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Implementation of Markerless Web-Based Augmented Reality for Product Visualization Using RAD Method (Case Study: Citra Artframe)

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Abstract

Citra Artframe, a producer of frames and art prints in the micro, small, and medium enterprise sector, uses two-dimensional catalogs that limit prospective buyers' ability to assess product dimensions, colors, and fit within their interiors. This study developed and evaluated a web-based augmented reality (AR) system for interactive product visualization. Using Rapid Application Development, the system integrated WebXR for immersive sessions, device tracking, and hit testing with Three.js for rendering and manipulating 3D models. Markerless plane detection enabled users to place models in GLB format on walls, translate, rotate, resize, reposition, or remove them, and capture screenshots. The system passed all 31 primary black-box test scenarios. User acceptance testing with 23 respondents yielded 367 valid item responses, a mean rating of 4.72 out of 5, and an acceptance index of 94.50%. The ratings showed high internal consistency (Cronbach's alpha = 0.931). The system met the tested functional requirements and received high initial user acceptance, supporting its use for interactive product previews. These findings indicate potential for digital promotion at Citra Artframe. Its impact on business outcomes remains to be evaluated.

Keywords: Markerless Augmented Reality; Product Visualization; Rapid Application Development; Three.js; WebXR

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INTRODUCTION

Digital transformation has reshaped marketing strategies and consumer interactions, particularly among micro, small, and medium enterprises (MSMEs). Digital technologies are increasingly utilized not only to expand market reach but also to provide more interactive product information that enables consumers to evaluate purchasing alternatives (Melumad et al., 2020). For visually oriented products, such as picture frames and art prints, product visualization is particularly important because purchasing decisions are influenced by perceptions of dimensions, colors, designs, and compatibility with physical surroundings. In digital commerce, Augmented Reality (AR) offers interactive visual experiences that can potentially reduce consumer uncertainty during purchasing decisions (Hoffmann & Mai, 2022). AR-based shopping experiences may also strengthen consumer engagement through more contextualized product interactions (Chakraborty et al., 2022).

Citra Artframe is an MSME specializing in the production and sale of frames and art prints through online and offline channels. Its online marketing activities utilize Instagram, WhatsApp, and marketplace platforms to display product images, dimensions, prices, and description (Kisawike & Ndekwa, 2026). However, the existing product catalog primarily relies on two-dimensional (2D) images, which provide limited information regarding product proportions when displayed on walls and their visual compatibility with prospective buyers' interior spaces. This limitation may create an experience gap between the product representation presented in digital catalogs and consumers' expectations of how products would appear in actual environments. This concern is consistent with research examining AR-enabled digital shopping, which emphasizes the importance of visual experience and product interaction in consumer evaluation (Qin et al., 2021). Moreover, AR-based shopping experiences can provide more informative product-use contexts than conventional visual representations (Park & Yoo, 2020).

The identified problem was supported by a preliminary survey conducted through Google Forms on August 20, 2026. Of the 35 responses collected, 33 were considered valid after two responses were excluded based on the screening criteria. Among the valid respondents, 24 had viewed the catalog, consulted the seller, or purchased products from Citra Artframe. Within this subgroup, 18 respondents (75%) reported difficulty estimating product dimensions when displayed on walls, while the same number expressed concerns regarding color and design compatibility. Furthermore, 19 respondents (79.2%) considered

wall-based product simulation important or very important. These findings were complemented by interviews with the business owner and observations of marketing activities, indicating that chat-based consultations remain an alternative when the catalog provides insufficient visual information. Collectively, these findings suggest the need for a visualization medium that intuitively connects digital product representations with actual spatial environments.

Augmented Reality is a technology that integrates virtual objects into physical environments interactively and in real time, allowing users to perceive their surroundings while interacting with digital elements (Arena et al., 2022). In marketing contexts, AR facilitates try-before-you-buy experiences by enabling consumers to simulate product usage or placement before purchasing. This approach is particularly relevant to interior decoration products, as consumers can assess product dimensions, positioning, and appearance within contextualized environments. AR applications in retail may also strengthen consumer engagement and shopping experiences (Chakraborty et al., 2022). Accordingly, this study considers AR not merely as an additional visual feature but as a technological approach to addressing the product visualization requirements identified at Citra Artframe.

Web-based Augmented Reality, commonly referred to as WebAR, offers a relevant alternative for MSMEs because AR experiences can be accessed through browsers without requiring users to download and install dedicated applications. WebXR provides a standardized interface for supporting immersive web-based experiences, including session management, device tracking, and interaction with physical environments (MacIntyre & Smith, 2018). WebAR also offers more accessible delivery of digital experiences to users (Raval et al., 2021). Through this technology, applications can utilize device capabilities to detect users' positions and orientations while supporting interaction with their physical surroundings. This approach offers potential for developing flexible and accessible digital visualization solutions for businesses with limited technological resources. The broader development of extended reality technologies further establishes the relevance of browser-based immersive applications in contemporary digital environments (Radianti et al., 2020).

This study implements markerless WebAR using plane detection to enable frame models to be positioned on wall surfaces without requiring physical markers. Markerless AR offers more flexible interaction with physical environments, particularly through surface recognition for virtual object placement (Wedel et al., 2020). Plane detection is also relevant

for visualizing objects on flat surfaces, including decorative items within interior spaces (Nowacki & Woda, 2020). To support three-dimensional rendering and object manipulation, the system utilizes Three.js, a JavaScript library that enables interactive 3D graphics rendering in browsers through WebGL (Dou et al., 2020). Web-based 3D rendering technologies further facilitate flexible and interactive product visualization (Boutsi et al., 2023). The integration of these technologies provides the technical foundation for positioning and manipulating virtual frames within users' physical environments.

Previous studies have examined AR applications in digital commerce, product visualization, and web-based application development. Hoffmann and Mai (2022) investigated AR shopping experiences and their implications for consumer behavior, while Qin et al. (2021) examined the influence of mobile AR on consumer decision-making. Raval et al. (2021) demonstrated the application of WebAR in developing interactive visualization systems, whereas McNally & Koviland (2024) explored web-based AR systems as an approach to immersive application development. From a software development perspective, Fauzi et al. (2023) identified Rapid Application Development (RAD) as an approach that supports shorter development cycles and adaptability to user requirements. Saputra et al. (2024) also applied RAD in developing an AR application. These studies provide relevant foundations for AR implementation, WebAR technologies, and development methodologies; however, the integration of wall-based visualization for frames and art prints, interactive object manipulation, browser accessibility, and transaction-related functionalities within an MSME website remains a relevant development context for this study.

The research gap does not concern AR development in general but the implementation of markerless WebAR to address the limitations of conventional 2D product catalogs for frames and art prints at Citra Artframe. The gap specifically concerns the integration of three-dimensional wall placement through plane detection, interactive object manipulation, browser-based accessibility without application installation, and connectivity with product catalog and transaction functionalities. This integration represents an implementation context tailored to the operational requirements of an MSME and the visual characteristics of its products.

The novelty of this study lies in developing a browser-based markerless WebAR product visualization system that integrates WebXR and Three.js to proportionally display frames and art prints on wall surfaces. The system incorporates rotation, translation, scaling,

repositioning, object deletion, and screenshot functionality, while connecting product visualization with Citra Artframe's ordering workflow. This implementation is grounded in the principle of interactive integration between virtual objects and physical environments (Rauschnabel et al., 2022), the utilization of WebXR for immersive browser-based experiences (McNally & Kolivand, 2024), and web-based three-dimensional rendering through Three.js (Buyukdemircioglu & Kocaman, 2020).

This study adopts the Rapid Application Development (RAD) methodology, comprising requirement planning, user design, construction, and cutover, to support a structured, iterative, and user-responsive system development process. The methodology is employed to design, develop, and evaluate the WebAR product visualization system for the Citra Artframe website. Accordingly, the study focuses on developing a system that enables prospective buyers to visualize frames and art prints within physical environments through browser-based access, interactively manipulate three-dimensional models, and explore products alongside the transaction process. The evaluation focuses on functional performance and initial user acceptance rather than measuring sales growth or product-return rate reductions.

METHODS

This study employed a development research approach with a descriptive orientation to develop a Web-based Augmented Reality (WebAR) product visualization application for Citra Artframe, a micro, small, and medium enterprise (MSME). A case study approach was adopted to identify user requirements, design, develop, and evaluate the system within the context of the business processes of the research subject. System development followed the Rapid Application Development (RAD) methodology, comprising four phases: requirement planning, user design, construction, and cutover. This approach facilitated iterative system development through the involvement of the MSME owner and prospective users in refining requirements, design decisions, and implementation.

The research design focused on developing a system in response to limitations in two-dimensional (2D) product catalog visualization and evaluating its functionality and initial user acceptance. The needs-assessment indicators included difficulties estimating frame dimensions on walls, concerns regarding color and design compatibility with interior spaces, actions taken when catalog information was insufficient, and perceived importance of

visualizing products on personal walls. These indicators informed the formulation of contextual visualization requirements. Interface design was additionally guided by Nielsen (1994) ten usability heuristics: visibility of system status, match between the system and the real world, user control and freedom, consistency and standards, error prevention, recognition rather than recall, flexibility and efficiency of use, aesthetic and minimalist design, error recognition and recovery, and help and documentation. Technical development indicators encompassed markerless visualization, three-dimensional object manipulation, WebXR compatibility, transaction functionality, data management, and fallback mechanisms.

Participants comprised preliminary survey respondents and users involved in User Acceptance Testing (UAT). The preliminary questionnaire collected 35 responses on August 20, 2026. Two responses were excluded based on the screening criteria, resulting in 33 valid responses, including 24 respondents who had previously interacted with Citra Artframe. Respondents were selected through experience-based screening to ensure relevance to online frame and art print purchasing. UAT involved 23 respondents to assess initial system acceptance following development. Detailed demographic characteristics and the specific sampling procedure for UAT were not explicitly documented.

Data were collected through structured interviews or confirmations with the MSME owner, business-process observations, a preliminary questionnaire, documentation, functional testing, and UAT. Preliminary data collection examined catalog presentation, customer consultations, visualization needs, and transaction processes. Questionnaire data were analyzed descriptively using frequencies and percentages, while interview and observation findings were coded thematically, triangulated, and mapped to a fishbone diagram and system requirements. Development subsequently involved flowchart, UML, database, and wireframe design, implementation, and technical and functional verification. System evaluation comprised black-box testing and WebAR compatibility testing, followed by UAT analysis using the mean, standard deviation, acceptance index, proportion of scores 4–5, and Cronbach's alpha. The study did not measure changes in sales or product return rates.

RESULTS

System Overview and Implementation

The research resulted in a web-based Citra Artframe e-commerce system integrating a frame product catalog, art print catalog, custom frame builder, shopping cart, customer address management, checkout, invoice generation, admin dashboard, and WebAR-based product visualization. The system was developed to provide a more interactive product visualization experience, enabling users to explore frame options and visualize three-dimensional objects in real-world environments through a smartphone browser without requiring additional application installation.

The system implementation encompasses both customer-facing and administrative functionalities. On the customer side, the system provides access to product catalogs, product details, frame customization through the custom frame builder, order processing, and augmented reality visualization. On the administrative side, the system provides product, art print, slider, and order management, as well as dashboard statistics. Integration with Firebase, Cloudinary, API.co.id, and Flip sandbox also supports authentication, digital asset management, shipping cost calculation, and payment processing.

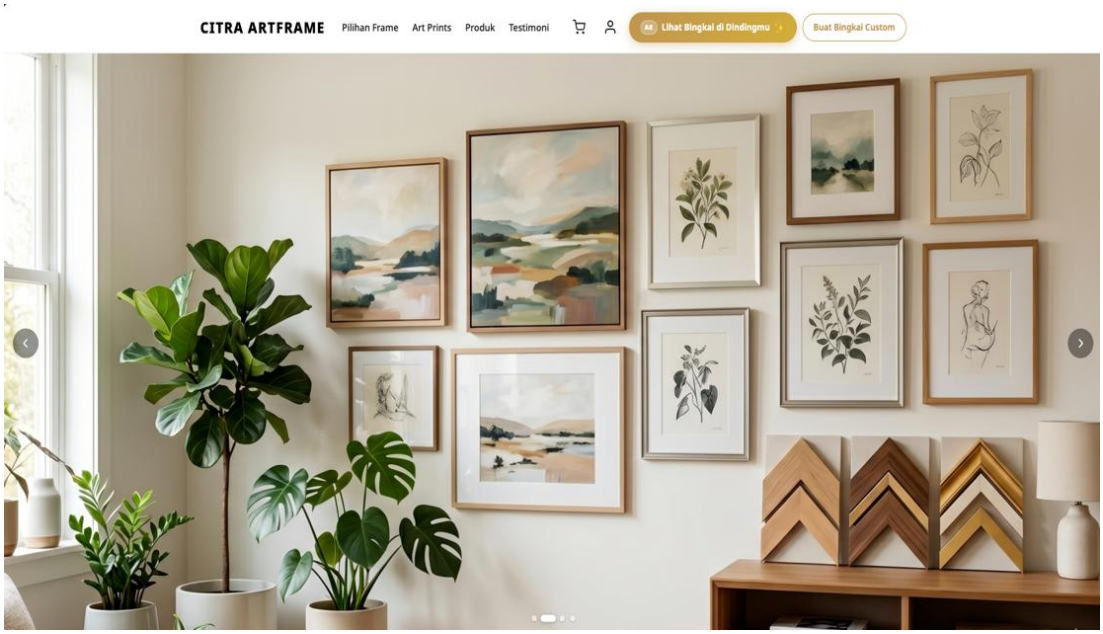


Figure 1. Citra Artframe Homepage

Figure 1. Citra Artframe Homepage shows the Citra Artframe homepage, which serves as the main interface for users to access the website's features, explore available products, and navigate to other sections of the platform.

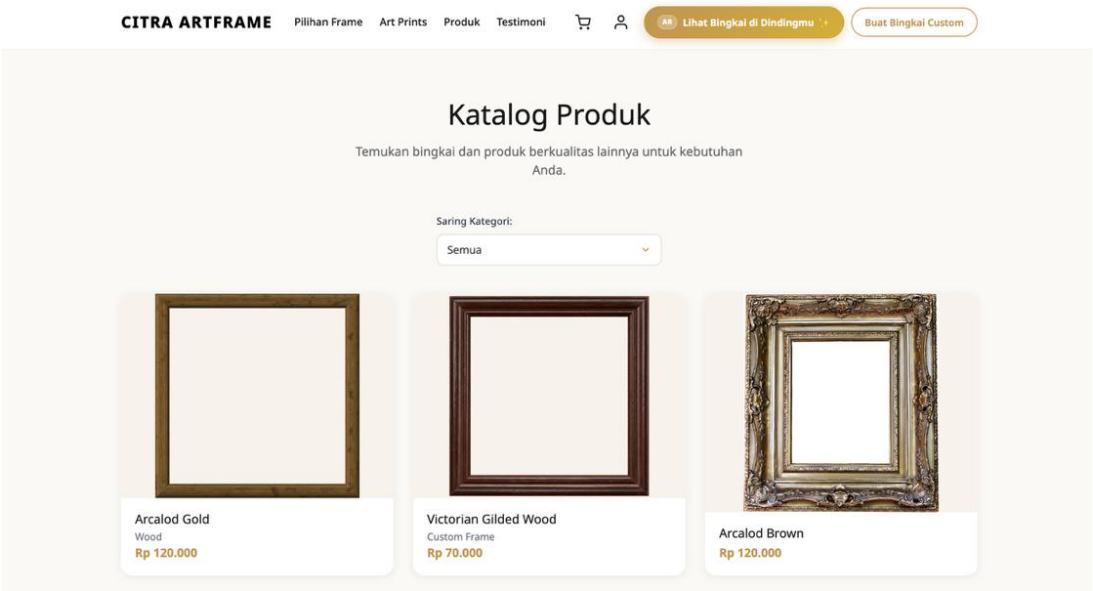


Figure 2. Product Catalog Page

Figure 2. Product Catalog Page shows the product catalog page, which presents the available frame products to users, allowing them to browse and explore product options before selecting a frame.

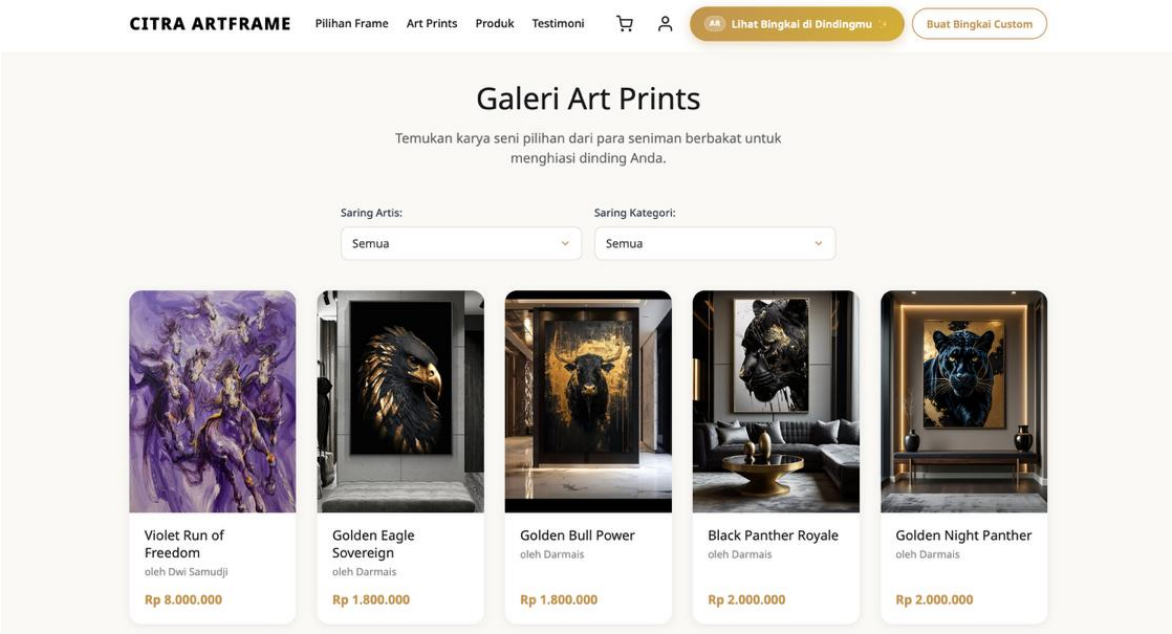


Figure 3. Art Print Catalog Page

Figure 3. Art Print Catalog Page shows the art print catalog page, which displays the available artwork collections that users can explore and select as part of their framing preferences.

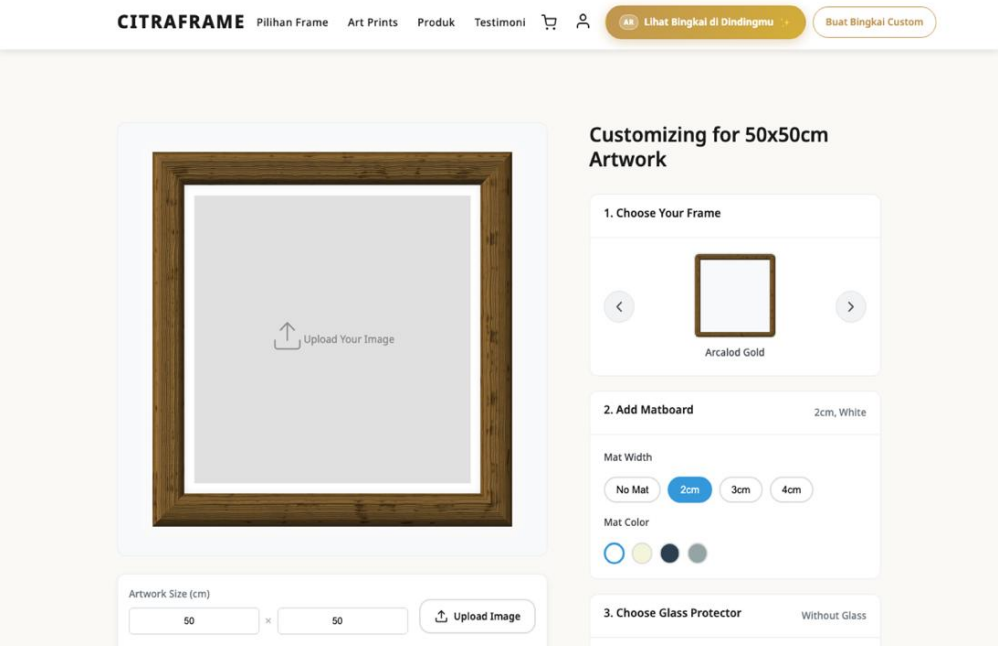


Figure 4. Custom Frame Builder Page

Figure 4. Custom Frame Builder Page shows the Custom Frame Builder page, which enables users to customize frame configurations by selecting available options according to their preferences before proceeding with the purchasing process.

Authentication, Authorization, and Transaction Implementation

The system implements separate authentication and authorization mechanisms for customers and administrators. Customer authentication is integrated with Firebase, whereas administrator access uses JWT. Administrative endpoints are protected through authorization middleware, preventing requests without valid tokens from accessing protected resources. API endpoints also return JSON responses with HTTP status codes 401 or 403 instead of HTTP 302 redirects for unauthenticated or unauthorized requests.

Order detail access is also protected. Customers can only access their own orders, while administrators can access order details according to their authorization privileges. Requests from other users are rejected with a 403 response, whereas unauthenticated requests receive a 401 response.

Table 1. Authorization Testing Results

Test Scenario	Expected Result	Actual Result	Status
Accessing /api/admin/stats without JWT	401 JSON	401, without redirect	PASS

Test Scenario	Expected Result	Actual Result	Status
Accessing /api/orders{id} without authentication	401 JSON	401, without redirect	PASS
Order owner accessing their own order	200	200	PASS
Other user accessing an order	403	403, generic response	PASS
Admin accessing order details	200	200	PASS
Invalid JWT	401 JSON	401, without redirect	PASS

Source: Compiled by the researcher (2026)

Table 1. Authorization Testing Results shows that the authorization mechanisms successfully differentiate between unauthenticated requests, unauthorized access, customer ownership, and administrator access. The results indicate that the protected endpoints enforce access restrictions according to the defined authentication and authorization rules.

The checkout implementation includes validation of customer information, delivery address, order items, products, quantities, and stock availability. The system recalculates product prices, subtotals, shipping costs, and transaction totals on the backend, preventing reliance on values submitted by the frontend. Flip sandbox integration is also implemented to generate payment URLs and manage payment statuses. When payment processing fails, the system changes the order status to payment_failed and restores stock through a compensating transaction mechanism.

Table 2. Checkout and Payment Testing Results

Test Scenario	Actual Result	Status
Empty order items	Request rejected, 400	PASS
Invalid email	Request rejected, 400	PASS
Invalid phone number	Request rejected, 400	PASS
Incomplete address	Request rejected, 400	PASS
Nonexistent product	Request rejected, 400	PASS
Insufficient stock	Request rejected, 400	PASS
Frontend price manipulation	Total recalculated using database prices and server-side shipping data	PASS
Order before payment	pending_payment	PASS
Successful Flip sandbox request	Payment URL stored; status awaiting_payment	PASS
Failed Flip sandbox request	Status payment_failed; stock restored	PASS

Source: Compiled by the researcher (2026)

Table 2. Checkout and Payment Testing Results shows that the checkout process enforces server-side validation and transaction calculations, while payment integration manages transitions

between payment states. The results also demonstrate that the system handles payment failures through status updates and stock restoration rather than treating failed transactions as completed payments.

Admin Interface and Database Implementation

The administrative panel provides dashboard statistics, product management, art print management, slider management, order listings, order details, and transaction status updates. CRUD operations were tested using controlled test data, while the application was evaluated using non-PII beta catalog data. The test results indicate that create, read, update, and delete operations for products, art prints, and sliders were executed according to the testing scenarios. The order management functionality was also tested through order listing, order detail retrieval, and order status updates. These features enable administrators to manage catalog content, maintain product information, monitor incoming orders, and update transaction statuses through the administrative interface.

The administrative dashboard presents system statistics to support the monitoring of e-commerce activities. Product and art print management interfaces facilitate the maintenance of catalog data, while slider management enables the administration of promotional content displayed on the website. The order management interface provides access to order lists, individual order details, and transaction status updates. The implementation of these functionalities demonstrates that the administrative panel supports the operational requirements of the e-commerce system, particularly in managing product information, catalog content, and customer transactions.

The database implementation also includes migrations for the products, art_prints, orders, order_items, sliders, custom_orders, user_addresses, and cart_items tables. The migrations were designed to add the required structures and indexes without deleting existing tables or data. Migration testing on the Aiven beta database was successful, including the addition of the payment_url and artwork_image_url columns to the orders table and supporting indexes. These results indicate that the database structure was successfully updated to accommodate the system's operational requirements and support the integration of the e-commerce features.

WebAR Implementation

WebAR was implemented through the integration of the WebXR Device API and Three.js using a three-dimensional GLB model. The frame.glb model was successfully loaded

through the local server with an HTTP 200 response and a file size of 1,522,172 bytes. Browser testing also confirmed that the main assets were accessible and that the previously used placeholder texture reference was no longer present in the runtime code.

WebXR was used to check device support for the immersive-ar mode, activate AR sessions and camera access, obtain device poses, and provide hit-test results for identifying candidate real-world surfaces. Meanwhile, Three.js was used to construct the scene, load the GLB model, configure the camera and renderer, process object positions and orientations, display the reticle, and render the three-dimensional object on the screen. The integration of these two technologies enables the system to separate environmental tracking and pose acquisition from three-dimensional scene construction and rendering. WebXR provides the AR session, device tracking, and hit-test pose, while Three.js uses these data to transform the model and render the three-dimensional object in the camera view.

The WebXR implementation includes device compatibility checking, immersive-ar session requests, hit-test source creation, frame-by-frame hit-test processing, and frame placement based on surface poses assessed as stable. The system uses a reticle to indicate candidate placement positions, with visual indicators distinguishing candidate, stable, and lost-tracking states. This mechanism allows users to identify the potential position of the frame before confirming its placement in the real-world environment. When the hit-test result does not reach a stable condition or the device does not support the required native AR pathway, the system provides a manual placement mechanism based on the camera pose and adjustment parameters.

During smartphone testing, the system successfully detected wall surfaces and provided a frame placement pose without requiring physical markers. The markerless detection mechanism enabled the three-dimensional frame to be positioned in the camera view based on the detected surface. The implementation was designed to facilitate the visualization of frame products within the user's surrounding environment through a browser-based AR experience, without requiring the installation of a separate application.

Three.js was used to adjust the frame model's scale, orientation, and position based on the product dimensions and hit-test pose. The model was placed into the scene after the user confirmed the available position. Users could also perform subsequent interactions, including repositioning, rotation, scale adjustment, object deletion, repositioning to another location, and screenshot capture. Direct testing demonstrated that these interactions could

be performed on the smartphone used in the evaluation. The interaction functionality provides users with the ability to modify the position and appearance of the displayed frame within the camera view according to the available system controls.

Successful surface detection and object placement were based on direct testing and functional observation on the smartphone used in the evaluation. This study did not numerically measure positional deviation, scale error, or orientation error. Therefore, the results demonstrate functional implementation and markerless visualization within the tested environment, rather than measured spatial accuracy or universal device compatibility.

Black-Box and Nonfunctional Testing Results

Black-box testing was conducted to evaluate system outputs based on input scenarios and expected results. Testing covered public pages, frontend assets, authentication, authorization, product management, art print management, slider management, custom orders, and order administration. In addition to black-box testing, unit testing, Aiven database integration testing, Firebase integration testing, Flip sandbox integration testing, Cloudinary integration testing, and API.co.id integration testing were conducted in the beta environment.

Table 3. Summary of System Testing Results

Testing Group	PASS	FAIL	Not Applicable
Unit Test Mock	23	0	0
Integration Test Aiven	19	0	0
Black box HTTP Local	31	0	0
Firebase Integration	8	0	0
Flip Sandbox Integration	7	0	0
Cloudinary Integration	4	0	0
API.co.id Integration	2	0	0
WebAR, browser, performance, and usability	10	0	0
Frontend Build	0	0	0

Source: Compiled by the researcher (2026)

Table 3. Summary of System Testing Results shows that the tested system components completed their respective testing scenarios without recorded failures. The frontend build category was classified as not applicable because the frontend was served as a static application without a package.json file. The results indicate successful functional verification within the tested beta environment rather than universal validation across all devices and deployment environments.

Compatibility testing was conducted using desktop browsers and a physical Android smartphone. Local HTTP testing showed that the public pages and main assets were accessible with HTTP 200 responses, including JavaScript, CSS, and the GLB model. Direct WebAR testing on the smartphone also demonstrated that camera access and hit-testing mechanisms could be used to detect wall surfaces and place frame objects using markerless AR. These results indicate that the system's principal functionalities could be accessed and operated within the tested environment.

Performance evaluation was conducted through qualitative observation on the tested device. The system was able to load pages and display WebAR objects without significant visual interruptions during observation. However, the study did not use dedicated numerical measurements for loading time, frame rate, latency, or device resource consumption. Consequently, the performance results are limited to functional observations during testing and do not represent quantitative performance benchmarks.

User Acceptance Testing (UAT) Results

User Acceptance Testing (UAT) was conducted using a questionnaire consisting of 16 Likert-scale statements rated from 1 to 5, covering ease of use, feature and system usefulness, user satisfaction, and continued use intention. A total of 23 respondents participated after trying the main website workflow, custom frame builder, WebAR visualization, shopping cart, and checkout. Of the 368 possible responses, 367 valid responses were obtained because one response to P5 was missing. Consequently, P5 had 22 valid responses, while the other 15 items had 23 valid responses each.

Table 4. Descriptive Statistics of User Acceptance Testing

ID	Indicator	n	Rata-rata ± SD	Indeks (%)	Skor 4–5 (%)
P1	General ease of use	23	4,74 ± 0,54	94,78	95,65
P2	Interface comprehensibility	23	4,87 ± 0,34	97,39	100,00
P3	Custom Frame builder usability	23	4,74 ± 0,45	94,78	100,00
P4	AR Activation without Installation	23	4,65 ± 0,57	93,04	95,65
P5	System and feature usefulness	22	4,73 ± 0,46	94,55	100,00
P6	Wall surface detection	23	4,74 ± 0,54	94,78	95,65
P7	3D object manipulation	23	4,61 ± 0,58	92,17	95,65
P8	Manual placement assistance	23	4,78 ± 0,42	95,65	100,00
P9	Screenshot functionally	23	4,78 ± 0,42	95,65	100,00
P10	Overall satisfaction	23	4,78 ± 0,52	95,65	95,65

ID	Indicator	n	Rata-rata ± SD	Indeks (%)	Skor 4–5 (%)
P11	3D object proportion and realism	23	4,65 ± 0,57	93,04	95,65
P12	Reduction of color/size uncertainty	23	4,65 ± 0,57	93,04	95,65
P13	Stability and responsiveness	23	4,74 ± 0,54	94,78	95,65
P14	Shopping experience satisfaction	23	4,65 ± 0,57	93,04	95,65
P15	Continued use intention	23	4,70 ± 0,56	93,91	95,65
P16	Intention to reuse AR	23	4,78 ± 0,52	95,65	95,65

Source: Compiled by the researcher (2026)

Table 4. Descriptive Statistics of User Acceptance Testing shows that user acceptance scores were consistently high across the 16 evaluation items. The highest mean score was obtained for interface comprehensibility (P2), with a mean of 4.87 and an acceptance index of 97.39%. The lowest mean score was recorded for 3D object manipulation (P7), with a mean of 4.61 and an acceptance index of 92.17%. Although P7 received the lowest score, its acceptance index remained above 90%, indicating favorable user perceptions of the available object manipulation functionality.

The distribution of the 367 valid responses consisted of 11 responses rated 3, 79 responses rated 4, and 277 responses rated 5, with no responses rated 1 or 2. The overall mean was 4.72, with a standard deviation of 0.51 and an acceptance index of 94.50%. Furthermore, 97.00% of responses were rated 4 or 5. This distribution demonstrates that respondents generally provided favorable assessments of the system's usability and functionality following their experience using the website and WebAR features.

Table 5. UAT Results by Evaluation Dimension

Dimension	Butir	n Valid	Mean	Index (%)	Score 4–5 (%)
Ease of use	4	92	4,75	95,00	97,83
Feature and system usefulness	5	114	4,73	94,56	98,25
User satisfaction	5	115	4,70	93,91	95,65
Continued use intention	2	46	4,74	94,78	95,65
Overall	16	367	4,72	94,50	97,00

Source: Compiled by the researcher (2026)

Table 5. UAT Results by Evaluation Dimension shows that all evaluation dimensions achieved acceptance indices above 93%. Ease of use obtained the highest dimensional mean score of 4.75, followed by continued use intention at 4.74, feature and system usefulness at 4.73, and user satisfaction at 4.70. These results indicate favorable initial user perceptions across the evaluated aspects of the system. The scores suggest that respondents perceived the system as relatively easy to

operate and useful for supporting the online shopping process, including the visualization of frame products through WebAR.

Reliability testing of the 16 items using 22 complete responses resulted in a Cronbach's alpha of 0.931, indicating high internal consistency of the UAT instrument. User acceptance was also supported by the results across all dimensions, suggesting that the system was perceived as easy to use, useful, satisfactory, and potentially suitable for continued use.

DISCUSSION

The findings demonstrate that the development of a WebAR-based product visualization system for Citra Artframe successfully integrated three-dimensional product visualization with the user's physical environment through a smartphone browser. This achievement indicates not only the feasibility of implementing WebXR and Three.js within a web-based e-commerce system but also the relevance of interactive visualization in addressing the difficulties consumers encounter when evaluating framed products through conventional two-dimensional catalogs. Before the system was developed, prospective customers experienced difficulties estimating product dimensions, colors, designs, and the suitability of frames for their walls or interior spaces. The preliminary investigation indicated that 78.8% of respondents frequently experienced difficulties estimating product dimensions, while 81.8% expressed concerns regarding color and design compatibility, and an equivalent proportion considered wall-based product simulation important or very important. These findings suggest a gap between the visual information presented in digital catalogs and the actual context in which products are intended to be used. Accordingly, WebAR implementation can be interpreted as an attempt to address the limitations of conventional product representation by providing contextual visualization within the user's physical environment, rather than merely introducing a technological feature into a website.

Regarding the first research question, the successful development of a browser-accessible WebAR visualization system using WebXR and Three.js without requiring additional application installation demonstrates the potential of web technologies to deliver augmented reality experiences integrated with e-commerce functionalities. WebXR manages the AR session, camera access, device pose tracking, and hit-test results, whereas Three.js handles scene construction, three-dimensional rendering, object transformations, and visual interactions. This division of responsibilities enables the integration of the camera-captured

physical environment with digital frame models in an interactive manner. The use of GLB assets also facilitates the integration of three-dimensional objects into the web-based rendering pipeline. These findings are consistent with McNally and Kolivand (2024), who examined WebXR as a platform for developing web-based augmented reality systems, and with Dou et al. (2020) and Buyukdemircioglu and Kocaman (2020), whose works provide a theoretical basis for using Three.js in web-based three-dimensional visualization. The contribution of this implementation lies in integrating these technologies to address the product visualization requirements of a framing business, rather than developing WebXR or Three.js as technological innovations in their own right. Browser-based access may also reduce barriers associated with application installation, although accessibility remains dependent on device compatibility, browser support, camera permissions, and AR capabilities.

Regarding the second research question, the implementation of markerless AR through surface detection demonstrates that the system can identify surfaces suitable for placing frame models within the user's physical environment. Hit-testing enables the system to obtain candidate object positions based on the interaction between the device and detected surfaces, thereby eliminating the need for physical markers. The successful visual placement of objects and observed stability during smartphone testing indicate that this mechanism can support simulations of frame placement on walls. Nevertheless, operational success should be distinguished from objectively measured spatial accuracy. This study did not quantify positional deviation, scale error, or orientation accuracy using independent measurement instruments. Therefore, the findings should be interpreted as demonstrating successful surface detection and object placement during testing rather than establishing geometric accuracy at a specific numerical level. These findings are consistent with Nowacki and Woda (2020), who examined the capabilities of ARCore and ARKit for AR applications, and Raval et al. (2021), who demonstrated the relevance of WebAR for furniture visualization. The present study extends these applications to framed products, for which dimensional perception and visual compatibility with wall surfaces are particularly important.

Regarding the third research question, the implementation of rotation, translation, and scale adjustment demonstrates that AR visualization functions not merely as a passive representation of a product but also as a user-controlled visual exploration medium. Touch-based interactions enable prospective customers to adjust the position and orientation of frames according to their spatial conditions and visual preferences. This capability is

important because the effectiveness of product visualization depends not only on rendering quality but also on the flexibility users have to evaluate products from relevant perspectives. These findings support the discussion of extended reality experiences by Rauschnabel et al. (2022) and the examination of augmented reality shopping experiences by Chakraborty et al. (2022). Furthermore, Qin et al. (2021) and Park and Yoo (2020) provide conceptual foundations for the potential of mobile AR to support consumer decision-making through more interactive and informative visual experiences. Within this study, object manipulation can be understood as a mechanism that enriches product evaluation, although its direct effect on purchasing decisions has not been empirically established.

The User Acceptance Test further supports the interpretation that the system was not only technically functional but also received positive initial acceptance from its users. The evaluation involving 23 respondents and 16 statements produced an overall mean score of 4.72 out of five, an acceptance index of 94.50%, and 97.00% of responses within scores four or five. Ease of use obtained a mean of 4.75, perceived feature and system usefulness 4.73, user satisfaction 4.70, and continued-use intention 4.74. These results suggest that the WebAR experience, including the visualization and object manipulation features, was positively perceived by respondents. However, UAT outcomes represent user-perceived acceptance rather than technical performance, spatial accuracy, or commercial effectiveness. This interpretation is consistent with the emphasis on interactive shopping experiences in AR-related e-commerce research discussed by Hoffmann and Mai (2022) and Qin et al. (2021), although the present findings do not establish equivalent business outcomes in the Citra Artframe context.

The contribution of this study also lies in integrating WebAR with the broader transactional workflow of Citra Artframe. The system incorporates product visualization alongside catalogs, shopping carts, checkout, order validation, authentication, product management, and payment processing through the Flip sandbox. This integration demonstrates that product visualization innovations can be developed as part of a more comprehensive digital business system. Successful checkout validation, administrative access protection, asset management through Cloudinary, and integration with API.co.id and Flip sandbox indicate that the supporting transactional components functioned within the tested environment. For an SME, this approach potentially strengthens the connection between product exploration and purchasing workflows. Practically, Citra Artframe gains a prototype that may serve as a foundation for developing more contextualized digital shopping

experiences. Methodologically, the findings demonstrate the applicability of Rapid Application Development (RAD) in integrating visualization requirements, transaction workflows, and user evaluation within a software development cycle.

Nevertheless, several limitations should be acknowledged. WebAR testing was conducted within a limited device and environmental context, meaning compatibility and stability cannot be generalized across all smartphones, browsers, lighting conditions, or wall-surface characteristics. Surface detection and object placement are also influenced by tracking quality, surface texture, and environmental conditions. User acceptance was assessed using 23 respondents and descriptive analysis, limiting statistical generalization to the broader Citra Artframe customer population. Furthermore, the study did not measure changes in purchasing decisions, sales conversion, product returns, or customer service effectiveness following system implementation. Performance evaluation was also not reported using standardized quantitative metrics, such as frame rate, latency, or spatial placement deviation. Consequently, the primary contribution of this study is the successful implementation, functional integration, and initial user acceptance of WebAR as a web-based product visualization medium. Future research could examine cross-device compatibility, spatial accuracy, quantitative performance metrics, and longitudinal consumer behavior to establish the broader effects of WebAR adoption on customer decision-making and SME business performance.

CONCLUSION

This study successfully designed, implemented, and evaluated a WebAR-based product visualization system for Citra Artframe using WebXR and Three.js. The system enables users to access product visualization through compatible smartphone browsers without requiring additional application installation. The implementation of markerless augmented reality with plane detection supports wall-surface detection and the placement of three-dimensional frame models within users' physical environments. Furthermore, the system provides interactive functionalities, including translation, rotation, scale adjustment, repositioning, object removal, and screenshot capture, enabling users to explore products more flexibly.

The integration of WebAR with product catalogs, the custom frame builder, shopping carts, checkout, payment processing, invoices, and administrative functionalities

demonstrates that augmented reality visualization can be incorporated into a comprehensive web-based e-commerce system. Black-box testing confirmed that all 31 primary scenarios fulfilled their expected outcomes. User Acceptance Testing involving 23 respondents yielded an acceptance index of 94.50%, an overall mean score of 4.72, and an instrument reliability coefficient of 0.931, indicating highly positive initial user acceptance.

This study contributes to the application of WebAR in SME e-commerce by integrating contextual product visualization, interactive three-dimensional manipulation, and web-based transactional functionalities. The developed system may help consumers evaluate product suitability within their living spaces before purchasing while supporting the digital transformation of Citra Artframe's services. Future development should focus on expanding device compatibility, optimizing three-dimensional assets, improving interaction mechanisms, incorporating wall measurement and dimensional calibration, and enabling the visualization of multiple products within a single AR session. Further empirical evaluation is also recommended to assess spatial accuracy, technical performance, and the actual effects of WebAR implementation on consumer behavior and business performance.

REFERENCES

Arena, F., Collotta, M., Pau, G., & Termine, F. (2022). An overview of augmented reality. *Computers, 11*(2), Article 28. https://doi.org/10.3390/computers11020028

Boutsi, A.-M., Ioannidis, C., & Verykokou, S. (2023). Multi-resolution 3D rendering for high-performance web AR. *Sensors, 23*(15), Article 6885. https://doi.org/10.3390/s23156885

Buyukdemircioglu, M., & Kocaman, S. (2020). Reconstruction and efficient visualization of heterogeneous 3D city models. *Remote Sensing, 12*(13), Article 2128. https://doi.org/10.3390/rs12132128

Chakraborty, D., Singu, H. B., & Patre, S. (2022). Fitness apps's purchase behaviour: Amalgamation of stimulus-organism-behaviour-consequence framework (S–O–B–C) and the innovation resistance theory (IRT). *Journal of Retailing and Consumer Services, 67*, Article 103033.

Dou, Q., Lin, Z., Magee, D. R., & Cohn, A. G. (2020). 3D mapping from partial observations: An application to utility mapping. *Automation in Construction, 117*, Article 103229.

Fauzi, M. A., Tribiakto, H., Moniva, A., Amir, F., Ilyas, I. K., & Utami, E. (2023). Systematic literature reviews on rapid application development information system. *Bulletin of Computer Science and Electrical Engineering, 4*(1), 57–64. https://www.bcsee.org/index.php/bcsee/article/view/1181

Hoffmann, S., & Mai, R. (2022). Consumer behavior in augmented shopping reality. A review, synthesis, and research agenda. *Frontiers in Virtual Reality, 3*, Article 961236. https://doi.org/10.3389/frvir.2022.961236

Kisawike, B., & Ndekwa, A. G. (2026). Consumer behavior in the era of digital marketing: A case of Instagram shoppers in Tanzania. *Cureus Journal of Business and Economics*.

MacIntyre, B., & Smith, T. F. (2018). Thoughts on the future of WebXR and the immersive web. In *2018 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)* (pp. 338–342). IEEE.

McNally, K. F., & Koviland, H. (2024). A web-based augmented reality system. *EAI Endorsed Transactions on Scalable Information Systems, 11*(6). https://doi.org/10.4108/eetsis.5481

Melumad, S., Hadi, R., Hildebrand, C., & Ward, A. F. (2020). Technology-augmented choice: How digital innovations are transforming consumer decision processes. *Customer Needs and Solutions, 7*(3–4), 90–101. https://doi.org/10.1007/s40547-020-00107-4

Nielsen, J. (1994). Enhancing the explanatory power of usability heuristics. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 152–158). Association for Computing Machinery.

Nowacki, P., & Woda, M. (2020). Capabilities of ARCore and ARKit platforms for AR/VR applications. In W. Zamojski, J. Mazurkiewicz, J. Sugier, T. Walkowiak, & J. Kacprzyk (Eds.), *Engineering in dependability of computer systems and networks: Proceedings of the Fourteenth International Conference on Dependability of Computer Systems DepCoS-RELCOMEX, July 1–5, 2019, Brunów, Poland* (pp. 358–370). Springer. https://link.springer.com/chapter/10.1007/978-3-030-19501-4_36

Park, M., & Yoo, J. (2020). Effects of perceived interactivity of augmented reality on consumer responses: A mental imagery perspective. *Journal of Retailing and Consumer Services, 52*, Article 101912.

Qin, H., Peak, D. A., & Prybutok, V. (2021). A virtual market in your pocket: How does mobile augmented reality (MAR) influence consumer decision making? *Journal of Retailing and Consumer Services, 58*, Article 102337.

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education, 147*, Article 103778.

Rauschnabel, P. A., Felix, R., Hinsch, C., Shahab, H., & Alt, F. (2022). What is XR? Towards a framework for augmented and virtual reality. *Computers in Human Behavior, 133*, Article 107289.

Raval, R., Sankhla, T., Shah, R., & Nadkarni, S. (2021). Developing markerless augmented reality for furniture mobile application. *International Journal of Education and Management Engineering, 11*(1), 11–18. https://doi.org/10.5815/ijeme.2021.01.02

Saputra, K. S. A., Putera, W. A., & Dewi, N. P. J. T. (2024). Peningkatan Pengalaman Calon Wisatawan dengan Aplikasi Augmented Reality di Taman Hutan Raya Mangrove Ngurah Rai Bali dengan Metode RAD (Rapid Application Development). *JTIM: Jurnal Teknologi Informasi dan Multimedia, 6*(3), 330–345. https://doi.org/10.35746/jtim.v6i3.595

Wedel, M., Bigné, E., & Zhang, J. (2020). Virtual and augmented reality: Advancing research in consumer marketing. *International Journal of Research in Marketing, 37*(3), 443–465.