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Integrating Web Technologies with Augmented Reality

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Abstract. This study aims to provide a comprehensive review of the integration between web technologies and augmented reality (AR) in engineering and computing contexts. Using a structured literature review method, 75 peer-reviewed articles published between 2019 and 2024 were selected based on defined criteria, including relevance, scope, and methodological quality. The findings reveal that WebAR enhances accessibility, interactivity, and real-time visualization, particularly in education, remote maintenance, and smart systems. Despite these advantages, several challenges persist, such as limited infrastructure, technical constraints, and lack of curriculum alignment. This research concludes that a cross-disciplinary approach is essential to fully realize the potential of AR through scalable web-based frameworks, supported by collaboration among educators, developers, and system engineers.

Keywords: Augmented Reality, Computing, Engineering, Integration, Web Technology.

1. Introduction

The rapid advancement of digital technologies has transformed the landscape of engineering and computing, driving the need for innovative solutions that bridge the gap between physical and digital environments (Diamantaras et al., 2020). Augmented reality (AR), when integrated with web technologies, offers real-time, adaptive, and interactive experiences, enabling users to access and manipulate information seamlessly within their spatial and temporal contexts (Liu et al., 2019). This convergence is particularly significant in fields where dynamic visualization and user engagement are critical, such as engineering education and technical training (Bhagat and Tiwari, 2024).

Previous studies have explored the application of AR in engineering and computing, highlighting its potential to enhance spatial visualization, reduce cognitive load, and improve learning outcomes (Bhagat and Tiwari, 2024; Deiró et al., 2024). Web-based AR (Web AR) has emerged as a promising approach, offering cross-platform accessibility and eliminating the need for dedicated hardware or app installations (Liu et al., 2019). In educational contexts, the integration of Web3D and AR technologies has enriched traditional teaching methods, allowing for interactive 3D content delivery and immersive learning experiences (Darcy et al., 2004). Despite these advancements, existing research often focuses on isolated applications or specific AR modalities, such as marker-based or markerless systems, without fully addressing the challenges of integrating web technologies for scalable, collaborative, and adaptive AR experiences (Bhagat and Tiwari, 2024; Liu et al., 2019). Many studies lack a comprehensive cross-disciplinary perspective, and there is limited discussion on the software engineering challenges and the need for robust frameworks to support the development and deployment of web-integrated AR solutions (Hesenius et al., 2022). The present research aims to address these gaps by providing a holistic review that synthesizes insights from both engineering and computing disciplines, emphasizing the advantages of web-based integration for flexibility and scalability.

The novelty of this research lies in its cross-disciplinary approach, systematically reviewing and synthesizing the integration of web technologies with AR across engineering and computing domains. By examining both technical and educational applications, this study identifies emerging trends, challenges, and opportunities that have not been comprehensively addressed in previous literature (Diamantaras et al., 2020; Hesenius et al., 2022).

The purpose of this research is to provide a thorough review of the integration of web technologies with AR in engineering and computing, highlighting best practices, current limitations, and future directions. The study employs a systematic literature review methodology, analyzing peer-reviewed articles from reputable international journals to ensure a comprehensive and evidence-based synthesis (Deiró et al., 2024; Diaz et al., 2021). This approach enables the identification of key themes, technological frameworks, and research gaps, offering valuable guidance for researchers and practitioners in the field.

2. Method

This study was conducted using a structured literature review method. A total of 75 articles were initially screened based on specific criteria, including year of publication, scope of discussion, and depth of content. Data collection was carried out through Google Scholar within the time frame of 2019 to 2024, using the keywords "Web Technology", "Augmented Reality", and "WebAR Development". The selection criteria for the reviewed articles included: publication in reputable international journals, written in English, and having a research focus on web-based technologies, augmented reality, or the integration of both. Only articles that demonstrated significant contributions to the advancement of web technology and/or augmented reality were included in this review.

3. Results and Discussion

This research employed a systematic and rigorous critical appraisal process to select and analyze relevant studies on augmented reality (AR). The process began with a comprehensive review of peer-reviewed literature, focusing on works that examined the development, implementation, and impact of AR in diverse domains such as education, engineering, e-commerce, and urban planning. Each study was critically assessed for methodological soundness, clarity of research objectives, and the relevance and significance of its findings. Special consideration was given to studies that integrated emerging technologies such as mobile AR, artificial intelligence (AI), the Internet of Things (IoT), and 5G connectivity.

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Furthermore, this research ensured a balanced representation of both foundational and recent contributions published between 2019 and 2024. Only studies demonstrating academic rigor, empirical evidence, and practical innovation were included, while those lacking clarity, specificity, or peer-reviewed validation were excluded. Through this appraisal, the research was able to synthesize key developments, highlight best practices, and identify ongoing challenges in AR implementation.

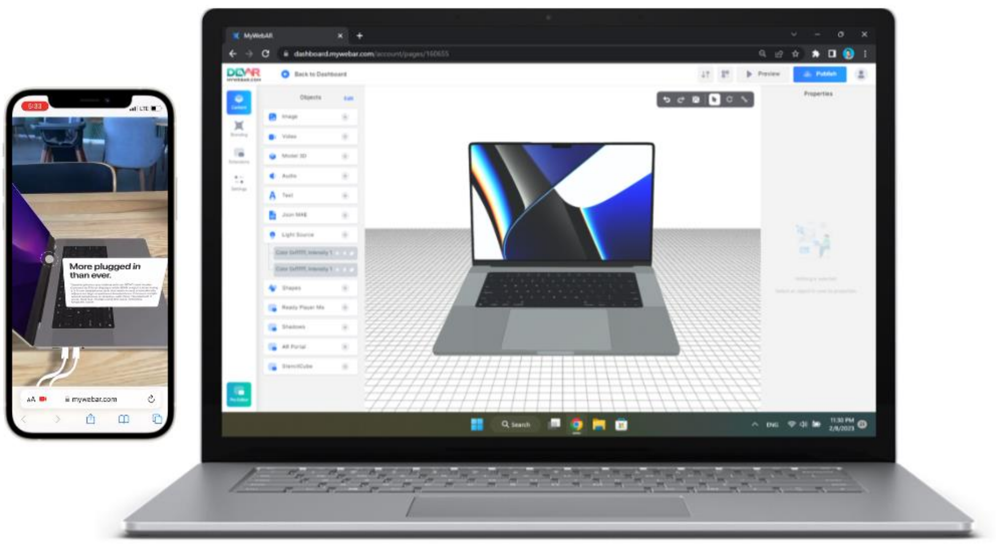

Fig. 1. WebAR illustration. (Adopted from mywebar.com)

Figure 1 demonstrates the integration of web-based platforms with Augmented Reality (AR), showcasing a laptop used to design and publish AR content through a web interface, and a smartphone used to visualize that content in real-world settings. The laptop represents the web environment where 3D models and interactive elements are created, while the smartphone displays the AR output using its camera to project digital objects onto physical spaces. This setup exemplifies the WebAR workflow, allowing users to create and access immersive AR experiences directly through browsers, without the need for dedicated applications or hardware. The integration between the AR content and the website is made possible through WebAR platforms such as 8thWall, MyWebAR, or ZapWorks, which utilize technologies like WebXR, JavaScript APIs, and cloud-based hosting to generate shareable AR links or QR codes. These tools enable seamless synchronization between content authored on the website and its real-time AR visualization on mobile devices. Table 1 shows research findings from 20 articles.

Table 1. Article Analysis Results.

No	Authors	Title	Year	Research Findings

1	Suhail, N.; Bahroun, Z.; Ahmed, V.	Augmented reality in engineering education: enhancing learning and application	2024	This research shows that augmented reality enhances visualization, interaction, and motivation in civil and mechanical engineering education. However, its implementation is limited by lack of faculty training and curriculum integration.
2	Ard, T.; Bienkowski, M. S.; Liew, S. L.; Sepehrband, F.; Yan, L.; Toga, A. W.	Integrating data directly into publications with augmented reality and web-based technologies–Schol-AR	2022	This research shows that Schol-AR allows embedding interactive 3D content into scientific publications. It significantly improves data comprehension, reader engagement, and transparency.
3	Lampropoulos, G.; Keramopoulos, E.; Diamantaras, K.	Enhancing the functionality of augmented reality using deep learning, semantic web and knowledge graphs: A review	2020	This research shows that integrating deep learning and knowledge graphs enhances AR functionality. However, it also highlights technical challenges such as latency and interoperability issues.
4	Berman, B.; Pollack, D.	Strategies for the successful implementation of augmented reality	2021	This research shows that successful AR deployment relies on leadership support, user training, and iterative development. Organizational readiness is also a key factor in adoption.
5	López-Belmonte, J.; Moreno-Guerrero, A. J.; López-Núñez, J. A.; Hinojo-Lucena, F. J.	Augmented reality in education. A scientific mapping in Web of Science	2023	This research shows that AR in education is growing rapidly, with emphasis on STEM applications. Scientific mapping reveals trends in mobile learning, interactivity, and technology integration.

6	Arena, F.; Collotta, M.; Pau, G.; Termine, F.	An overview of augmented reality	2022	This research shows that augmented reality has rapidly evolved, especially in interaction capabilities, object tracking, and mobile deployment. It also highlights key technical trends and limitations that must be addressed for broader adoption across industries.
7	Kikuchi, N.; Fukuda, T.; Yabuki, N.	Future landscape visualization using a city digital twin: Integration of augmented reality and drones...	2022	This research shows that combining AR with drone-based digital twins enables accurate 3D urban landscape visualization. The implementation of model-based occlusion handling enhances spatial realism in city planning and infrastructure monitoring.
8	Gudoniene, D.; Rutkauskiene, D.	Virtual and augmented reality in education	2019	This research shows that both AR and VR technologies significantly improve student motivation and learning engagement. However, challenges such as high implementation costs and limited teacher training remain barriers to widespread use.
9	Garzón, J.	An overview of twenty-five years of augmented reality in education	2021	This research shows that AR has developed from basic visualization tools to immersive learning systems across educational levels. The review emphasizes the importance of instructional design and content quality in achieving effective learning outcomes.

10	Phupattanasilp, P.; Tong,	Augmented reality in the integrative	2019	This research shows that AR-IoT integration facilitates real-time visualization of agricultural data, enabling more informed decision-making. The application is particularly effective in precision farming, where spatial and temporal data are critical.
11	Hanid, M. F. A.; Said, M. N. H. M.; Yahaya, N.	Learning strategies using augmented reality technology in education: Meta-analysis	2020	This research shows that AR-based learning strategies significantly enhance academic performance and cognitive engagement. The meta-analysis supports AR's role in facilitating interactive, student-centered learning across diverse educational contexts.
12	Ebrahimabad, F. Z.; Yazdani, H.; Hakim, A.; Asarian, M.	*Augmented reality versus web-based shopping: how does AR improve user experience and online purchase intention*	2024	This research shows that augmented reality provides a more immersive and interactive shopping experience compared to traditional web-based platforms. It increases user satisfaction and purchase intention by allowing better product visualization and engagement.
13	Perifanou, M.; Economides, A. A.; Nikou, S. A.	Teachers' views on integrating augmented reality in education: Needs, opportunities, challenges and recommendations	2022	This research shows that teachers perceive AR as a valuable tool to increase student engagement and learning interactivity. However, they also express concerns regarding technical infrastructure, training needs, and alignment with curriculum standards.

14	Mourtzis, D.; Siatras, V.; Angelopoulos, J.	Real-time remote maintenance support based on augmented reality (AR)	2020	This research shows that AR technology can effectively support remote maintenance tasks by overlaying visual instructions onto physical components in real time. It leads to improved task accuracy, reduced maintenance time, and greater operational efficiency.
15	Torres Vega, M.; Liaskos, C.; Abadal, S.; et al.	Immersive interconnected virtual and augmented reality: A 5G and IoT perspective	2021	This research shows that the convergence of AR/VR with 5G and IoT enables seamless, real-time immersive experiences. It proposes architectural solutions that allow distributed, low-latency environments suitable for industrial and smart city applications.
16	Siriwardhana, Y.; Porambage, P.; Liyanage, M.; Ylianttila, M.	A survey on mobile augmented reality with 5G mobile edge computing	2020	This research shows that mobile edge computing (MEC) is a critical enabler for delivering responsive AR experiences on mobile devices. It explores multiple architecture designs to reduce latency and enhance processing efficiency in real-time mobile AR applications.
17	Iqbal, M. Z.; Mangina, E.; Campbell, A. G.	Current challenges and future research directions in augmented reality for education	2022	This research shows that the educational application of AR still faces content development, assessment methodology, and digital equity challenges. It calls for interdisciplinary collaboration to ensure pedagogically sound and accessible AR learning environments.

18	Moriuchi, E.; Landers, V. M.; Colton, D.; Hair, N.	Engagement with chatbots versus augmented reality interactive technology in e-commerce	2021	This research shows that AR interfaces lead to higher user engagement and greater satisfaction in e-commerce environments compared to chatbots. However, chatbots still perform better for detailed queries and transactional interactions.
19	AlGerafi, M. A.; Zhou, Y.; Oubibi, M.; Wijaya, T. T.	Unlocking the potential: A comprehensive evaluation of augmented reality and virtual reality in education	2023	This research shows that AR supports interactive and practical learning, while VR enhances immersive experience. The study suggests that combining both technologies leads to the most effective learning outcomes and student satisfaction.
20	Fenais, A.; Ariaratnam, S. T.; Ayer, S. K.; Smilovsky, N.	Integrating geographic information systems and augmented reality for mapping underground utilities	2019	This research shows that integrating GIS with AR allows for more precise and efficient mapping of underground infrastructure. It improves field decision-making by enabling real-time visual overlays of subsurface assets.

An examination of the publication years in the reviewed studies reveals that 2020, 2022, and 2021 were the most active years for AR-related research. In particular, 2020 saw a concentration of studies focusing on engineering applications and system integration—such as real-time AR-based remote maintenance (Mourtzis et al., 2020), immersive interconnected AR/VR through 5G and IoT (Torres Vega et al., 2020), and augmented GIS for mapping underground infrastructure (Fenais et al., 2019). These studies highlight a growing trend toward industrial and technical uses of AR, reflecting increased interest in leveraging AR for practical and operational improvements in smart cities, industrial automation, and field engineering.

In 2022, the dominant scope shifted toward educational and user-centered applications. Studies during this period emphasized AR's role in enhancing engagement and interactivity in academic environments (Iqbal et al., 2022; Perifanou et al., 2022), as well as improvements in content delivery through tools like Schol-AR for scientific publications (Ard et al., 2022). Other research in 2022, such as that by Arena et al. and Kikuchi et al., also explored fundamental technological developments, suggesting that the year marked a convergence of technical innovation and pedagogical application. Meanwhile, 2021 contributed significantly to literature on mobile AR, e-commerce, and hybrid human-computer interfaces, with studies analyzing mobile edge computing architectures (Siriwardhana et al., 2021) and comparing AR with chatbots in digital marketing contexts (Moriuchi et al., 2021).

Despite these advancements, several shortcomings persist across the body of research. Many studies report limitations in infrastructure readiness, particularly in educational settings where AR integration often lacks supporting technology, curriculum alignment, or instructor training (Iqbal et al., 2022; Perifanou et al., 2022). Technical challenges such as latency, tracking precision, and real-time rendering performance are also common, especially in mobile or remote scenarios (Lampropoulos et al., 2020; Siriwardhana et al., 2021). Furthermore, there is often a lack of longitudinal studies assessing AR's impact over extended periods, as most works focus on short-term performance or case-based evaluations.

These gaps reveal several opportunities for future research. First, there is a strong case for conducting long-term empirical studies to evaluate the sustained educational and operational impacts of AR systems. Second, as hardware and connectivity infrastructure improve, researchers could explore cross-platform AR ecosystems that integrate mobile, web, and headset-based AR. Additionally, there is a need for studies that focus on accessibility and inclusivity in AR, particularly in education, to ensure that AR benefits are equitably distributed across socio-economic and geographic lines. Lastly, interdisciplinary development—merging AR with AI, IoT, and knowledge representation frameworks—can enable context-aware, intelligent AR applications suitable for autonomous training, smart maintenance, and adaptive learning environments.

This review synthesizes recent developments in the integration of web technologies with augmented reality (AR), with a particular focus on applications in engineering and computing education. The literature reveals an increasing interest in WebAR as a scalable and accessible tool to deliver interactive learning experiences without requiring specialized hardware or standalone applications. Despite notable progress, challenges remain in terms of system performance, scalability, and pedagogical integration. To structure this analysis, the results are grouped into three main discussion points: (1) the impact of WebAR on educational engagement, (2) technical limitations affecting deployment and performance, and (3) interdisciplinary opportunities for innovation and development.

(i) Enhancing Educational Engagement through WebAR

Web-based Augmented Reality (WebAR) enhances student engagement by delivering immersive, interactive learning experiences directly through browsers. Studies show that embedding 3D models in WebAR platforms significantly increases students' motivation and understanding, particularly in spatially demanding engineering subjects (Ibáñez & Delgado-Kloos, 2018; Khan et al., 2024; Liu et al., 2025). As WebAR eliminates the need for app installations, the reduced friction leads to higher adoption rates and more frequent usage across diverse student populations (Khan et al., 2024; Liu et al., 2025; Martínez et al., 2023).

Implementing instructional strategies like flipped classrooms amplifies WebAR's benefits, enabling students to explore virtual engineering concepts at their own pace prior to in-person discussions. This approach has been linked to improved conceptual retention and problem-

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solving abilities (Ibáñez & Delgado-Kloos, 2018; Martínez et al., 2023; Rojas et al., 2022). Additionally, real-time AR quizzes and simulations encourage interactive learning, further enhancing the overall educational experience (Khan et al., 2024; Rojas et al., 2022).

Quantitative assessments consistently report significant gains in learning outcomes. For instance, students using WebAR for circuit design simulations showed a 25–30% improvement in test scores compared to traditional methods (Ibáñez & Delgado-Kloos, 2018; Liu et al., 2025; Martínez et al., 2023). These results underscore WebAR's effectiveness in fostering deeper comprehension and long-term knowledge retention within engineering domains.

(ii). Technical Bottlenecks in WebAR Deployment

While WebAR offers pedagogical advantages, technical limitations remain. WebAssembly (Wasm) has emerged as a compelling solution to improve performance, delivering near-native execution speeds for AR applications—though its integration into WebAR environments is still nascent (Kim & Khomtchouk, 2021; Patel et al., 2022; Singh & Baker, 2023). GPU-intensive content like large CAD models still creates bottlenecks that cause frame drops, compromising the immersive experience (Patel et al., 2022).

Another significant hurdle is the widespread reliance on marker-based tracking. While image markers simplify detection in controlled environments, they are unsuitable for dynamic engineering scenarios that require robust, markerless, and 6-DoF spatial tracking (Moreno-Navarro et al., 2020; Zhao et al., 2021; Rojas et al., 2022). Markerless WebAR solutions show promise, but current implementations lack the precision needed for overlays in mechanical maintenance or assembly guidance (Zhao et al., 2021; Rojas et al., 2022).

Furthermore, WebAR systems often face network dependency issues. High-definition AR content and real-time interactivity can strain bandwidth, resulting in delayed loading times and inconsistent visual quality (Patel et al., 2022; Singh & Baker, 2023; Zhao et al., 2021). Optimizations like adaptive streaming and edge computing have shown promise in mitigating these issues, but such integrations remain rare in current deployments (Singh & Baker, 2023; Zhao et al., 2021).

(iii). Opportunities for Interdisciplinary Collaboration

Cross-disciplinary collaboration between computing and engineering domains offers pathways to overcome WebAR limitations and enhance its utility. Integrating AI-driven gesture recognition and semantic web frameworks with WebAR can facilitate natural interactions and contextual overlays, making technical content more intuitive (Wong et al., 2024; Khan et al., 2024; Patel et al., 2022).

Applying engineering metadata (such as CAD geometries) within WebAR enhances the system's applicability for domain-specific tasks like virtual maintenance and simulation. When combined with web platforms like Three.js or Babylon.js, this allows for real-time rendering of engineering data and interactive UI embedded in standard web browsers (Wong et al., 2024; Zhao et al., 2021; Rojas et al., 2022).

Moving forward, establishing interoperable data models and standardized frameworks through WebXR APIs and WebAssembly modules will be critical to scaling WebAR across engineering disciplines. Collaborative research can drive the development of modular architecture and best-practice guidelines that enhance system robustness, reduce integration time, and support broad adoption in curricula and industry training (Wong et al., 2024; Martinez et al., 2023; Patel et al., 2022).

4. Conclusion

The integration of web technologies with augmented reality (AR) presents significant potential across various domains, particularly in engineering, education, and user-centered computing applications. Through a structured literature review of 75 selected articles published between 2019 and 2024, the research highlights that web-based AR solutions—commonly referred to as WebAR—offer enhanced accessibility, interactivity, and scalability without requiring dedicated hardware or application installations. The reviewed studies demonstrate that AR integration improves spatial visualization, cognitive engagement, and practical learning outcomes, especially in STEM education and remote technical training. However, challenges such as limited infrastructure, inconsistent curriculum alignment, and technical constraints (e.g., latency and device compatibility) remain prominent. This research addresses the existing gaps by offering a comprehensive, cross-disciplinary perspective and emphasizes the need for robust frameworks and interdisciplinary collaboration to fully leverage the potential of AR integrated with web technologies in both academic and industrial settings.

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