Cureus Journal of Computer Science

Open Access Original Article

Towards Next-Gen E-Commerce: Performance-Driven Development of an Augmented Reality- and Voice-Integrated Web Store

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Received 04/28/2025
Review began 05/19/2025
Review ended 06/02/2025
Published 06/12/2025

DOI: https://doi.org/10.7759/s44389-025-04994-3

Abstract

According to a report by Statista, around 3.9 billion people worldwide are projected to shop online by 2029. Additionally, it has been projected that user penetration will soon reach 49.1%. As a result, enhancing user experience and interaction in e-commerce is both essential and challenging. To improve user engagement during online shopping, this research presents the design and implementation of a voice-enabled, augmented reality (AR)-integrated web store. We used cutting-edge web development tools like React.js, AR web frameworks, and Google speech recognition capabilities to create a voice-enabled, AR-integrated web store. The developed and implemented web store was evaluated using Google's Lighthouse tool, assessing key parameters including performance, accessibility, best practices, and search engine optimization. The evaluation yielded scores of 93% for performance, 89% for accessibility, 74% for best practices, and 92% for search engine optimization. The proposed method's performance was also compared to non-AR-integrated and non-voice-enabled e-commerce sites like ThreadUp, Decathlon, Mercari, Rakuten, and Best Buy. The findings indicate that the proposed voice-enabled AR-integrated web store outperforms traditional platforms. Therefore, this study suggests that integrating voice-enabled and AR-integrated web store can substantially improve user engagement and contribute to greater commercial success.

Categories: Augmented and Virtual Reality (AR/VR), User Experience (UX) Design, Web development
Keywords: augmented reality, e-commerce, web auditing, web technologies, react js

Introduction

The evolution in e-commerce and retail shopping has significantly transformed, with web portals and mobile apps becoming central platforms for online consumer engagement [1-3]. According to 'Statista' [3], there are currently 3.9 billion users worldwide utilizing web portals and mobile apps for online shopping. New technologies like augmented reality (AR) and virtual reality (VR) [4] can help improve businesses by using these for web portal development [5,6]. With ongoing technological progress, integrating AR and VR into web portals is now feasible and beneficial for business growth [4,7]. AR can be vital in promoting sustainability while significantly enhancing user engagement [8]. Integrating AR into a web store means adding features that allow customers to see and interact with products more realistically using their phone or computer. Suppose a customer wants to buy furniture; they can let you place a virtual sofa in their room to see how it fits. This enhances the actual realism and actual visualization, which reduces uncertainty and helps customers make better buying decisions. E-commerce is the foundation of a web store - it is the process of buying and selling products online. A web store is a type of e-commerce platform where businesses showcase their products, and customers can browse, choose, and purchase items digitally. When AR is added to e-commerce, it improves the shopping experience by letting customers see and interact with products more realistically. AR for e-commerce is a massive help in creating an immersive experience to help customers choose a product. Immersive AR formats such as 3D product images, holograms, and virtual showrooms help consumers discover and get inspired by products in engaging environments [9]. Users can see how furniture fits in their room, try on virtual clothing, or test how makeup products look on their faces, all from the comfort of their homes. AR for e-commerce [10] is a massive help in creating an immersive experience to help customers choose a product. Immersive AR formats such as 3D product images, holograms, and virtual showrooms help consumers discover and get inspired by products in engaging environments.

In recent days, voice interfaces are increasingly transforming the retail landscape by enhancing user interaction and accessibility [11]. Recent studies have explored the integration of voice technology within virtual fashion experiences and real-time e-commerce management systems [12-13]. Also, several works offer valuable insights into the synergy between voice technology and augmented reality in modern e-commerce platforms [14-17].

How to cite this article
Shivsharan N M, Bhosale O, Kazi A, et al. (June 12, 2025) Towards Next-Gen E-Commerce: Performance-Driven Development of an Augmented Reality- and Voice-Integrated Web Store. Cureus J Comput Sci 2 : es44389-025-04994-3. DOI https://doi.org/10.7759/s44389-025-04994-3

The contributions of this research are as follows:

1. The design and development of an effective and user-friendly web store that incorporates AR technologies to enhance the e-commerce experience.

2. The integration of a sound-enabled interface to improve user engagement.

3. A new approach to utilizing AR to enhance interactivity in online shopping, thus advancing e-commerce solutions.

The rest of the content of the research paper includes, after the Introduction section, the Related Work, a comprehensive review of existing research, and highlights the identified gaps. To address these gaps, the Proposed System section presents the designed solution aimed at overcoming the gaps found in prior studies. The experimental work carried out to implement the proposed system is presented in the Implementation section. Presents the experimental work carried out to realize the proposed system in detail. This is followed by the Results and Conclusion sections. The Results section highlights the outcomes of the implemented system, while the Conclusion summarizes the overall work and the key achievements.

Materials And Methods

Related work

The fundamental steps for designing and developing websites are outlined in the study by Fajfar [18]. The concepts, features, and benefits of AR and VR, along with their integration into web portals to enhance business, are discussed in many studies [4,5,19-21]. Ebrahimabad et al. [22] discussed how AR-integrated web stores enhance business. Roy and Kanjilal [23] explore how performance can be improved using an AR-based web store. An empirical study on consumers' experience and satisfaction using AR apps in e-shopping is proposed by Voicu et al. [24], where the authors focus on user satisfaction and experience. The use of AR in e-commerce to enhance customers' purchase intentions is proposed by Diana et al. [25]. Addressing challenges faced by visually impaired users through the integration of a voice assistant in an AR-enabled web store is proposed in the study by Villegas-Ch et al. [26].

Study	Method	Results	Future Scope
[1]	Mobile service quality	The implications of both theoretical and practical aspects of service quality in the context of mobile shopping are evaluated	More age-diverse population
[2]	Hierarchical model of mobile service quality	The results identify the key success factors for marketers implementing mobile and QR code marketing strategies	Cultural contexts
[5]	Quantitative research designed to collect and analyze research data	Influence of AR features	Integration with other technologies like VR
[8]	A qualitative method to explore the experiences and views of Gen Z consumers concerning augmented reality in online fashion retail	Influence on purchase behavior	AR features on specific metrics like conversion rates, return rates
[9]	Employed embedded voice real-time systems within the realm of e-commerce	Enhanced responsiveness	Connecting with cloud-based platforms and AI recommendation systems
[11]	In-depth interviews	Enhanced usage of voice interface	Use voice modality to interact with the e-retailer
[12]	XR-based virtual fashion store that mimics real-world customer-helper interactions by integrating Amazon Alexa as a voice assistant	Enhanced user comfort	Voice assistance with other emerging technologies
[16]	The fuzzy set qualitative comparison analysis method and the partial least squares technique	Voice assistants with connection to privacy-related elements that influence customer involvement	The intention to continue using voice assistants, often known as electronic word-of-mouth

TABLE 1: Detailed Insights Into Recent Research Studies

AI, Artificial Intelligence; AR, Augmented Reality; VR, Virtual Reality

Table *1* presents a comprehensive summary of key literature relevant to the development of voice-enabled, AR-integrated e-commerce platforms. It highlights various methodologies applied across studies, ranging from AR marketing evaluations to the integration of voice interfaces in retail environments. The findings consistently show enhanced user engagement, satisfaction, and purchase intent. Future research directions include personalized AR, voice-AR fusion, and immersive shopping experiences supported by advanced technologies such as AI and blockchain, and the metaverse [27]. Recent studies on integrating AR into web stores and their impact on business and user experience have been thoroughly examined and analyzed [28].

Gap analysis

A comprehensive review of existing literature highlights substantial progress in the individual application of AR and voice technologies. However, it also reveals several critical gaps that this study seeks to address, including the absence of integrated AR and voice-enabled solutions, limited performance evaluation of such hybrid platforms, and a lack of real-world comparative analysis with existing e-commerce systems.

Representative design

The proposed system is to be designed to address the growing demand for enhanced user interaction in online shopping environments. As the global e-commerce user base continues to expand, which has been projected to reach 3.9 billion by 2029, hence, there is a clear need for platforms that go beyond traditional web interfaces to offer immersive and intuitive shopping experiences. In response, this study presents the design and implementation of a next-generation e-commerce web store that integrates AR for interactive product visualization and voice-enabled features for accessible, hands-free navigation.

Proposed system

This section provides a detailed description of the design, development, and implementation of the proposed system. Figure *1* illustrates the workflow of the system's development and implementation process.

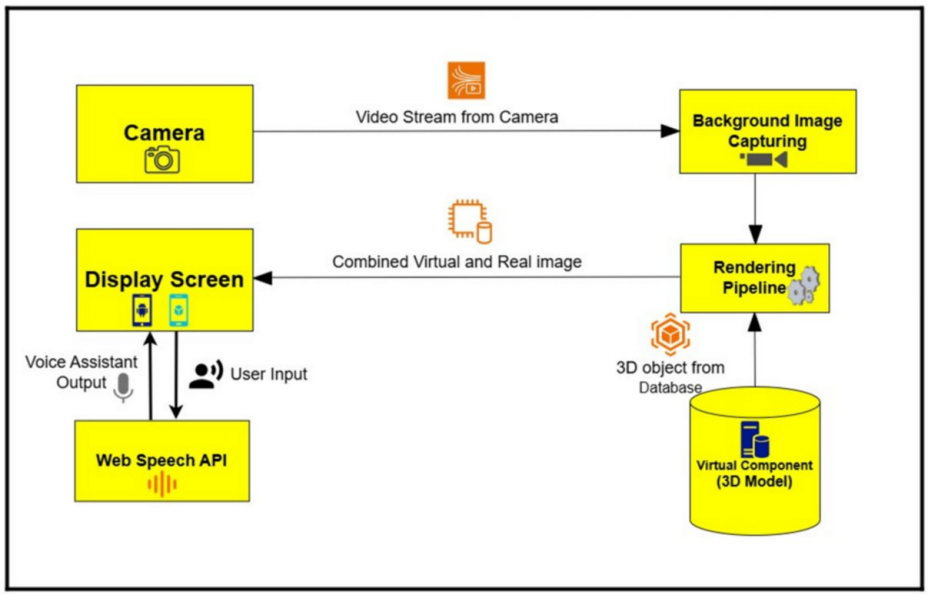

FIGURE 1: Proposed System for Designing and Developing an Augmented Reality-Integrated Web Store With Voice Assistant

Figure *1* describes a system that combines real and virtual elements using a camera and a display screen. It involves capturing a background image and rendering 3D objects or models from a database to create a combined virtual and real image. This setup is likely used in AR applications.

Design and Development of a Web Store With AR Integration

The design and implementation of a web store that integrates AR take advantage of modern web technologies to improve user engagement and product visualization. Built on a React.js framework, the front end employs a component-based architecture to ensure modularity and scalability. The 'React Router' is used to facilitate seamless navigation. Similarly, state management is achieved using React hooks (e.g., useState) [29-30]. The hybrid approach is used for styling and responsive layout by combining CSS and inline styles. The integration of AR is fully powered by Google Model Viewer, which enables cross-platform compatibility through WebXR [31], Scene Viewer, and Quick Look modes. Thus, the proposed framework supports the manipulation of interactive 3D models along with rotation, zoom, and shadow effects, to simulate and feel the interaction of real-world products. The features like dynamic lighting and auto-rotation enhance the user experience. The AR integration also adheres to progressive enhancement principles, and it also ensures functionality even on non-AR-compatible devices via fallback 2D imagery. The user device has cameras (usually both front and back) and various sensors that provide data to interpret the real world. The front-facing (selfie) camera is not supported. The rear-facing (world) camera is emulated with a virtual scene. The camera itself may have a depth sensor and be able to determine the range, dimensions, and other useful data about the targets it detects. On devices that support 60 fps, it limits the camera capture frame rate to 30 fps. Mostly, only a single camera frame for rendering is needed to buffer. Each additional camera frame buffered increases memory utilization. For example, a 1080p texture consumes approximately 6MB of memory. The glTF file for each 3D model is stored in the database. The glTF file and the data from the phone camera are taken as input for the rendering pipeline. glTF was designed and specified by the Khronos Group for the efficient transfer of 3D content over networks. The core of glTF is a JSON file that describes the structure and composition of a scene containing 3D models. The top-level elements of this file are as follows:

1. Scenes and Nodes: Basic structure of the scene

2. Cameras: View configurations for the scene

3. Meshes: Geometry of 3D objects

4. Buffers and Buffer Views: Data references and data layout descriptions

5. Materials: Definitions of how objects should be rendered

6. Textures, Images, and Samplers: Surface appearance of objects

7. Skins: Information for vertex skinning

8. Animations: Changes of properties over time

Voice Assistant

The 'Web Speech API' for bidirectional speech recognition and synthesis is employed for implementing the voice assistant module. This enables a real-time natural language processing environment. It uses 'React Hooks' (useState, useEffect, useCallback), which follows an event-driven architecture to handle asynchronous voice commands. Custom React components manage microphone activation, command parsing, and feedback delivery via a floating UI element. Speech synthesis provides auditory feedback, while error-handling mechanisms address unsupported browsers and misinterpreted commands.

Implementation Steps

Figure 2 illustrates the flow chart that implements the approach considered to develop a website with AR integration.

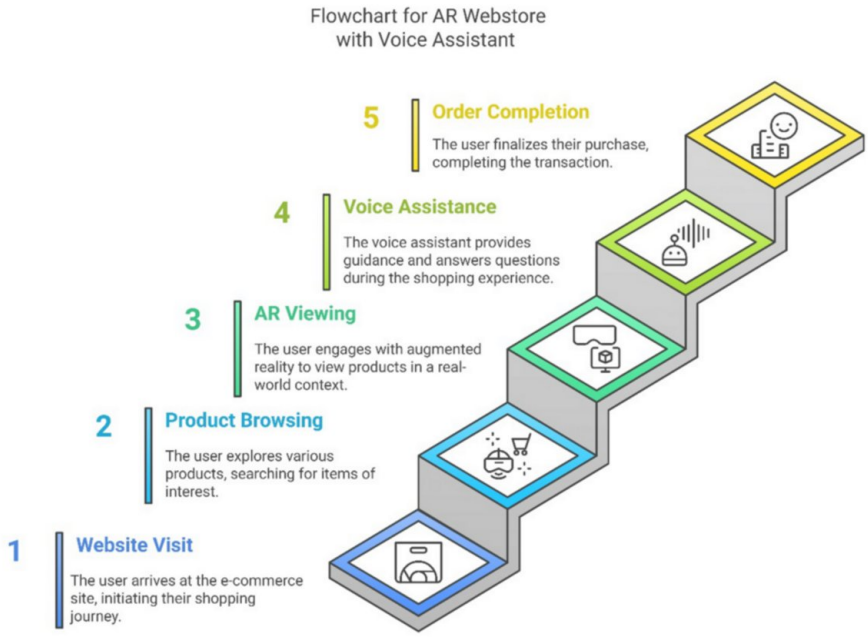

FIGURE 2: Flowchart Illustrating the Workflow of the Proposed Augmented Reality-Integrated Web Store

Results

The results of the proposed AR-based web store system, designed, developed, and implemented, are presented in this section.

Browse products

Like traditional online shopping, users browse a curated selection of items. In this browsing phase, user-driven exploration is emphasized to identify products of interest.

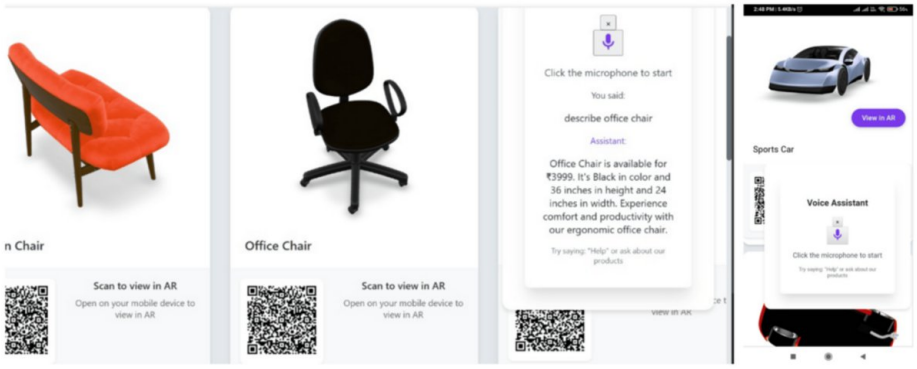

FIGURE 3: Browsing and Visualizing Products Through the Device

View in AR

Once the product gets selected, users activate the AR view. This feature leverages device cameras and sensors to superimpose a 3D model of the product in the user's physical environment (e.g., viewing a virtual chair in their living room). Figure *3* presents the output of the AR model as requested by the user. The AR-integrated web store enables users to browse and visualize products in AR. Users can select different product variants (e.g., color) using a drop-down menu. Each product has a QR code that, when scanned, allows AR viewing on a mobile device.

Figure *4* shows the AR functionality of the web store in action. Figure *4*(a-f) illustrates how the website's AR feature places virtual objects (cars, chairs, planters) in real-world environments. The user selects a product on the website and scans a QR code or uses an AR button on their mobile device (input). The output is the realistic overlay of the chosen 3D model in the user's surroundings. This helps users visualize how items will look and fit in their actual space.

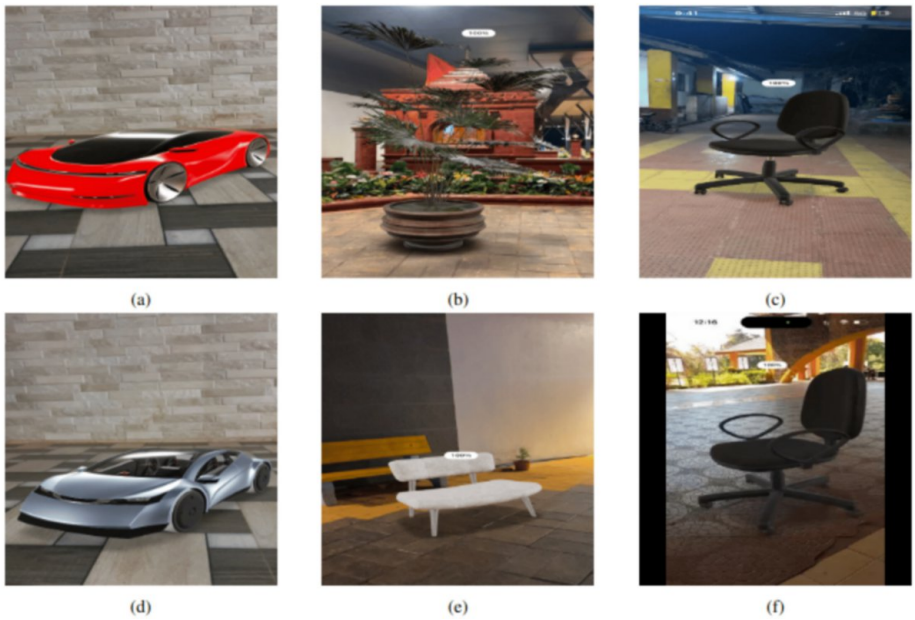

FIGURE 4: Snapshots Showing the Projection of Objects in a Real-World Environment

Use voice assistant

During the AR interaction phase, users interact with a voice-enabled assistant for a hands-free experience. Consider an example: the assistant asks questions such as 'What is the dimension of the product?' This feature improves accessibility, particularly for users with mobility constraints or those who are visually impaired.

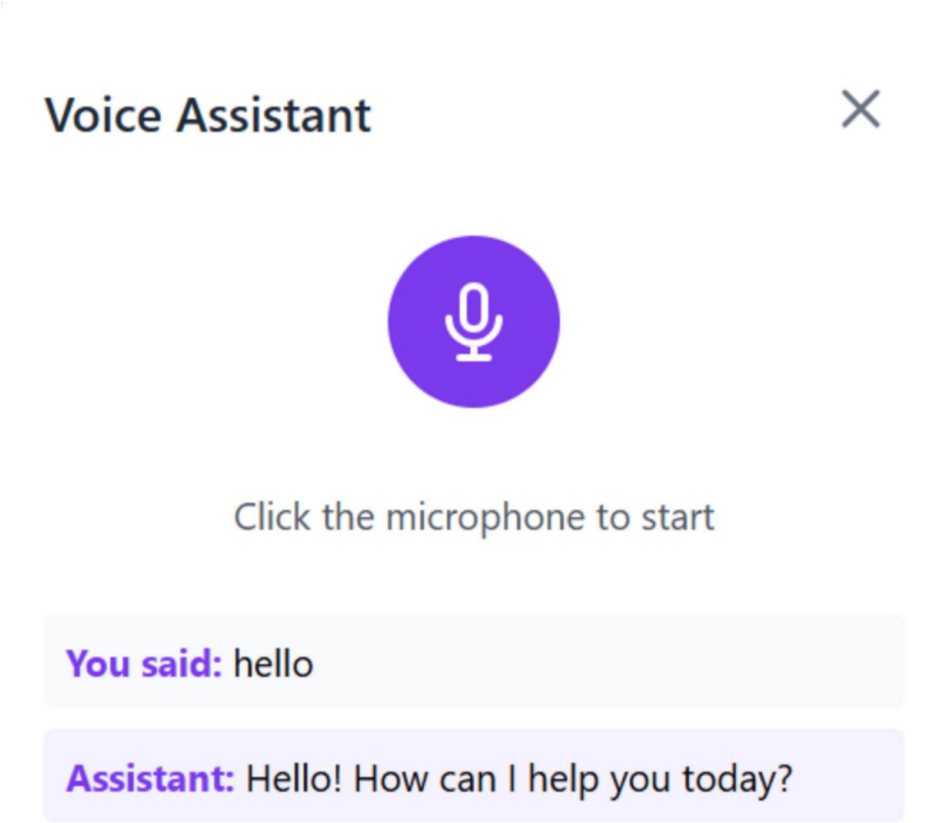

FIGURE 5: Implementation of Voice Assistant in the Augmented Reality Web Store

Figure 5 shows the Voice Assistant feature of the AR web store. In addition, users interact with the web store using the voice assistant by speaking into their microphones. The input is the user's voice command, and the output is the assistant's response, helping users navigate the website, find products, or get help.

Complete order

After evaluating the product using the features of the AR-integrated web store and the voice-enabled web portal, the users proceed to the checkout. The platform integrates secure payment gateways, order summaries, and confirmation notifications. The design and implementation of a web store that integrates AR takes advantage of modern web technologies to improve user engagement and product visualization.

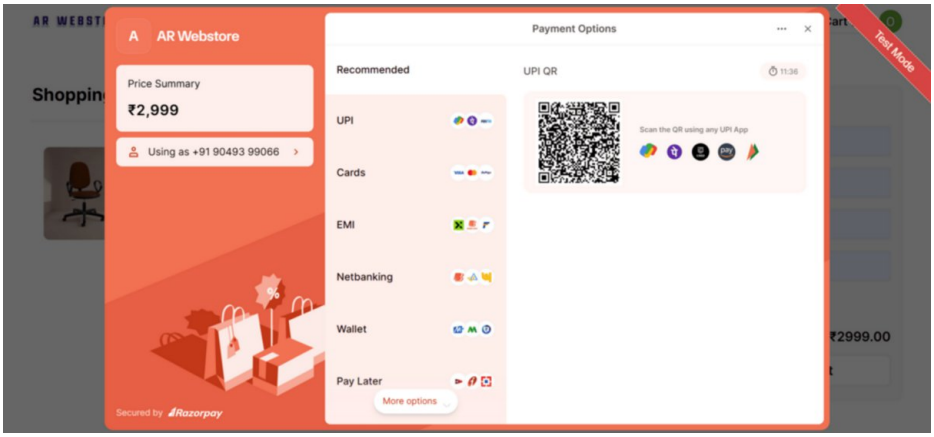

FIGURE 6: Implementation of Payment Methods in the Augmented Reality Web Store

The final step in online shopping is making a payment; therefore, we integrated the payment gateway, as illustrated in Figure 6. The snapshot shows the payment process in the AR-integrated web store using 'Razorpay'.

Users can select a payment method such as UPI, cards, EMI, net banking, wallets, or pay later. The output is a payment confirmation after successful processing. The interface ensures a smooth and secure checkout experience for purchasing items from the store.

Discussion

The overall design, development, and implementation of the AR-based web store to enhance business have been studied and carried out in this work. The system has also been evaluated using a web audit tool, such as Google's Lighthouse. This section presents the performance evaluation and analysis of the developed system.

Performance evaluation

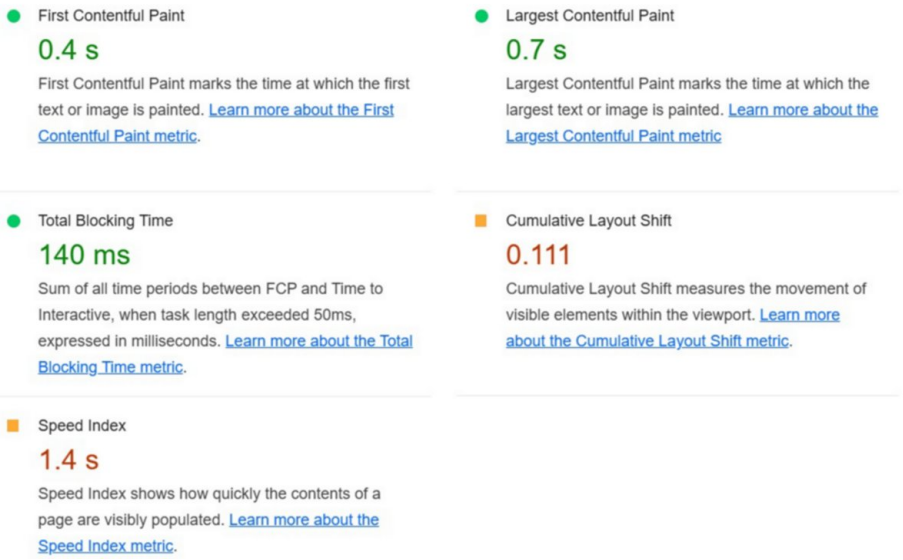

FIGURE 7: Google Lighthouse Report Showcasing the Performance of the Proposed Augmented Reality-Based Web Store System

This research employed Google Lighthouse [31-32], a tool designed to assess the performance, accessibility, SEO, and best practices of web pages.

The following results were obtained after applying Google Lighthouse to designed and developed web store integrated with AR technology.

Figure 7 presents the performance analysis of the AR-integrated website developed and implemented in this investigation. The following are some important performance metrics of Google's Lighthouse:

1. First Contentful Paint (FCP): At 0.4 s, the FCP outperforms the recommended threshold of less than or equal to 1.8 s, indicating efficient server response times and minimal render-blocking resources.

2. Largest Contentful Paint (LCP): The LCP of 0.7 s meets the ideal goal of 2.5 s or less, showcasing efficient loading of essential resources. Nevertheless, additional improvements could be realized by implementing lazy loading or giving priority to content that appears above the fold.

3. Total Blocking Time (TBT): A TBT of 140 ms is below the advisable threshold of 200 ms, suggesting that there are minimal delays caused by JavaScript execution. This indicates successful implementation of code-splitting, asynchronous loading, or a reduced effect from third-party scripts.

4. Cumulative Layout Shift (CLS): The CLS score of 0.111 slightly exceeds the ideal less than or equal to 0.1 benchmark. This suggests minor instability due to dynamically injected content (e.g., ads, lazy-loaded images).

5. Speed Index (SI): An SI of 1.4 s signifies rapid visual completion, well under the less than or equal to 3.4 s target. This highlights efficient resource prioritization, such as font preloading or optimized image formats (e.g., WebP).

Figure *8* showcases the performance analysis of the developed and implemented AR-integrated web store in this research. The following is a detailed summary of the lighthouse report to improve the performance metrics.

FIGURE 8: Google Lighthouse-Generated Report Showcasing the Performance of the Proposed AR-Based Web Store System

1. Performance: A performance score of 93 indicates outstanding performance, exceeding the recommended threshold of less than or equal to 90. It shows optimized resource delivery (e.g., compressed images, code splitting). It suggests efficient JavaScript execution and minimal render-blocking resources. Metrics such as LCP and FCP are probably in line with ideal benchmarks that promote quick user interaction.

2. Recommendations: Maintain enhancements by assessing external scripts and implementing lazy loading for non-essential assets.

3. Accessibility: A score of 9 indicates good accessibility, although some minor issues remain. Possible shortcomings include missing alt text for images, incorrect labeling of interactive elements, and inadequate contrast ratios for text.

4. Best Practices: A score of 74 highlights vulnerabilities, such as mixed content (HTTP resources on HTTPS pages), missing security headers (e.g., Content Security Policy), or outdated dependencies. These issues expose the application to potential security risks and compatibility challenges.

5. SEO: A score of 92 signifies robust SEO optimization, with proper meta descriptions, mobile-friendly design, and valid schema markup. Minor gaps may include missing canonical tags or unoptimized image alt attributes, which could impede ranking potential.

Performance analysis

The performance of the implemented 'AR web store' was evaluated using Google's Lighthouse tool, considering key parameters such as performance, best practices, SEO, and accessibility. The outcome of the proposed AR web store was compared with popular e-commerce websites such as Best Buy, Decathlon, Mercari, Rakuten, and Thredup. The comparative analysis, including the numerical values of the parameters, is presented in Table *2* and is graphically illustrated in Figure *9* for better representation. From Table *2* and Figure *9*, it is observed that the proposed 'AR web store,' which integrates AR into the website, enhances all performance parameters and outperforms existing websites without AR integration.

	Performance	Accessibility	Best Practices	SEO
Best Buy [33]	61	75	74	85
Decathalon [34]	40	77	70	92
Mercari [35]	29	88	56	92
Rakuten [36]	32	55	70	85
Thredup [37]	40	83	56	92
AR Web store	90	89	74	100

TABLE 2: Performance Evaluation of the Proposed AR-Based Web Store System Versus Existing E-Commerce Websites Without AR

AR, Augmented Reality; SEO, Search Engine Optimization

1. Performance Enhancements: To boost site speed, defer non-critical JavaScript/CSS files (e.g.,'layout.css') and minify code to reduce load times. Optimize large files like 'main-app.js' (1,901 KiB) and replace bulky images with modern formats (e.g., WebP/AVIF) for faster loading. Avoid delaying key images (e.g., 'img.w-screen') and extend caching for third-party scripts (e.g., Razorpay's 'checkout.js'). Fix caching headers and reduce long JavaScript tasks to improve responsiveness.

2. Accessibility Improvements: Add labels to buttons and custom controls for screen readers. Fix low-contrast text (e.g.,'text-grey-2') and improve navigation with skip links and semantic tags. Ensure headings and page structure follow accessibility standards.

3. Best Practices: Strengthen security by adding headers (CSP, HSTS) to prevent attacks. Replace third-party cookies (e.g., Razorpay's tracking cookies) and resolve browser console errors. Include source maps for debugging JavaScript files.

4. SEO Optimization: SEO fundamentals like meta tags, alt texts, and crawlable links are well-implemented. Validate structured data manually for accuracy.

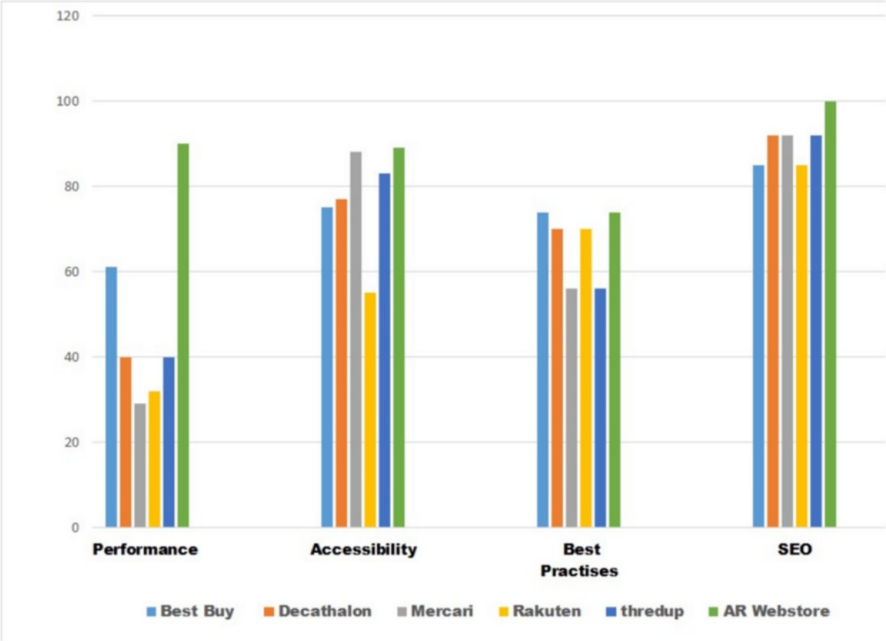

FIGURE 9: Comparative Analysis of Google Lighthouse Reports for Existing E-Commerce Websites (Best Buy, Decathlon, Mercari, Rakuten, and Thredup) and the Proposed AR Web Store

AR, Augmented Reality; SEO, Search Engine Optimization

Conclusions

After a comprehensive state-of-the-art literature review, this research identified that integrating AR and voice assistant technologies into modern e-commerce web stores significantly enhances user experience, engagement, and accessibility. Hence, it can ultimately lead to growth in e-business. Also, the literature review in this domain reveals a growing demand for immersive and user-friendly shopping experiences, highlighting the need for solutions that effectively bridge the gap between actual physical and online digital commerce. This research adopted a design, development, and implementation approach, integrating AR through WebXR and associated required libraries for implementation. The performance of the implemented AR-integrated, voice-enabled web store was evaluated using the open-source Google Lighthouse tool.

This research focuses on combining voice interaction and AR within a web-based framework. The study accomplished an adequate job of showing how AR enables people to see things in real-life environments. It has also been noted that the voice assistant provides a more inclusive, hands-free, and organic way of interacting. The effectiveness of the developed system was evaluated using the Google's Lighthouse tool, which assessed key performance dimensions, including performance, accessibility, best practices, and SEO. The evaluation yielded scores of 93 for performance, 89 for accessibility, 74 for best practices, and 92 for SEO. These results reflect not only technical efficiency but also user-centric design improvements in the prototype. Future research in this field could focus on advancing AR interactivity through real-time object manipulation and environment-aware spatial mapping, leveraging emerging metaverse concepts. These directions have the potential to redefine current e-commerce paradigms and unlock new possibilities for immersive online shopping experiences.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Nitin M. Shivsharan, Omkar Bhosale, Amin Kazi, Sejal Gawas, Bhakti Shirsat

Acquisition, analysis, or interpretation of data: Nitin M. Shivsharan, Omkar Bhosale, Amin Kazi, Sejal Gawas, Bhakti Shirsat

Drafting of the manuscript: Nitin M. Shivsharan, Omkar Bhosale, Amin Kazi, Sejal Gawas, Bhakti Shirsat

Critical review of the manuscript for important intellectual content: Nitin M. Shivsharan, Omkar Bhosale, Amin Kazi, Sejal Gawas, Bhakti Shirsat

Supervision: Nitin M. Shivsharan

Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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