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Digitizing Campus Experience: Immersion and Interaction through 3D Navigation with A-Frame

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Abstract

The advancement of information and communication technology has profoundly altered numerous facets of society, particularly in education. Institutions of higher education have significantly profited from these improvements, especially in improving services and facilities for students, prospective students, and the public. The public requires broad understanding involving campus conditions and circumstances to enhance their advertising and recognition activities for broader acknowledgment. Therefore, suitable digital media are required to deliver comprehensive and informative campus information. The utilization of virtual reality (VR) technology for virtual campus tours is an increasingly popular innovation, enabling visitors to explore the campus and feel its ambiance without physical presence. Nonetheless, numerous organizations have difficulties in developing genuinely interactive and immersive virtual tour experiences. This research is to investigate the application of A-Frame in developing a web-based campus tour to improve user engagement and immersion. The employed research methodology is research and development (R&D) utilizing a Waterfall development model that are include: requirements analysis, system design, implementation and development, and evaluation and improvement. Sampling for functional testing is involved 100 secondary school's students in Jawa Barat. The findings indicate that employing A-Frame for developing a campus online tour can yield a gratifying, interactive, and immersive experience. Furthermore, functional and security assessments demonstrate that the system operates effectively and is secure for use. System assessment and enhancements are conducted in response to user feedback to guarantee the system's relevance and alignment with user requirements. This research offers a viable method for enhancing the engagement and immersion of campus tours, serving as a reference for other educational institutions in the adoption of VR technology.

Keywords: *A-Frame, Virtual Reality, Campus Tour, Immersion, WebXR Approach.*

1. Introduction

The continuous development of information and communication technology has transformed paradigms in many aspects of life, particularly in education. Higher education institutions have significantly benefited from these advancements, particularly in improving the quality of services and facilities for students, prospective students, and the general public. The deployment of virtual reality (VR) technology for virtual campus tours has been rapidly adopted [1], [2], [3]. This technology enables visitors to navigate the campus, observe its facilities, and immerse themselves in the campus ambiance without physical presence.

Despite the wide acceptance of VR, many institutions continue to encounter obstacles in developing virtual tours that are interactive and immersive. A deficiency in interactivity and immersion may reduce visitor engagement and impede a comprehensive understanding of the campus. An improved and more efficient technology solution is required to elevate the quality of the virtual experience. Campus information provides an opportunity to fully expose the institution to the public. This allows visitors to familiarize themselves with the campus virtually while observing its general state.

Virtual Reality (VR) enables users to engage with simulated digital environments. This technology has been widely implemented across multiple sectors, such as education, entertainment, and industry. In the educational universe, virtual reality can facilitate more captivating and interactive learning experiences [4], [5], [6]. A-Frame is a widely utilized framework for creating virtual reality content. A-Frame is an open-source framework based on HTML that enables the straightforward creation of web-accessible VR applications [7], [8], [9].

A-Frame provides a range of components and functionalities for creating VR content, involving compatibility with diverse VR devices and user interaction capabilities [10], [11]. Utilizing A-Frame in the context of a campus web tour presents numerous substantial benefits [12], [13]. A-Frame facilitates the creation of VR content that is accessible via web browsers, eliminating the need for specialized hardware and enhancing user accessibility [14], [15], [16].

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In addition to A-Frame, several additional technologies are used to enhance the quality of the campus web tour. Three.js is a JavaScript library used to create 3D graphics on the web, offering features for developing more complex and realistic 3D visualizations [10], [17], [18]. WebXR is an API that enables the development of both VR and augmented reality (AR) experiences on the web, supporting a wide range of hardware and offering more natural and intuitive interactions [6], [19], [20], [21], [22], [23].

For capturing the campus environment in 360 degrees, cameras, including Panorama 360 or Life360, are employed, facilitating the comprehensive and intricate capture of panoramic images and thereby establishing a robust visual foundation for the virtual tour experience [24], [25]. The system's backend employs Express.js and PostgreSQL for data management and to deliver an efficient, scalable API.

Therefore, enhancing user interaction and immersion in the virtual campus tour experience requires a specific approach. One solution that can be implemented is the utilization of A-Frame and the aforementioned technologies. By using A-Frame, Three.js, WebXR, and 360-degree cameras, supported by a robust backend with Express.js and PostgreSQL, it is hoped that a campus web tour can be developed that not only presents visually appealing information but also fosters better interaction between users and the virtual environment.

This study aims to explore and analyze the utilization of A-Frame in creating a campus web tour to enhance user interaction and immersion. Furthermore, this research also seeks to identify the strengths and weaknesses of using this technology in this context and provide recommendations for further development. Thus, the utilization of A-Frame in creating campus web tours is expected to offer an effective solution for creating more interactive and immersive virtual tour experiences. This research will explore how A-Frame and additional technologies can improve user interaction and immersion, as well as analyze the factors influencing the successful implementation of this technology in the context of virtual campus tours.

2. Literature Review

2.1. Browser-Based Virtual Reality and Campus Access

Research on immersive and extended reality spans education, information systems, tourism, museums, and metaverse applications [15], [24], [26]. Reviews of higher-education VR report considerable diversity in hardware, learning tasks, interaction designs, and evaluation methods [27], [28], [29]. Web delivery is particularly relevant for campus communication because a standard browser can lower the entry barrier for users who do not own head-mounted displays. Web-based VR nevertheless creates design trade-offs: developers must balance visual fidelity, device compatibility, loading performance, navigational clarity, and accessibility [30].

2.2. Interaction, Presence, and User Experience

Immersion is not a single outcome. The CAMIL framework explains how technological immersion, control, and representational fidelity may support presence and agency, which can then influence affective and cognitive responses [31]. Meta-analyses report positive but heterogeneous effects of VR, reinforcing the need to measure specific constructs rather than infer engagement from the technology alone [32]. Usability instruments such as the UEQ and UEQ+ illustrate the importance of reporting the instrument, sample, scale, descriptive statistics, and interpretation procedure [33].

2.3. Research Gap and Positioning

Existing campus and 360-degree tour studies establish practical relevance[34], [35], while educational applications show that interactive media can support exploration and engagement across different contexts [36]. However, artifact descriptions are not substitutes for reproducible evaluation. The present study is positioned as a development-and-evaluation case study, not as a controlled test of learning effectiveness. Its novelty lies in the integrated, browser-first architecture and in reporting three complementary evidence layers - functional behavior, user perceptions, and targeted web-security checks - while explicitly bounding the claims that can be made from aggregate data.

3. Method

3.1. Research Design

The study used a research-and-development design organized through a sequential Waterfall process [18], [37]. The phases were requirements analysis, system design, implementation, testing, and evaluation with improvement. This design was selected because the core requirements were defined before implementation and the developed artifact could be evaluated against those predefined requirements. The unit of analysis was the browser-based virtual campus tour and its interaction with intended users.

3.2. Requirements and System Architecture

Functional requirements covered navigation, access to facility information, interaction with 3D objects, integration of 360-degree imagery, route selection, and optional account management. Non-functional requirements covered responsiveness, interface clarity, browser and device compatibility, security, and scalability. Table 1 presents the traceability baseline used during design and testing.

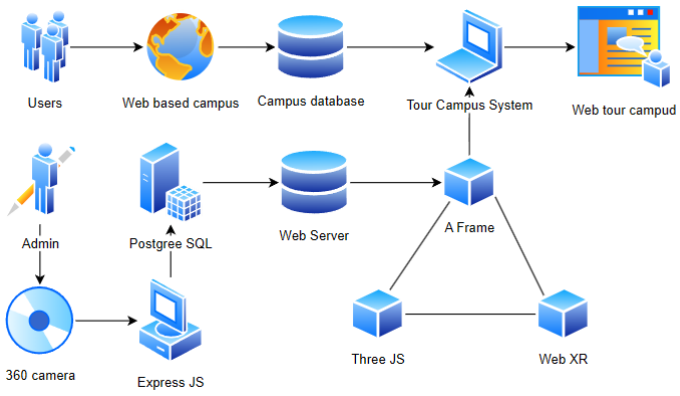

Fig 1. System architecture of the browser-based virtual campus tour

Table 1. System requirements

Category	Requirement and evaluation intent
Functional - navigation	Users can move between campus locations through an intuitive route.
Functional - information	Users can access accurate facility information from the interface.
Functional - 3D interaction	Users can rotate, zoom, or select supported three-dimensional objects.
Functional - 360 imagery	Panoramic campus images can be displayed within the tour.
Functional - route selection	Users can select available destinations and tour routes.
Non-functional - performance	The interface responds without disruptive delay under the tested conditions.
Non-functional - compatibility	The basic tour is accessible through major desktop or mobile browsers.
Non-functional - security	Input and query points are examined for selected web-application vulnerabilities.
Non-functional - scalability	The architecture separates front end, API, and database components.

3.3. Implementation

A-Frame was used to compose the virtual scene and interactive elements. Three.js supported three-dimensional rendering, and WebXR provided access to compatible immersive functions. The visual layer incorporated 360-degree campus images. Express.js implemented the application programming interface, while PostgreSQL stored facility and interaction-related data. Separating the interface, service, and data layers supported maintainability and enabled targeted testing of user-facing functions and web inputs.

3.4. Evaluation Design

3.4.1. Functional Evaluation

Black-box testing examined observable system behavior without inspecting source code. The available study documentation reports 100 participants comprising current and prospective students. Participants exercised the navigation, facility-information, and 3D-object functions. For each predefined case, the observed result was compared with the expected outcome and recorded as passed or not passed.

Table 2. Functional testing protocol

Feature	Test action	Acceptance criterion
Interactive navigation	Move from one campus location to another.	The requested destination opens and navigation remains usable.
Facility information	Open facility information from the menu or map.	The corresponding facility information is displayed.
3D-object interaction	Rotate or zoom a supported object.	The selected interaction is executed without blocking the tour.

3.4.2. Security Evaluation

Three information-technology security team members conducted targeted web-application checks using OWASP ZAP. The documented protocol focused on SQL injection at forms and query points and on cross-site scripting at user-input points. Findings were to be recorded by vulnerability type and severity. Because these tests cover only selected attack classes and configurations, the absence of an alert is interpreted as no finding under the tested conditions rather than proof of complete system security.

Table 3. Targeted security testing protocol

Vulnerability class	Test focus	Acceptance criterion
SQL injection	Forms and query parameters used by the tour.	No SQL-injection alert is recorded under the tested conditions.
Cross-site scripting	User-input points exposed by the application.	No reflected or stored XSS alert is recorded under the tested conditions.

3.4.3. Interaction and Experience Evaluation

A separate group of 10 participants completed a short questionnaire after using the system. Each item used a five-point response scale, where higher values represented a more favorable perception. The reported items addressed ease of navigation, visual quality, system responsiveness, and perceived data security. The instrument also included an overall-experience question, but the available results contained no aggregate value for that item; it was therefore not used in the quantitative summary.

Table 4. Interaction and experience questionnaire

Construct	Question	Scale
Ease of navigation	How easy was it to navigate the virtual environment?	1 = very difficult; 5 = very easy
Visual quality	How would you rate the visual quality of the virtual environment?	1 = very poor; 5 = excellent
System responsiveness	How responsive was the system during 3D interactions?	1 = very unresponsive; 5 = very responsive
Perceived data security	Did you feel that your data were secure while using the system?	1 = strongly disagree; 5 = strongly agree
Overall experience	How satisfied were you with the overall campus-tour experience?	1 = very dissatisfied; 5 = very satisfied

3.4.4. Analysis Strategy

Functional and security outcomes were summarized as counts of predefined cases that met their acceptance criteria. Questionnaire results were reported as item means. To improve interpretability without creating new observations, each mean was also divided by the scale maximum and expressed as a percentage. An unweighted descriptive composite was calculated from the four reported item means. Participant-level responses were not available in the available dataset; consequently, standard deviations, confidence intervals, reliability coefficients, and inferential tests were not calculated.

3.5. Evaluation and Improvement Cycle

Findings from functional, experience, and security evaluations were reviewed against the initial requirements. Rendering optimization and API-level protections were prioritized, and user suggestions concerning customizable routes and more detailed location information were incorporated into the refined prototype. After modification, key functions were rechecked to reduce the risk that changes introduced regressions. Only aggregate, non-identifiable evaluation results are reported.

4. Results and Discussion

4.1. Developed Virtual Campus Tour

The resulting application delivered a browser-accessible campus environment in which users could move between locations, open facility information, and interact with supported objects. A-Frame and Three.js handled the virtual scene and visual interaction, while WebXR enabled compatible immersive modes. The 360-degree imagery provided a realistic representation of campus locations without making a head-mounted display mandatory for basic access. Figure 2 shows the implemented browser interface.

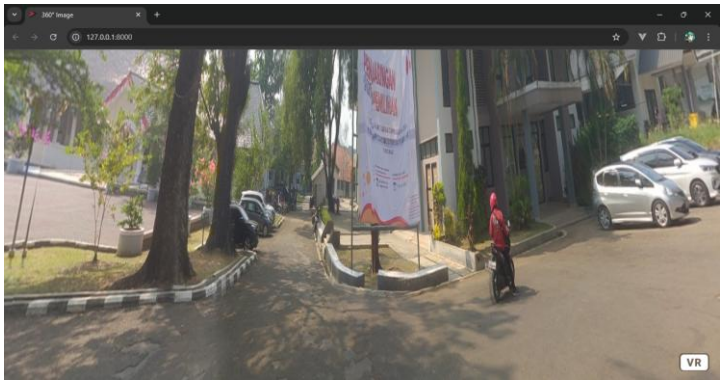

Fig 2. Browser view of the implemented 360-degree campus environment

4.2. Functional Results

All three predefined feature-level test cases were recorded as passed. This corresponds to a 3-of-3 feature-case pass rate (100%). The result establishes that the tested functions met their stated acceptance criteria in the evaluated build. It does not quantify participant-level errors or completion times because the available evaluation records did not contain per-participant execution data.

Table 5. Functional testing results

Feature	Observed outcome	Result
Interactive navigation	Users could move between the tested campus locations.	Passed
Facility information	The selected facility information was displayed.	Passed
3D-object interaction	Supported rotate and zoom interactions were executed.	Passed

4.3. Security Results

The targeted assessment recorded no finding for the two tested vulnerability classes. Thus, 2 of 2 predefined security checks met their acceptance criteria. These results apply only to the tested application build, inputs, and scan conditions. A broader security assessment would also report tool version, scan policy, authenticated coverage, endpoint inventory, severity counts, manual verification, and retesting evidence.

Table 6. Targeted security testing results

Vulnerability class	Recorded observation	Result
SQL injection	No SQL-injection alert was recorded at the tested forms or query points.	No finding
Cross-site scripting	No XSS alert was recorded at the tested user-input points.	No finding

4.4. Interaction and Experience Results

The four reported questionnaire means ranged from 4.40 to 4.70 on a five-point scale. Visual quality received the highest mean (4.70; 94% of the scale maximum), followed by system responsiveness (4.60; 92%), ease of navigation (4.50; 90%), and perceived data security (4.40; 88%). The unweighted mean of the four reported item means was 4.55, equivalent to 91% of the scale maximum. These values describe favorable perceptions within the 10-person evaluation group; they should not be interpreted as population estimates or as evidence of statistically significant improvement.

Table 7. Descriptive interaction and experience results (n = 10)

Reported item	Mean (1-5)	Normalized score
Ease of navigation	4.50	90%
Visual quality	4.70	94%
System responsiveness	4.60	92%
Perceived data security	4.40	88%
Unweighted composite of four reported item means	4.55	91%

4.5. Iterative Improvements

Evaluation feedback informed two visible refinements. First, rendering was optimized to improve the tour's behavior on lower-specification devices. Second, customizable routes and more detailed location information were incorporated in response to user suggestions. API protections were also reviewed following the targeted security assessment. These changes demonstrate the role of evaluation in product refinement, although objective before-and-after performance measurements were not available for comparison.

4.6. Discussion

The findings support the feasibility of a browser-first virtual campus tour. The high visual-quality and responsiveness means are consistent with the proposition that representational fidelity and user control can contribute to presence and agency [29]. They also align with prior case studies that reported favorable usability and engagement in interactive virtual environments [30], [31], [33]. However, this study measures perceptions of navigation, visual quality, responsiveness, and security; it does not directly measure a validated presence or immersion construct. The claim should therefore remain at the level of a favorable interactive experience rather than a proven increase in immersion.

The browser-based design is an important practical contribution. Reviews have identified accessibility, hardware cost, compatibility, and usability as recurring barriers to adoption [34], [36]. Providing a non-headset mode increases reach while retaining a pathway to WebXR-compatible immersive devices. This architecture is especially relevant to institutional promotion, where visitors may use heterogeneous hardware and may be unwilling to install a dedicated application.

The study also illustrates why multiple evaluation layers are necessary. Functional pass results show that specified features operated in the tested build, questionnaire means describe user perceptions, and targeted security checks provide bounded evidence about two web vulnerabilities. None of these layers can substitute for the others. In particular, a user's feeling that data are secure is not a technical security measure, and a scan with no recorded alert cannot demonstrate comprehensive security. Separating these outcomes improves the reproducibility and interpretive discipline of the study.

Several limitations constrain the conclusions. The usability group was small (n = 10), and the available dataset contained aggregate means rather than participant-level responses. The study did not include a comparison tour, pretest-posttest design, standardized presence scale, task-completion time, error rate, device-specific performance benchmark, or long-term usage analytics. Recruitment procedures and participant characteristics require fuller reporting. Security testing covered only SQL injection and cross-site scripting under the documented protocol. Future work should preserve raw anonymized responses, use a validated usability or presence instrument, report dispersion and reliability, compare browser and headset conditions, measure objective performance across devices, and conduct a documented authenticated security assessment.

5. Conclusion

This study developed a browser-based virtual campus tour by integrating A-Frame, Three.js, WebXR, 360-degree imagery, Express.js, and PostgreSQL. All three predefined functional cases were recorded as passed, the four reported user-experience items produced means between 4.40 and 4.70 on a five-point scale, and no SQL-injection or cross-site-scripting finding was recorded under the targeted test

conditions. The evidence supports the practical feasibility of the architecture and indicates favorable perceptions among the evaluated users. It does not establish causal improvement, population-level effectiveness, validated immersion, or comprehensive security. The main contribution is a traceable development and evaluation workflow that can guide higher-education institutions seeking a low-barrier virtual-tour implementation. Future studies should combine standardized instruments, participant-level statistics, objective performance metrics, comparison conditions, and broader security evidence.

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