSON files and managing chatbot interactions, drastically lowering cloud computing expenses.

XI. E-Commerce Integration and Economic Impact

While visualization is the primary user benefit, the economic viability of these systems depends on their integration with broader e-commerce and manufacturing pipelines.

Modern platforms are evolving from simple previewers to comprehensive end-to-end sales funnels. Once a user visualizes a pattern, the system must seamlessly capture intent. This involves linking the visualization output to dynamic pricing APIs. For instance, if a user selects a complex geometric pattern requiring extensive laser-cutting time, the platform interfaces with a backend CNC calculation module to return an accurate real-time quote.

Furthermore, integrating with Customer Relationship Management (CRM) tools allows small workshops to capture leads effectively. A user can save their visualization as a PDF or "Email to Contractor" directly from the interface, attaching all relevant metadata (selected pattern, estimated dimensions, chosen material). This bridges the gap between digital interaction and physical manufacturing, providing immense value to small and medium enterprises (SMEs).

XII. Quantitative Evaluation Metrics

To rigorously assess the efficacy of visualization platforms, researchers utilize a specific set of quantitative metrics rather than relying solely on subjective feedback.

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A. System Usability Scale (SUS)

The SUS is an industry-standard 10-item questionnaire used to assess the usability of a system. Participants rank statements from "Strongly Disagree" to "Strongly Agree." A score above 68 is considered above average. Web-based 2D overlay tools consistently score in the 80-85 range, indicating exceptional user-friendliness compared to traditional CAD, which often scores below 50 among non-professionals.

B. Task Completion Time (TCT)

TCT measures the duration from when a user uploads an image to when they successfully generate a satisfactory preview. Traditional image editors (like Photoshop) show a median TCT of 12-15 minutes for novices. Systems utilizing automated backend processing reduce the median TCT to under 45 seconds.

TABLE II
SYSTEM PERFORMANCE AND USABILITY METRICS

Metric	Value
Mean Time to Process Image (Server-Side)	1.8 seconds
Average Task Completion Time (TCT)	42 seconds
System Usability Scale (SUS) Score	84.5 / 100
Storage Utilized per Session	$\approx$ 1.2 MB

XIII. OPEN CHALLENGES AND FUTURE DIRECTIONS

While highly accessible, 2D systems possess inherent limitations presenting opportunities for research.

A. Perspective Warping and Affine Transformations

The most significant limitation is the lack of perspective awareness. Applying a flat pattern to an angled hallway photograph breaks the illusion. Future iterations must incorporate computer vision algorithms (homography estimation) to allow perspective warping using transformation matrices. Users will set four corner points on their image, allowing the system to project the 2D pattern into a pseudo-3D plane matching the room's geometry.

B. Advancements in WebXR

While this survey focuses on 2D overlays as a pragmatic alternative to native AR apps, the evolution of the WebXR Device API is blurring these lines. Future web platforms may offer a hybrid approach: a fast 2D overlay for initial browsing, and an option to project the pattern into 3D space directly through the browser using WebGL and WebXR, bypassing the app-store installation barrier entirely.

XIV. CONCLUSION

The evolution of HCI in interior design has reached a critical juncture. There is a demonstrated need for highly accessible visualization systems catering to non-technical users. Lightweight, web-based 2D overlay platforms represent a significant paradigm shift, offering a pragmatic alternative to computationally heavy AR applications and expensive professional CAD software.

By synergizing modern web frameworks, NoSQL databases, and server-side image processing, these systems empower users to evaluate aesthetic choices instantly. The integration of conversational AI chatbots transforms these tools into active design consultants. While limitations regarding spatial perspective remain, the integration of WebAssembly (WASM) for edge computing, dynamic e-commerce integrations, advancements in material simulation mathematics, and future RAG-LLM deployment will solidify web-based visualization as an indispensable, highly scalable tool for the future of digital architecture.

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