

Evaluating browser-based immersive technology for cultural heritage

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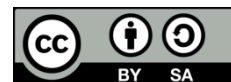
WebAR

WebVR

ABSTRACT

Digital cultural heritage requires accessible information and communication technology (ICT) channels that can present cultural content without requiring dedicated software installation. This study evaluates a browser-based WebAR–WebVR platform for the interactive exploration of Malay hand-drawn batik. The evaluation comprised expert readiness review, functional verification, task-based interaction involving 60 participants aged 15–30 years, a five-point user-perception questionnaire, and qualitative technical observation. All eight predefined WebAR and WebVR functions produced the expected outcomes on Google Chrome using a Vivo Y36 5G smartphone and a VR Box. Mean scores were 4.60 for ease of interaction, 4.40 for increased interest in batik, 4.20 for attractiveness, and 4.60 for cultural-promotion usefulness. Triangulation of functional, perceptual, and operational evidence showed that successful task completion corresponded with positive ease ratings, while complex multimedia assets increased loading and rendering burden. Lighting, marker visibility, camera permission, device capability, and multimedia complexity were the main operating constraints. The findings provide practical evidence for browser-based cultural ICT applications in museums, tourism, and digital education.

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1. INTRODUCTION

Digital cultural heritage increasingly relies on information and communication technology (ICT) to preserve, represent, and disseminate cultural knowledge beyond physical sites. Augmented, virtual, mixed, and extended reality support interactive cultural communication through three-dimensional visualization and immersive interaction [1]-[4]. Their value for public-facing heritage services depends on usability, interaction quality, access conditions, and perceived usefulness [5]-[7]. In museums, tourism, and digital education, browser-accessible immersive media can complement physical collections by connecting cultural content to institutional websites and online learning environments.

AR and VR provide complementary interaction modes: AR overlays contextual information in the physical environment, whereas VR enables exploration of simulated cultural spaces [8]-[10]. User-

experience research shows that immersive heritage applications also depend on interaction consistency and accessibility [5], [11], [12]. Browser-based delivery can reduce installation and distribution barriers; WebAR supports browser-based three-dimensional interaction [13]-[17], while WebVR provides immersive scenes through web technologies [18], [19]. Here, browser accessibility means direct web access without installing a dedicated native application; it does not denote compliance with disability-accessibility standards. Browser delivery remains subject to permissions, browser compatibility, device capability, rendering load, and interaction design.

Batik is an important Indonesian cultural heritage whose motifs, production techniques, meanings, and regional identities require more than static digital presentation. Previous studies have examined AR for batik visualization and marketing, user acceptance, and emerging digital environments [20]-[22], while related work demonstrates AR-based communication of local cultural content [23]. These studies establish batik as a relevant case for evaluating how browser-based immersive ICT supports cultural interpretation, interest, and digital promotion.

The object evaluated in this study was a browser-accessible environment for exploring Malay hand-drawn batik through two complementary interaction paths. The WebAR path supported marker-based three-dimensional visualization, touch rotation and zoom, and cultural-information access; the WebVR path supported virtual-scene loading, gaze-based navigation, object selection, and information viewing. The functions define the evaluation scope. The article assesses their operation and interaction outcomes rather than presenting the system-development process as a new contribution.

Although browser-based WebAR and WebVR systems have been studied, integrated evaluations of both modalities within one cultural-heritage platform remain limited. Functional outcomes, user perception, and operating conditions are also frequently reported as separate evidence, making it difficult to explain why a system can complete its intended tasks while still encountering interaction or rendering constraints. This study therefore asks: (1) do the intended WebAR and WebVR task sequences operate under the specified browser/device configuration; (2) how do user-perception indicators correspond with the functional outcomes; and (3) which operating conditions influence interaction? The contribution is an integrated and explicitly bounded evaluation that relates readiness, functional, perceptual, and technical evidence without claiming universal compatibility or superiority over native applications.

2. RESEARCH METHOD

2.1. Research design

This study used an evaluative design to assess a completed browser-based immersive platform. The evaluated system originated from a multimedia development life cycle workflow [24], but the development stages were outside the analytical scope and were not treated as findings in this article. The completed system was examined through three evidence streams: functional outcomes, aggregate user-perception indicators, and qualitative technical observations. Expert review served as a readiness check before participant testing. The evidence streams were then compared to identify convergence, contrast, and explicit interpretive boundaries.

2.2. Study site and participants

Evaluation was conducted at Batik Prima Jaya, Tanjung Kasau Village, Batu Bara Regency, Indonesia, from July to November 2025. Sixty participants aged 15-30 years were selected from an estimated frame of 140 potential users through proportionate stratified random sampling, representing 42.9% of the frame. The sampling procedure allocated selections in proportion to predefined strata and used random selection within each stratum to limit overrepresentation of a single group. The retained records did not contain a separate stratum-by-stratum allocation; therefore, representativeness was assessed based on the final demographic profile of the participants, including gender, age group, and prior AR/VR experience. Because eligibility was restricted to users aged 15-30 years at a single study site, the findings should be interpreted within this specific participant group and should not be generalized to other age groups or broader cultural-heritage audiences.

2.3. Evaluated platform and system configuration

The evaluated configuration used AR.js for marker-based tracking, A-Frame for browser-delivered three-dimensional and virtual-reality scenes, and Blender to prepare web-ready three-dimensional assets. These tools were retained because they supported a common browser-oriented workflow across marker interaction, scene rendering, navigation, and asset preparation, consistent with browser-based WebAR and WebVR studies [13]-[19]. Their selection was pragmatic and does not imply technical superiority over alternative frameworks. Testing used Google Chrome on a Vivo Y36 5G smartphone, with a VR Box for immersive WebVR viewing. A fixed configuration allowed the functional and interaction outcomes to be

interpreted within a defined technical context. The platform could be linked from museum, tourism, or educational web portals, but institutional integration and large-scale use were not evaluated.

2.4. Evaluation procedure

Figure 1 presents the complete evaluation procedure for the browser-based WebAR–WebVR platform, including the overall evaluation stages and the interaction flows for both WebAR and WebVR. As shown in Figure 1(a), the evaluation comprised four sequential stages. Four experts with experience in immersive technology, user experience, and cultural content first reviewed interface clarity, interaction consistency, item wording, content suitability, and readiness for participant testing. Functional verification then established whether the predefined outputs occurred. Task-based evaluation recorded participants' immediate perceptions after interaction, while technical observation documented contextual conditions that could explain or qualify the other findings. Each stage therefore served a distinct evidential role rather than repeating the same assessment.

During the WebAR task sequence shown in Figure 1(b), participants accessed the platform through the browser, granted camera permission, and scanned the marker. If the marker was not detected, lighting and marker visibility were adjusted before scanning was repeated. Successful detection was followed by three-dimensional rendering, touch-based rotation or zoom, and access to cultural information. The decision branch therefore represents an environmental detection condition rather than failure of the intended WebAR function.

During the WebVR task sequence shown in Figure 1(c), participants entered the virtual scene and waited for the 360-degree environment to load. If loading was unsuccessful, the scene was reloaded before navigation continued. After successful loading, participants used gaze-based navigation, selected an object with the cursor, and opened its cultural information. The post-task questionnaire was administered after both interaction sequences, while browser behavior and operating conditions were observed throughout.

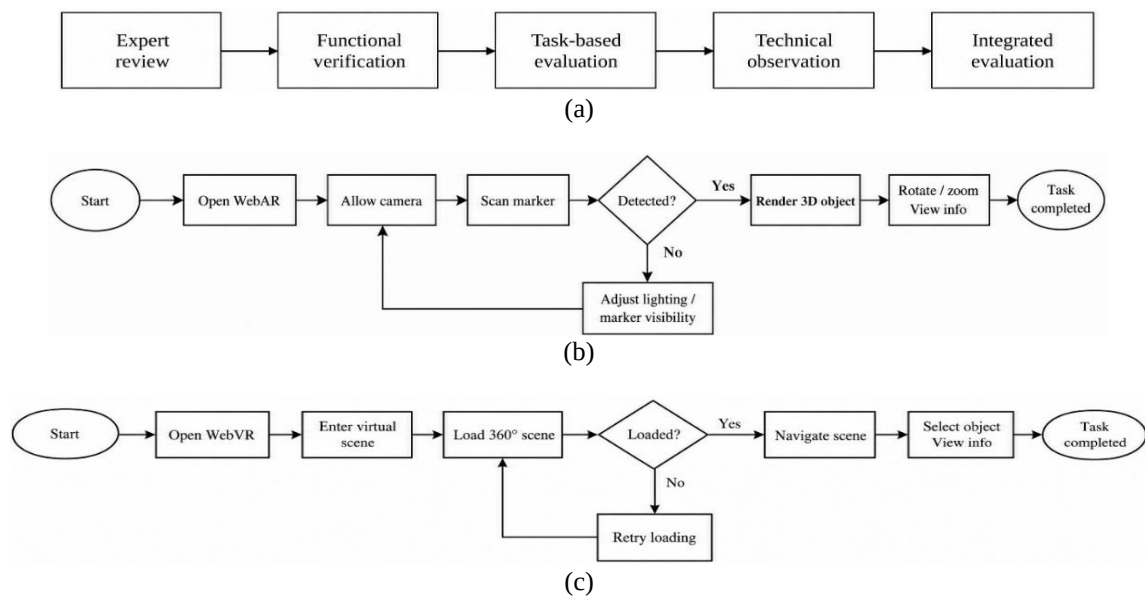


Figure 1. Evaluation procedure for the browser-based WebAR–WebVR platform
(a) Overall evaluation procedure, (b) WebAR interaction flow, and (c) WebVR interaction flow

2.5. Instruments and data analysis

Data were collected using an expert review form, functional verification checklist, five-point Likert post-task questionnaire, and technical observation sheet. The questionnaire assessed ease of interaction, increased interest in batik, attractiveness compared with conventional media, and cultural-promotion usefulness; comparable AR/VR evaluation procedures are reported in [25]–[27]. The four experts examined content relevance, wording clarity, and alignment between the questionnaire items and the WebAR/WebVR task sequence before administration. Because item-level expert ratings were not retained, the review supports qualitative content readiness rather than a formal content-validity index. Functional verification classified

each predefined function according to whether the expected outcome occurred under the fixed configuration. Technical observation recorded marker visibility, permission state, scene loading, rendering behavior, and interaction responsiveness; it did not instrument frame rate, latency, bandwidth, or memory use.

For questionnaire indicator j , each participant provided one response on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Let x_{ij} denote participant i 's score for indicator j , and let N denote the number of participants. The observed total score was calculated as follows:

$$S_j = \sum_{i=1}^N x_{ij} \quad (1)$$

The mean score for each indicator was then calculated using:

$$\bar{x}_j = \frac{S_j}{N} \quad (2)$$

In this study, $N = 60$. The mean scores ranged theoretically from 1.00 to 5.00, with higher values indicating more positive participant perceptions of the evaluated interaction indicator. Item-level content-validity indices, Cronbach's alpha, and complete response-frequency distributions were unavailable; consequently, the questionnaire was treated as a structured descriptive instrument, and no post hoc psychometric or response-frequency reconstruction was performed. Technical observations were grouped into environmental input, access and configuration, and content and rendering conditions. The evidence streams were compared for convergence and contrast, while causal and cross-platform claims were excluded.

2.6. Ethical considerations

Participation was voluntary; participants were informed about the study and provided consent before data collection. Results were reported in aggregate form without individual identification.

3. RESULTS AND DISCUSSION

3.1. Expert review results

Expert review functioned as a readiness gate rather than a scored outcome. As summarized in Table 1, the interface, interaction sequence, and cultural content were considered sufficiently clear and appropriate for participant testing. Because item-level scores and a formal content-validity coefficient were unavailable, the result is interpreted only as qualitative readiness evidence.

3.2. Participant profile

Table 2 shows a broadly balanced gender composition and a sample concentrated in the younger age groups. More importantly for interpretation, most participants had no previous AR/VR experience. The evaluation therefore primarily reflects first-time or low-experience immersive-technology users rather than experienced users.

Table 1. Expert review summary

Evaluation aspect	Main finding	Action/interpretation
Interface clarity	Reviewed qualitatively for clarity and readability before participant testing	Used as a readiness criterion; no numeric expert score is reported.
Interaction consistency	Reviewed across the intended WebAR and WebVR task sequences	Used to confirm that the interaction flow was suitable for subsequent evaluation.
Cultural-content suitability	Reviewed for relevance and appropriateness of the cultural information presented	Retained as qualitative content-readiness evidence.
Evaluation readiness	Expert review preceded functional verification and user evaluation	The study proceeded to the subsequent evaluation stages; no quantitative expert mean is claimed.

Table 2. Participant demographics

Variable	Category	Frequency	Percentage
Gender	Male	32	53.33%
	Female	28	46.67%
Age	15–20 years	24	40.00%
	21–25 years	22	36.67%
	26–30 years	14	23.33%
AR/VR experience	Have used AR/VR before	18	30.00%
	Have never used AR/VR before	42	70.00%

3.3. Functional verification results

Table 3 records successful expected outcomes for all eight predefined functions. More important than the number of successful items is the continuity of the two task sequences: WebAR progressed from marker detection to cultural-information display, while WebVR progressed from scene loading to cultural-information access. The checklist therefore verifies end-to-end functional continuity under the tested configuration rather than only the presence of isolated interface controls. Figure 2 presents representative interfaces from the evaluated WebAR and WebVR task sequences. Specifically, Figure 2(a) illustrates the WebAR interaction sequence, including marker-based access to the three-dimensional cultural content, whereas Figure 2(b) shows the WebVR immersive interface used for virtual-scene navigation and cultural-information access. Because the checklist recorded expected outcomes rather than repeated trials, failure rates, or timing measurements, the result should be interpreted as configuration-specific functional verification rather than as reliability or compatibility benchmarking.

Table 3. Functional verification results

Module	Feature	Result
WebAR	Marker detection	Successful
WebAR	3D object visualization	Successful
WebAR	Touch-based rotation and zoom	Successful
WebAR	Information display	Successful
WebVR	Virtual scene loading	Successful
WebVR	Gaze navigation	Successful
WebVR	Cursor-based object selection	Successful
WebVR	Cultural information access	Successful

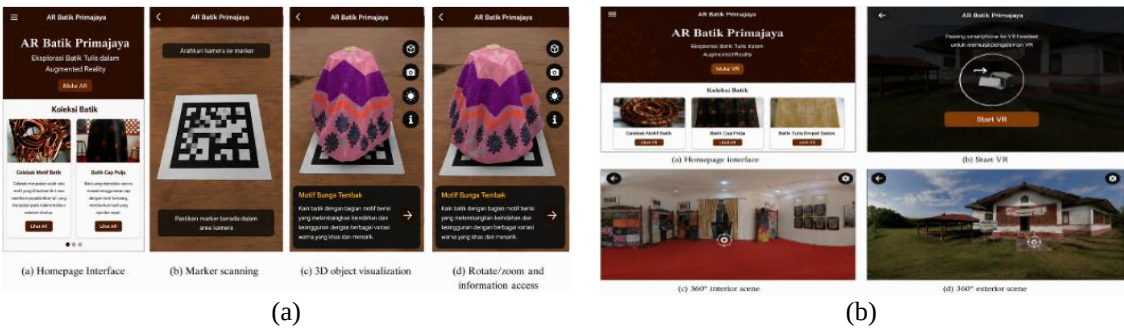


Figure 2. Representative interfaces from the evaluated WebAR and WebVR task sequences
(a) WebAR interaction sequence and (b) WebVR immersive interface sequence

3.4. User-perception evidence in the integrated evaluation

The questionnaire scores were calculated using (1) and (2). For each indicator, the responses from 60 participants were summed to obtain the total score and divided by the number of participants to obtain the mean score. Table 4 summarizes the total and mean scores for the four user-perception indicators evaluated in the study. For Q1, a total score of 276 produced a mean score of 4.60 (276/60), and the same calculation procedure was applied to Q2–Q4.

The mean scores varied moderately across the four indicators. Ease of interaction and cultural-promotion usefulness received the highest mean scores of 4.60, followed by increased interest in batik at 4.40 and attractiveness compared with conventional media at 4.20. All indicators obtained mean scores above 4.00 on the five-point scale, indicating generally positive participant perceptions. The successful completion of the predefined tasks was consistent with the high ease-of-interaction score, whereas the comparatively lower attractiveness score coincided with the observed loading and rendering burden of more complex multimedia assets. These relationships are descriptive and do not demonstrate causal superiority over conventional media, native applications, or other browser and device configurations.

Table 4. Mean user-perception scores for the evaluated interaction indicators

Code	Indicator	Total score	Mean score
Q1	Ease of interaction	276	4.60
Q2	Increased interest in batik (cultural engagement)	264	4.40
Q3	Attractiveness compared with conventional media	252	4.20
Q4	Cultural-promotion usefulness	276	4.60

3.5. Technical and interaction observations

Table 5 consolidates the operating conditions observed across the WebAR and WebVR tasks. These conditions are organized into three analytical groups: environmental input, including lighting and marker visibility; access and configuration, including camera permission, browser, device, and VR-viewer requirements; and content load, including multimedia complexity and rendering behavior.

Across these groups, most interruptions were conditional rather than permanent: marker detection improved when visibility was restored, WebAR proceeded after camera permission was granted, and heavier assets increased loading burden without preventing all interaction. These observations qualify the successful functional results by showing the conditions under which interaction became less consistent. The evidence remains qualitative because frame rate, latency, loading time, memory use, bandwidth, and repeated failure rates were not instrumented.

Table 5. Technical and interaction observation summary

Aspect	Observation
Marker tracking	Stable under sufficient lighting and clear marker visibility; less consistent under low lighting or partial obstruction.
Browser operation	The evaluated functions operated through Google Chrome on the tested Android smartphone.
Camera authorization	WebAR became operational after the user granted browser camera permission.
WebVR operation	The virtual environment operated using the tested smartphone and VR Box configuration.
Rendering behavior	Generally stable during testing; larger or more complex multimedia assets increased rendering and loading burden.
Interaction responsiveness	Touch, navigation, and object-selection interactions responded adequately during the evaluated tasks.

3.6. Discussion

Compared with studies that examine a single modality or a specific technical concern [13]-[19], this study treats WebAR and WebVR as complementary task paths and interprets four evidence layers together: readiness, functional outcomes, user perception, and operating conditions. This combined reading extends user-experience perspectives in immersive heritage [5], [11], [12] by showing how an apparently successful interaction sequence can still be qualified by environmental input, permissions, and multimedia load. It also complements batik-oriented AR research [20]-[23] by focusing on evidence relationships rather than on technology construction or marketing alone.

The evidence converged on interaction continuity but differed on visual evaluation. All intended functions produced the expected outcomes, and ease of interaction received the highest rating, supporting a consistent interpretation of low task difficulty under the tested configuration. Direct browser access may have reduced setup friction because participants opened the platform and granted permission rather than installing a separate application. This provides a plausible explanation for the positive ease score, but no native-application comparator was included and superiority cannot be inferred. Browser delivery also introduced trade-offs: camera permission, browser/device variability, and asset loading remained visible constraints, while the attractiveness score was lower for content associated with heavier rendering and loading demands.

The results have three important boundaries. First, testing was limited to one smartphone, one browser, and one VR viewer, so compatibility and reliability across devices were not established. Second, the questionnaire was analyzed descriptively because item-level psychometric and response-frequency data were unavailable. Third, technical observation did not include instrumented measurements of frame rate, latency, loading time, memory, bandwidth, or repeated failure rates. For museums, tourism services, and digital education, the results support the practical use of browser links within existing cultural ICT portals, but institutions should validate device coverage, permissions, content weight, and network conditions before wider use. Future work should add repeated trials, cross-device and cross-browser benchmarking, quantitative performance metrics, scalability testing, and longitudinal cultural-learning outcomes [28]-[30].

4. CONCLUSION

This study shows that complementary WebAR and WebVR interactions can operate coherently within a browser-based cultural-heritage environment under a defined device and browser configuration. The most important finding is not only that all eight functions produced expected outcomes, but that functional continuity, user perception, and operating conditions did not carry the same meaning. Positive ease ratings converged with task completion, whereas the lower attractiveness rating exposed the influence of asset complexity and rendering load. This distinction provides an ICT design insight: convenient access must be balanced with content optimization, permission handling, and device variability.

For museums, tourism portals, and digital education, browser-based immersive content can widen access by linking cultural experiences to existing web infrastructures without requiring a separate installation. Actionable priorities include lightweight multimedia assets, explicit camera-permission and interaction guidance, stable marker presentation, fallback instructions when scene loading fails, and device-aware browser testing. These implications concern the evaluated use context rather than a claim of new platform development. Future studies should verify scalability through repeated trials, instrumented performance measures, broader device/browser comparisons, and longitudinal assessment of cultural learning and engagement.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Yusuf Ramadhan Nasution						✓	✓	✓					✓	
Yustria Handika Siregar						✓	✓	✓						
Muhammad Eka Nurmaliana Pohan					✓	✓	✓	✓		✓	✓			

C : **C**onceptualization

M : **M**ethodology

So : **S**oftware

Va : **V**alidation

Fo : **F**ormal analysis

I : **I**nvestigation

R : **R**esources

D : **D**ata Curation

O : Writing - **O**riginal Draft

E : Writing - Review & **E**ding

Vi : **V**isualization

Su : **S**upervision

P : **P**roject administration

Fu : **F**unding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

INFORMED CONSENT

Participants were informed about the study and provided written consent before data collection. Personal information was kept confidential and results were reported only in aggregate form.

ETHICAL APPROVAL

Ethical approval was not required under the applicable institutional policy for this non-invasive usability evaluation without sensitive personal data; voluntary participation, consent, and confidentiality procedures were applied.

DATA AVAILABILITY

Aggregated data supporting the findings are available from the corresponding author upon reasonable request; individual-level data are not publicly available to protect participant privacy.

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