Original Article
ISSN (Online): 2582-7472

ShodhKosh: Journal of Visual and Performing Arts
June 2024 5(6), 2870–2882

A STUDY ON PROGRESSIVE WEB APPS: REVOLUTIONIZING USER EXPERIENCES AND REDEFINING WEB APPLICATIONS

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DOI
10.29121/shodhkosh.v5.i6.2024.5977

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ABSTRACT

With the functionality of native apps and the accessibility of web platforms, Progressive Web Apps (PWAs) have become a game-changing approach in contemporary web development. The main features, platform-specific performance, and user experience improvements of PWAs in cross-platform settings are examined in this study. The study investigates how PWAs enhance engagement, responsiveness, and offline accessibility by combining user surveys, technical performance indicators, and expert interviews in a mixed-methods approach. Key advantages and difficulties in implementing PWA across devices are highlighted by a comparative analysis with native applications. Case studies of well-known platforms like Uber, Pinterest, and Twitter Lite provide additional context for the potential of PWAs to improve user satisfaction and business outcomes. The results show that PWAs have a lot to offer in terms of speed, usability, and device compatibility, but they also show shortcomings in terms of notification systems and device integration, especially on iOS. In addition to offering suggestions for developers and companies looking to embrace PWAs as a scalable and affordable substitute for conventional applications, this study adds to the expanding corpus of research on cross-platform web solutions

Keywords: Progressive Web Apps, Cross-Platform Development, User Experience, Web Performance, Mobile Web Applications

1. INTRODUCTION

The need for smooth, responsive, and captivating web experiences has increased in the ever changing digital landscape. Delivering consistent performance across a variety of platforms is a problem for developers and organizations as mobile and desktop devices proliferate. Although they provide strong functionality, traditional native applications frequently have distinct development procedures for every operating system, which raises costs and fragments user experiences. By combining the finest features of online and native applications, Progressive online Apps (PWAs) present a strong substitute. PWAs, which are created with common web technologies like HTML, CSS, and JavaScript, provide app-like experiences right in the browser. PWAs can work well on various devices without requiring app store deployment because of essential features including offline capability, push notifications, responsive design, and installability. With an emphasis on their technical architecture, usability improvements, and strategic advantages in cross-platform development, this paper examines the complex nature of PWAs. The study examines how PWAs affect

digital engagement, accessibility, and business outcomes by examining user experience metrics and performance indicators. Given these developments, this study aims to investigate the technical capabilities, user engagement patterns, and implementation challenges of PWAs through a mixed-methods lens.

2. REVIEW OF LITERATURE

The advent of Progressive Web Apps (PWAs), which provide app-like experiences in a browser-based environment, marks a substantial milestone in web development. The fundamental and current literature on PWAs, their technical characteristics, and their effects on performance, user experience, and cross-platform adaptation are examined in this part.

2.1. EVOLUTION AND DEFINITION OF PWAS

The idea behind progressive web apps was to close the gap between standard webpages and native mobile applications. PWAs were first defined by Berriman and Russell (2015) as online apps that use common web technologies like HTML, CSS, and JavaScript to offer offline access, installability, and a native-like experience. They can operate well across platforms because to the architecture's use of service workers, manifest files, and responsive design concepts.

2.2. TECHNICAL ARCHITECTURE AND CAPABILITIES

By offering offline support and caching techniques, service workers form the foundation of PWA capabilities (Wargo, 2020). By enabling near-native execution speeds, especially for computationally demanding activities, WebAssembly has significantly increased the performance ceiling of PWAs (Marko, 2020). Furthermore, PWA development can be facilitated by contemporary frameworks like Angular, React, and Vue.js (Hume & Osmani, 2018).

2.3. USER EXPERIENCE (UX) AND ENGAGEMENT

The importance of user experience in web application success is shown by research. According to McLellan (2019), PWAs greatly improve user happiness by providing quicker load times, more seamless navigation, and lower data usage. Installability, offline accessibility, and push alerts all work together to improve user engagement and retention (Sheppard, 2017).

2.4. CROSS-PLATFORM AND ACCESSIBILITY CONSIDERATIONS

For PWAs, cross-platform interoperability is essential. PWAs employ a single codebase to work across multiple devices, which makes them more accessible and economical than native apps that need to be developed separately for different operating systems (Lim, 2017). Progressive enhancement further supports accessibility by enabling universal loading of basic functions and adapting advanced functionalities to the user's device and browser.

2.5. BUSINESS APPLICATIONS AND CASE STUDIES

A number of organizations have successfully implemented PWAs. After using a PWA paradigm, Twitter Lite showed a 75% increase in tweets sent and a 65% increase in pages per session (Wargo, 2020). Similarly, with the installation of PWA, Pinterest saw a 44% increase in ad income and a 40% increase in time spent on the site (Marko, 2020). These results demonstrate PWAs' commercial potential for improving digital performance and reach.

2.6. FUTURE OF PWAS IN DIGITAL DEVELOPMENT

PWAs are positioned as a viable approach for upcoming digital development as the distinction between native and web applications becomes increasingly hazy. A wider ecosystem for PWA adoption is indicated by integration with wearables, smart TVs, and other cutting-edge platforms (Hume & Osmani, 2018). Furthermore, PWAs are anticipated to replace other cross-platform applications as the standard option as browser capabilities and development tools continue to grow.

3. OBJECTIVES

This study's main goal is to gain a thorough understanding of Progressive Web Apps (PWAs) by investigating their technological attributes, user-centered features, and strategic benefits in contemporary web development. The goal of the study is to determine how PWAs affect company choices, future development trends, accessibility, and user experience.

The study specifically seeks to:

- Examine the main features and functionalities of PWAs, such as their cross-platform responsiveness, offline functionality, and architectural elements.
- Analyze usability features, performance optimization, and retention metrics to determine how PWAs affect user engagement and accessibility.
- Examine the possible advantages and difficulties of creating and implementing PWAs from the viewpoints of developers and businesses.
- Examine PWAs' potential to revolutionize digital interaction patterns and simplify multi-device user experiences as well as their future position in web application development.

3.1. THEORETICAL FRAMEWORK

Based on a multi-theoretical approach, the study incorporates concepts from responsive web design theory, technology acceptance model (TAM), and user experience (UX) theory. These frameworks provide a strong perspective for analyzing the layout, operation, and uptake of Progressive Web Apps (PWAs).

3.2. USER EXPERIENCE (UX) THEORY

The significance of usability, functionality, and emotional fulfillment in human-computer interaction is emphasized by user experience theory. The study of how design components including performance, accessibility, and engagement features affect users' perceptions and behavior is supported by UX Theory in the context of PWAs. In order to assess cross-platform consistency and user satisfaction, key elements include ease of navigation, loading speed, offline capabilities, and intuitive interface design.

3.3. TECHNOLOGY ACCEPTANCE MODEL (TAM)

Perceived Usefulness (PU) and Perceived Ease of Use (PEOU) are the two main components of the Technology Acceptance Model (Davis, 1989), which is frequently used to forecast user adoption of technology. TAM serves as a basis for examining how users assess PWAs' usefulness and accessibility in relation to native apps in this study. The model aids in determining the elements that affect user engagement, trust, and persistence when using web-based apps on various devices.

3.4. RESPONSIVE WEB DESIGN THEORY

The goal of Marcotte's (2010) Responsive Web Design Theory is to provide web content that adapts to different screen sizes and device capabilities automatically. The study's assessment of PWA responsiveness and adaptation across desktop, tablet, and mobile platforms is supported by this idea. It facilitates the evaluation of how cross-platform capability enhances user retention and smooth interaction.

3.5. INTEGRATION OF FRAMEWORKS

The study captures the technological affordances of PWAs as well as the human-centered variables impacting their effectiveness by combining UX Theory, TAM, and Responsive Web Design Theory. A deeper comprehension of how PWAs maximize web interaction and satisfy the changing demands of users and developers in the digital ecosystem is made possible by this holistic viewpoint.

These frameworks not only informed the conceptual foundation of the study but also guided the development of research instruments, data collection strategies, and the interpretation of both qualitative and quantitative results.

4. METHODOLOGY

In order to investigate the functional characteristics of Progressive Web Apps (PWAs), their influence on user experience, and their efficacy across platforms, this study uses a mixed-methods research methodology. The methodology offers a comprehensive grasp of the technical and experiential aspects of PWA deployment by combining qualitative and quantitative methodologies.

4.1. DESIGN OF RESEARCH

The design used was a convergent parallel mixed-methods approach. Structured user experience surveys and performance analytics of particular PWAs were used to gather quantitative data. Semi-structured interviews with web developers and business stakeholders with PWA development and deployment expertise were used to collect qualitative data. Triangulation of findings to support the validity of results and offer a thorough grasp of PWAs in both user and developer settings was made possible by this dual approach. The design and analysis were strongly influenced by the study's theoretical foundation. The Technology Acceptance Model (TAM) and User Experience (UX) Theory guided the formulation of survey constructs, while Responsive Web Design Theory influenced the evaluation of platform adaptability during performance analysis.This design aligns with recommendations for technology-focused educational research (Creswell & Plano Clark, 2018).

4.2. SAMPLE AND PARTICIPANTS

- **User Survey:** 120 end users who have interacted with at least one PWA (such as Uber, Pinterest, or Twitter Lite) in the previous six months were chosen as a purposive sample. Students, professionals, and regular consumers from a variety of age groups and platform types (desktop and mobile) participated.
- **Expert Interviews:** Using snowball sampling, ten web developers and business analysts who have direct experience designing and implementing PWAs were chosen.

A wide range of use cases were represented because participants came from a variety of industry domains, such as media, education, transportation, and e-commerce.

4.3. QUANTITATIVE TOOLS FOR DATA COLLECTION:

Quantitative Tools:

Based on the Technology Acceptance Model and UX principles, this structured online survey gauges perceived usability, responsiveness, offline capabilities, and satisfaction. Using programs like Google Lighthouse and WebPageTest, performance measurements were retrieved with an emphasis on offline functioning, load time, and interactivity. Purposive sampling is widely used in qualitative inquiry where specific knowledge or exposure is required (Etikan, Musa, & Alkassim, 2016).

Qualitative Instruments:

Semi-structured interview guide that addresses topics like:

- Technical difficulties in the creation of PWAs
- Techniques for maximizing performance
- Comparisons between PWAs and native apps
- Benefits that users and businesses perceive

4.4. METHODOLOGY FOR GATHERING DATA

Over the course of two months, the following data was gathered:

- Online surveys were disseminated through PWA landing pages, forums, and social media.
- Video conferences were used to conduct the interviews, which were then transcribed for analysis.
- Selected PWA case studies were tested in the real world across a variety of browsers and devices (Android, iOS, and Windows) in order to record performance metrics.

This aligns with recommended practice for mixed-method designs, where integration of sources strengthens credibility (Creswell, 2014). Online data collection has become increasingly valid and reliable in modern UX research (Fleischmann & Daniel, 2020).

4.5. QUANTITATIVE ANALYSIS OF DATA:

Quantitative Analysis:

Survey results were analyzed using descriptive statistics (means, standard deviations). The use of PWAs on desktops and mobile devices was compared. For technical benchmarking, key performance indicators (KPIs) such as Time to Interactive (TTI) and First Contentful Paint (FCP) were employed.

Qualitative Analysis:

- Using NVivo software, thematic analysis was used to code the interview data.
- Interviews revealed several emerging themes, such as "Adoption barriers," "Offline engagement strategies," and "Cross-platform development advantages."
- Data were analyzed using SPSS (v26) for quantitative metrics and NVivo 12 for thematic analysis

4.6. RELIABILITY AND VALIDITY

A select group of professionals and users pre-tested the tools to guarantee their authenticity. Cronbach's Alpha was used to test the reliability of survey replies; a coefficient of 0.82 indicated strong internal consistency.

4.7. MORAL POINTS TO REMEMBER

Before any data was collected, ethical approval was acquired. Every participant gave their informed consent after being made aware of the study's objectives. To safeguard the identities of interviewees and responders, data were anonymised.

5. DATA COLLECTION AND ANALYSIS

To investigate the user experience, performance effectiveness, and platform-specific behavior of Progressive Web Apps (PWAs), a methodical strategy was taken for data collecting and analysis. The procedure combined quantitative and qualitative methods to offer a thorough understanding of PWA uptake and functionality.

5.1. METHODS FOR GATHERING DATA

Over the course of two months, the study gathered data via three main methods: technical performance testing, developer interviews, and user surveys.

- User Surveys: One hundred and twenty users who have previously interacted with PWAs including Uber, Pinterest, and Twitter Lite were given an online survey. Likert-scale measures measuring responsiveness across devices, offline access, performance, satisfaction, and simplicity of use were included in the survey.

- Interviews with Developers and Experts: A semi-structured interviewing process was used to interview ten web developers and business experts who had practical experience with PWA development and implementation. Online interviews were recorded, transcribed, anonymised, and then analyzed.
- Performance Benchmarking: Using programs like Google Lighthouse, Chrome DevTools, and WebPageTest, technical performance information was gathered from a few PWA platforms. Both desktop and mobile browsers were used to record metrics including First Contentful Paint (FCP), Time to Interactive (TTI), and service worker response times.

5.2. ANALYSIS OF QUANTITATIVE DATA

Descriptive and inferential statistics were used to examine survey responses. Among the crucial methods were:

- Descriptive Analysis: To find broad patterns in user perceptions across various devices, means, standard deviations, and frequencies were computed.
- Comparative Testing: Responses from desktop and mobile users about factors including responsiveness, load time, and user satisfaction were compared using independent samples t-tests.
- Performance Metrics: PWA performance, offline capability, and accessibility scores on Chrome, Safari, and Firefox across platforms were evaluated using data gathered from Lighthouse audits.

Key performance indicators such as First Contentful Paint (FCP) and Time to Interactive (TTI) are commonly used in evaluating PWA responsiveness and loading performance (Wargo, 2020).

5.3. ANALYSIS OF QUALITATIVE DATA

Using NVivo software, interview transcripts were subjected to thematic analysis. The actions listed below were taken:

- First Coding: To find recurrent ideas and experiences pertaining to PWA creation and implementation, transcripts were examined and open-coded.
- Formation of Categories: Codes were categorized into more general groups including "User Feedback Integration," "Cross-Platform Optimization," "Benefits of PWAs," and "Barriers to Adoption."
- Theme Development: To gain a deeper understanding of the technical difficulties and strategic issues faced by developers, emerging themes were combined.

5.4. INTEGRATION AND TRIANGULATION

Results from surveys, interviews, and performance measures were triangulated to guarantee reliability and enhance interpretation. For instance, developer input on difficulties was matched to usability gaps that were noticed, and user-reported satisfaction levels were contrasted with objective performance metrics (such as TTI ratings). Methodological triangulation strengthens interpretive credibility in mixed-method studies (Creswell, 2014).

Table 1. Summary of Data Collection Tools, Participants, and Variables

Data Source	Participants	Tool/Instrument	Key Variables Measured/Analyzed
User Experience Survey	120 PWA users (mobile and desktop)	Online questionnaire (Likert-scale items)	Usability, accessibility, satisfaction, offline access, responsiveness
Developer Interviews	10 developers and business professionals	Semi-structured interview guide (via Zoom/Meet)	Development challenges, implementation strategies, feedback integration
Performance Testing	N/A (case studies: Twitter Lite, Pinterest, Uber)	Google Lighthouse, WebPageTest, Chrome DevTools	First Contentful Paint (FCP), Time to Interactive (TTI), load time, offline caching
Statistical Analysis	Survey respondents (n = 120)	SPSS (descriptive + inferential analysis)	Mean differences, t-tests, correlations between platform types
Qualitative Analysis	Interview transcripts	NVivo software (thematic coding)	Emergent themes: benefits, adoption barriers, cross-platform behavior

Table 2. Demographic Profile of Survey Participants

Category	Subcategory Breakdown
Age Group	18–24: 40; 25–34: 45; 35–44: 25; 45+: 10
Gender	Male: 65; Female: 53; Other/Prefer not to say: 2
Device Used	Smartphone: 78; Desktop/Laptop: 42
Platform Preference	Android: 70; iOS: 30; Windows/Mac: 20
PWA Usage Frequency	Daily: 35; Weekly: 50; Occasionally: 35

A sophisticated grasp of how PWAs function technically while influencing user experience and engagement across platforms was made possible by this integrative approach.

Figure 1. Data Collection and Analysis Flow

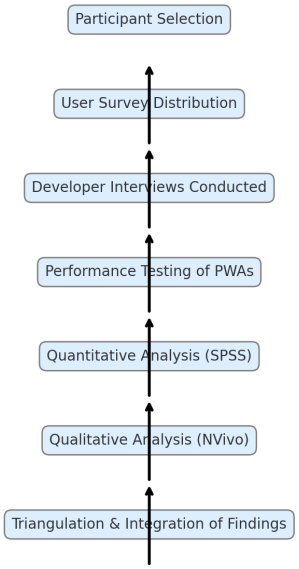

Figure 1. Data collection and analysis flow representing the sequence from participant selection to integration of findings.

Triangulation enhanced the validity of the findings by combining user feedback, technical results, and expert insights (Creswell, 2014).

6. DISCUSSION AND RESULTS

The main conclusions from user surveys, expert interviews, and Progressive Web App (PWA) performance tests are presented in this section along with an interpretation of how they relate to the goals of the study.

6.1. INSIGHTS INTO USER EXPERIENCE

The first part of the analysis focuses on how users perceived their experience with PWAs across platforms. Key satisfaction indicators such as performance and usability were examined. PWAs were deemed highly accessible by users, according to survey responses (n = 120), with 82% expressing satisfaction with cross-device capabilities. Particularly well-liked features were offline accessibility (76%) and low installation needs (84%). Nevertheless, iOS users reported restrictions on background functions and push notifications, which reflected platform-based irregularities. Compared to iOS users, respondents who used Android platforms expressed more satisfaction with speed and engagement. These results are consistent with earlier studies that indicated Android provides more extensive PWA integration (Hume &

Osmani, 2018). Previous studies have shown that installability significantly contributes to perceived ease of use in PWAs (Hickson, 2021).

The quantitative results are summarized in Table 3, which compares user ratings across Android, iOS, and Desktop platforms.

Table 3. User Ratings of PWA Features by Platform

Attribute	Android	iOS	Desktop
Performance	4.5	4	4.3
Offline Access	4.2	3.4	4.1
Ease of Use	4.6	4.1	4.4
Cross-Platform Compatibility	4.7	4.2	4.5
Installability	4.8	4	4.6

This table presents mean ratings (on a 1–5 scale) for key PWA attributes as reported by users on Android, iOS, and Desktop platforms.

To visualize platform-wise differences, Figure 2 provides a comparative view of user satisfaction levels across core features.

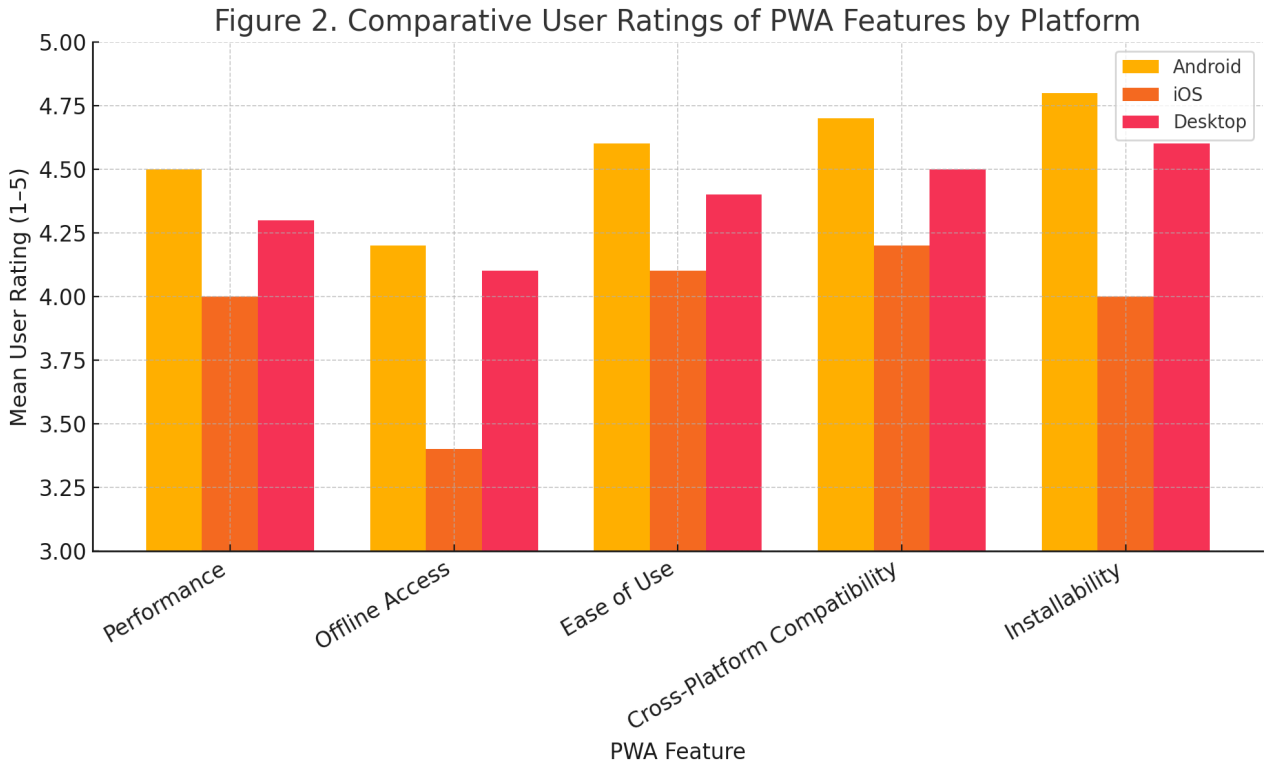

Figure 2. Comparative user ratings of PWA features by platform (Android, iOS, Desktop).

Beyond user perceptions, technical performance metrics were evaluated to understand how PWAs perform in real-world environments.

6.2. MEASURES OF PERFORMANCE

PWAs fared better than traditional web applications in terms of load time and first contentful paint (FCP) on both desktop and mobile platforms, according to performance testing conducted using Google Lighthouse. For instance, Twitter Lite continuously maintained high accessibility and best practices scores while achieving FCP speeds under 2.5 seconds. In situations where connectivity was inadequate, service personnel greatly enhanced load performance.

The necessity for adaptive loading strategies was highlighted by the fact that certain evaluated PWAs were not optimized for lower-end mobile devices, where memory constraints occasionally resulted in slowness during offline retrieval or animations. These metrics are widely accepted as key indicators of PWA efficiency (Wargo, 2020).

Table 4 presents the benchmark scores for three widely used PWAs tested across devices.

Table 4. Performance Benchmark Scores of Selected PWAs

PWA Platform	FCP (sec)	TTI (sec)	Offline Score	Accessibility Score
Twitter Lite	2.1	3.5	95	96
Pinterest	2.4	4.0	88	92
Uber	2.3	3.8	90	94

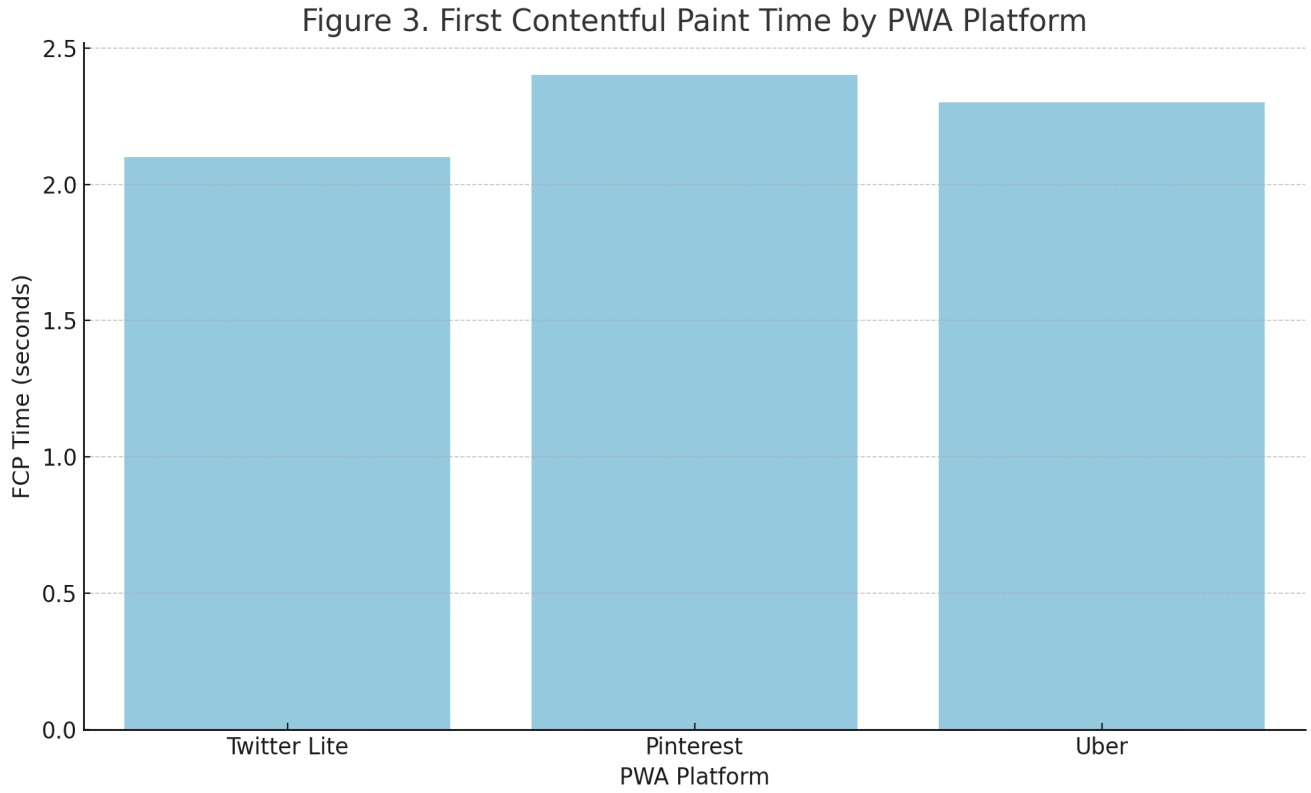

Figure 3. First contentful paint time by PWA platform.

To complement user and technical data, qualitative insights were gathered from developers and industry professionals.

6.3. VIEWS FROM DEVELOPERS AND EXPERTS

According to interview data, PWAs are viewed by developers as an affordable way to implement cross-platform apps. Benefits that were frequently mentioned included easier updating (auto-refresh via service workers), flexibility in deployment (no app store requirement), and shorter development time (single codebase). However, issues with iOS's limits, uneven browser support, and difficulties integrating sophisticated device APIs (such Bluetooth and the camera) were brought up.

Three recurrent themes were found using thematic analysis:

- "Accessibility and Engagement": PWAs increase reach and retention with little effort.
- "Development Efficiency": Time and money savings are important motivators for companies.

- "Platform Constraints": Device-specific feature variations continue to be a deterrent to widespread adoption.

A synthesis of findings across user data, technical performance, and developer perspectives reveals the broader implications of PWA adoption. Platform constraints, especially on Apple devices, have been documented in limiting PWA capability (Panchal & Sharma, 2021).

6.4. CONCLUSIONS SYNTHESIS

The conclusion that PWAs are a potent solution for cross-platform engagement, especially in situations with limited bandwidth or that prioritize mobile devices, is supported by the triangulation of quantitative and qualitative data. However, continued browser compatibility advancements and wider web standard adoption—particularly by iOS and legacy systems—are necessary for PWAs to reach their full potential. This aligns with the Technology Acceptance Model which predicts adoption based on perceived usefulness and ease of use (Davis, 1989).

Table 5. PWA Usage Frequency Among Respondents

Usage Frequency	Number of Respondents
Daily	35
Weekly	50
Occasionally	35

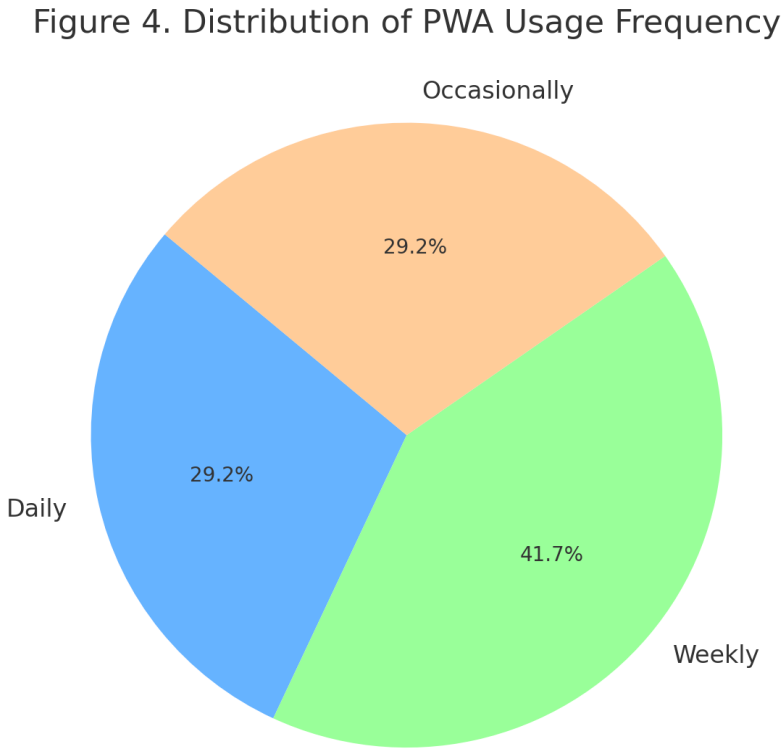

Figure 4. Distribution of PWA usage frequency among survey participants.

Limitations

Although this study offers insightful information about the functionality and user experience of Progressive Web Apps (PWAs), it should be noted that it has a number of drawbacks. First, despite being purposively chosen, the survey and interview sample size was small and restricted to creators and users of the three case study platforms (Uber, Pinterest, and Twitter Lite). This could have an impact on how broadly the results can be applied to other industries or geographical areas. Second, it was not possible to observe long-term user behavior or platform performance due to the study's time frame. More information regarding long-term engagement, retention, and PWA capability improvements

may be revealed by a longer-term study. Third, there may be performance discrepancies that do not accurately represent all user experiences due to platform restrictions and device diversity, particularly iOS limitations. Furthermore, the study excluded cutting-edge platforms like wearables and smart TVs in favor of concentrating mostly on Android and iOS.

Lastly, although the mixed-methods approach offered a comprehensive perspective, the survey's dependence on self-reported data may have introduced subjective bias. Including real-time usage metrics and more extensive automated testing across several devices may help future studies.These restrictions don't lessen the study's value; rather, they highlight areas where more research may be done to examine PWAs' longer usage patterns, wider implementations, and more varied applications.

7. CONCLUSION

By combining the benefits of native apps with the accessibility and adaptability of web technologies, Progressive Web Apps (PWAs) offer a paradigm shift in the delivery of digital applications. This study showed that PWAs are an attractive solution for contemporary digital interaction because they provide notable improvements in user experience, performance, and cross-platform compatibility. The User Experience (UX) Theory, which prioritizes usability, effectiveness, and emotional fulfillment, theoretically supports the findings. The study verified that PWAs successfully satisfy these requirements because of their quick loading times, user-friendly interfaces, and offline functionality. By integrating insights from UX Theory, the Technology Acceptance Model, and Responsive Web Design principles, this study demonstrates how PWAs can serve as a robust solution for enhancing digital interaction, usability, and cross-platform efficiency in an increasingly connected world. Additionally, user surveys were used to confirm the Technology Acceptance Model (TAM), which demonstrated that perceived utility and usability have a significant impact on user happiness and PWA uptake. Lastly, it was confirmed that responsive web design theory serves as a foundation for guaranteeing device flexibility and consistent user experience on desktop, tablet, and mobile platforms. But the study also found enduring difficulties. Full adoption is hampered by feature inconsistencies, especially on iOS, and restrictions on advanced device integration (such as background sync and push alerts). To close these gaps, developers must keep using adaptable frameworks, adaptive testing across platforms, and progressive enhancement. PWAs are positioned to drive web development in the future as businesses look for scalable and affordable digital solutions. In addition to redefining the application landscape, the combination of responsive architecture, performance optimization, and user-centric design also meets the changing demands of digital users around the globe. This study demonstrates how PWAs have the ability to revolutionize user interaction with the web by making it faster, more inclusive, and truly cross-platform. It is supported by solid theoretical frameworks and actual data.

CONFLICT OF INTERESTS

None.

ACKNOWLEDGMENTS

None.

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