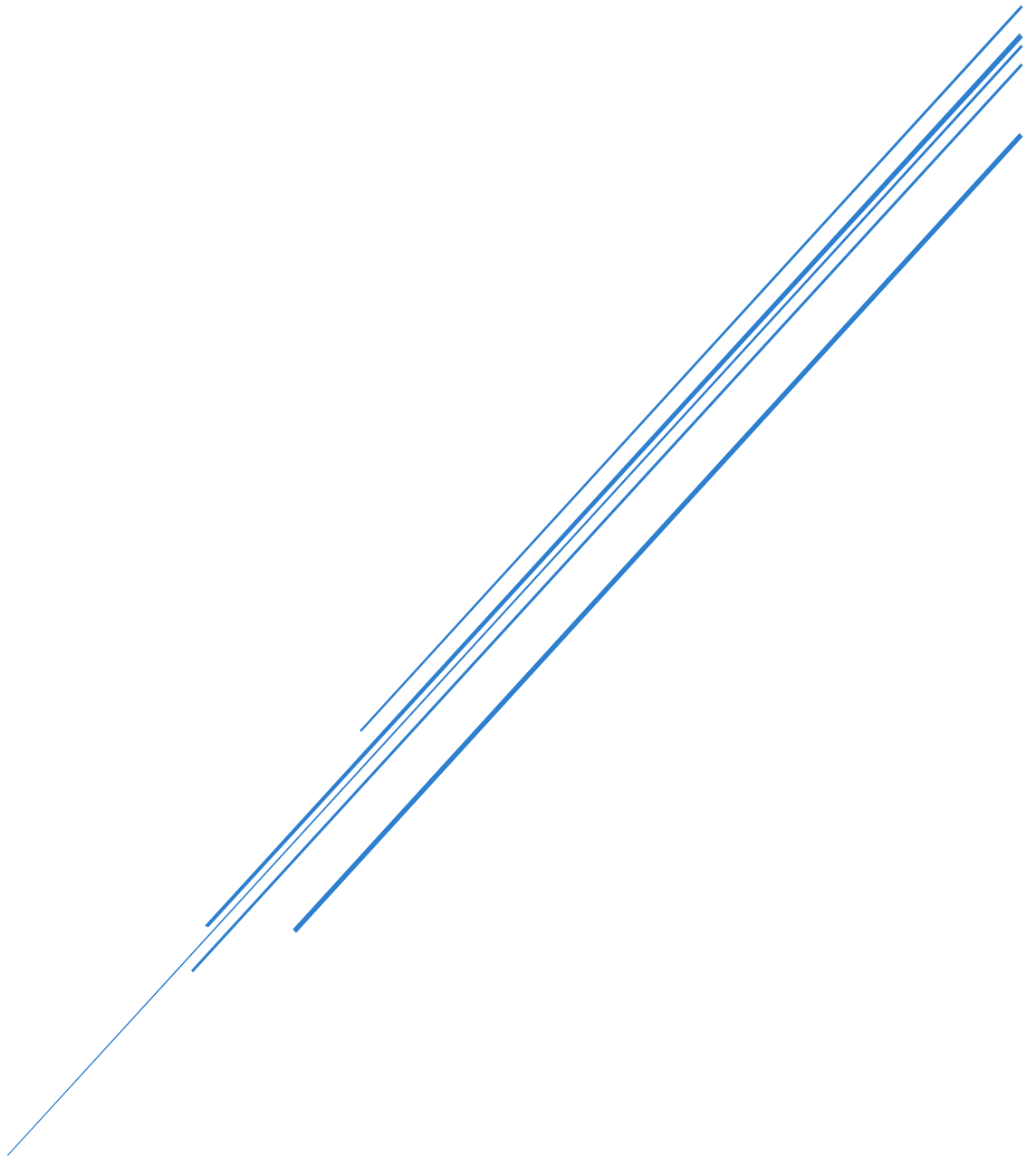


Optimising PWA Offline Capability for Seamless Cross-Border E-Commerce



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Abstract

In today's global digital economy, Progressive Web Applications (PWAs) present a powerful tool and promising solution for improving cross-border e-commerce. This paper examines how optimising PWA offline capabilities using service workers, caching, and offline-first design can overcome connectivity challenges in regions with unstable internet. It also explores how enhanced offline functionality supports accessibility, performance, and user experience across diverse cultural, economic, and technological contexts. Focusing on multinational enterprises (MNEs), the paper highlights the strategic value of PWAs in navigating regulatory and infrastructural differences, ultimately enhancing global user engagement and competitiveness.

Keywords

Progressive Web Apps, e-commerce, user experience, digital innovation, technological barriers, PWA offline capability, Cross-border e-commerce, Digital transformation, Multinational enterprises (MNEs), Internet accessibility, Global strategy.

Words Count: 1994

1. Introduction

The digitalisation of commerce (Acs, Song et al. 2021) has reshaped the global business landscape (Goyal, Sergi et al. 2019), enabling firms to transcend geographical barriers and reach diverse consumer bases (London and Hart 2004). However, international e-commerce encounters significant obstacles, particularly in regions with unreliable internet infrastructure (Lawrence and Tar 2010). Progressive Web Applications (PWAs) have emerged as a pivotal technology in mitigating these challenges by offering a seamless and resilient user experience (Biørn-Hansen, Majchrzak et al. 2017).

PWAs leverage service workers, caching mechanisms, and offline-first principles to maintain functionality even in limited-connectivity environments (Love 2018). This capability is particularly relevant in cross-border commerce, where digital platforms must accommodate varying levels of internet accessibility, regulatory constraints, and consumer expectations. Given the increasing role of digital technologies in international business, optimising PWA offline functionality presents an opportunity for multinational enterprises (MNEs) to strengthen market penetration and enhance user engagement across diverse regions (Biørn-Hansen, Majchrzak et al. 2018).

This paper explores how optimising PWA offline capability can enhance cross-border e-commerce by addressing critical challenges related to international business management, digital transformation, and global user experience (Lama 2019). It examines the influence of technological, cultural, and economic forces on PWA adoption and proposes strategies for improving offline performance to drive international competitiveness.

1.1 Research Questions

RQ1: How can improving website features that work without the internet make online shopping across borders smoother, especially for customers in areas with poor connectivity?

RQ2: What are the biggest challenges -technical, legal, and cultural - that global e-commerce businesses face when trying to offer a better offline shopping experience, and how can they solve them?

RQ3: What are the best ways to store and manage website data to ensure a fast, reliable, and hassle-free online shopping experience for international customers?

2. PWAs Role in International E-Commerce

2.1 Defining PWAs

A Progressive Web Application (PWA) is a web-based application that incorporates features traditionally associated with native mobile applications, including offline functionality, push notifications, and background synchronisation (Sheppard and Sheppard 2017). Central to this functionality are service workers, which operate in the background to cache content and support offline browsing (Love 2018). PWAs run across devices without requiring installation from app stores, offering a seamless and accessible digital commerce experience (Hume 2017).

3. PWAs Benefits for Global E-Commerce

PWAs provide key benefits tailored to international e-commerce needs.

3.1 Offline Functionality

By caching key resources, PWAs enable product browsing and cart access without constant internet, ideal for areas with unreliable connectivity (Lama 2019).

3.2 Cross-Platform Accessibility

Unlike native mobile apps that require separate development for iOS and Android, PWAs run on any browser, cutting development costs and ensuring a consistent user experience across devices (Majchrzak, Biørn-Hansen et al. 2018).

3.3 Improved Performance

PWAs use caching to load faster than traditional websites, reducing latency in low-connectivity areas (Hume 2017).

3.4 Lower Data Consumption

By storing assets locally, PWAs minimise data usage, making them ideal for markets with limited or costly internet (Majchrzak, Biørn-Hansen et al. 2018).

3.5 Ease of Maintenance

PWAs bypass app store approvals, allowing faster updates and security patches (Love 2018)

4. Cross-Border E-Commerce Challenges

Though advantageous, PWAs face specific challenges in international e-commerce:

4.1 Diverse Connectivity Landscapes

Internet access varies widely: developed countries have fast, stable connections, while many emerging markets face instability and data limits (Tandel and Jamadar 2018).

4.2 Regulatory and Compliance Issues

Regions enforce different data privacy laws (e.g., GDPR, CCPA), impacting PWAs' offline data storage and syncing (Rutter, Lauke et al. 2007).

4.3 Cultural and Linguistic Considerations

Language preferences, UI/UX, and payment preferences vary by country, requiring localised PWA strategies (Griffith 2017).

5. Optimising PWA Offline Capability for Cross-Border Commerce

To maximise PWA impact in international e-commerce, businesses must boost offline performance, user engagement, and regional adaptability:

5.1 Implementing Advanced Caching Strategies

Caching is vital to offline PWA functionality, enabling seamless browsing in low-connectivity settings by storing key assets in advance (Love 2018). Core techniques include: (i) Cache First Strategy—loading frequently used resources from cache before the network, (ii) Dynamic Caching—updating data when online while keeping older versions for offline access, and (iii) Background Syncing—saving user actions to be processed once connectivity returns (Zulfa, Hartanto et al. 2020).

5.2 Adopting an Offline-First Approach

An offline-first architecture prioritises cached content over network calls, boosting reliability and reducing user frustration (Hume 2017). Key implementations include: (i) storing user sessions locally for uninterrupted access, (ii) queueing transactions for later processing when online, and (iii) storing region-specific content offline, such as pricing, currency, and legal disclaimers.

5.3. Addressing International Compliance and Security

Given e-commerce's global scope, PWAs must comply with diverse data privacy and security regulations. Key strategies include: (i) encrypting offline data to prevent breaches, (ii) applying region-specific data retention policies aligned with laws like GDPR (Biørn-Hansen, Majchrzak et al. 2017), and (iii) offering clear consent mechanisms so users can control data storage (Rutter, Lauke et al. 2007).

5.4. Enhancing Multi-Language and Multi-Currency Support

To serve global audiences, PWAs should incorporate: (i) automatic language detection via browser and geolocation, (ii) dynamic currency conversion using real-time rates (Biørn-Hansen, Majchrzak et al. 2017), and (iii) culturally adapted UX/UI tailored to local payment methods, recommendations, and navigation (Rutter, Lauke et al. 2007).

6. Methodology

6.1 Research Design

This research adopts an interpretivist philosophy and an inductive, exploratory case study approach to examine PWAs offline capabilities. Rooted in the belief that knowledge is socially constructed, interpretivism allows for a nuanced exploration of director-level decision-makers' perspectives (Saunders, Lewis et al. 2023), within their organisational contexts (Jackson, Bazeley et al. 2019). A mono-method qualitative design will be employed, using semi-structured interviews with senior stakeholders to gather rich, contextual data and drawing on established technology adoption models and UX frameworks to inform the analysis. A snowball sampling technique will be used for hard-to-access participants, ensuring relevant expertise despite a limited sample size (Bell, Bryman et al. 2022). The case study strategy enables in-depth analysis of real-world practices and decision-making, capturing the complexities of digital transformation in retail settings (Saunders, Lewis et al. 2023). While the sample may not offer statistical generalisability, the study contributes valuable theoretical and practical insights. The is summarised in Figure 1 - Adapted from Saunders, M. N. K. et al. (2023, pp 176).

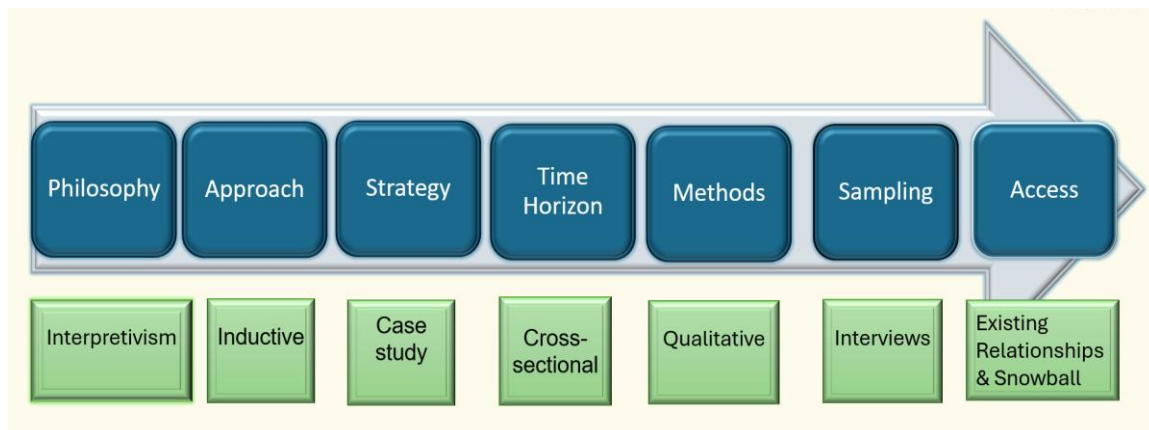


Figure 1 – Methodology

6.2 Sampling Methods

This study employs purposive and snowball sampling to recruit 20–25 senior stakeholders from UK-based retail organisations, ensuring participants possess relevant expertise in e-commerce, IT, digital transformation, or product development. These individuals are strategically positioned to offer in-depth insights into the offline capabilities of PWAs on cross-border ecommerce (Saunders, Lewis et al. 2023). The sample size may expand to 30 if thematic saturation has not been reached, balancing the need for depth with practical and ethical constraints (Guest, Bunce et al. 2006). Semi-structured interviews are the primary data collection method, offering rich, context-specific insights that quantitative approaches might overlook. While purposive sampling may limit generalisability, it enhances data validity by targeting key informants (Bell, Bryman et al. 2022). Participants will be drawn from a variety of retail sectors to ensure diverse perspectives on PWA adoption stages, from consideration to full implementation (Miles, Huberman et al. 2020). This approach aligns with the study's interpretivist philosophy and exploratory case study design (Saunders, Lewis et al. 2023), supporting a nuanced understanding of digital transformation in the UK retail landscape (Hancock, Algozzine et al. 2021).

6.3 Retailer Criteria and Access to Respondents

To explore the PWAs offline capabilities in retail e-commerce, this study will engage senior decision-makers from UK-based retailers that operate websites, mobile apps, and are at various stages of PWA implementation adoption (implemented, in progress, or under consideration). Participants must hold strategic roles in digital transformation and technology adoption, providing direct insights into how PWAs enhance user experience (Miles, Huberman et al. 2020). A diverse range of sectors; including fashion, FMCG, electronics, and online-only retailers, will be represented to ensure broad, sector-specific perspectives.

A combined purposive and snowball sampling (Noy 2008) approach will guide participant selection, targeting those with relevant expertise while expanding reach through referrals (Naderifar, Goli et al. 2017). The researcher will utilise a well-established professional network, built over 20 years in IT and e-commerce consulting, to initiate outreach via personalised emails and LinkedIn (Karapanos, Zimmerman et al. 2009). Interviews will be semi-structured and flexibly arranged (virtually or in-person), with all interactions conducted in line with ethical research standards, ensuring confidentiality and voluntary participation (Easterby-Smith, Thorpe et al. 2012).

Below is a list of UK-based e-commerce companies engaged in cross-border trade and at various stages of PWA adoption. These organisations meet the study's criteria for involving senior decision-makers in digital transformation and technology adoption across a diverse range of sectors, including fashion, FMCG, electronics, and online-only retail. The companies include those with fully implemented PWAs: George (ASDA) george.com, Superdrug superdrug.com, John Lewis johnlewis.com and Debenhams debenhams.com. Those currently progressing with or considering PWA implementation include Tesco tesco.com, UK Meds ukmeds.co.uk, BetterCommerce bettercommerce.io and Fruugo fruugo.co.uk.

These companies represent ideal candidates for exploring the offline capabilities of PWAs in retail e-commerce. Their active engagement in cross-border operations and varying stages of PWA adoption offer a valuable opportunity to gather sector-specific insights. Interviews with senior strategic leaders from these firms will provide meaningful data on how PWAs improve user experience and support international digital commerce strategies.

6.4 Methodology Limitations and Ethical Considerations

The methodology employed in this research is well-suited for studying digital innovation (Bell, Bryman et al. 2022), such as PWA offline capabilities, particularly through qualitative inquiry (Taherdoost 2022). Snowball sampling will be used to reach specialised (Parker, Scott et al. 2019), hard-to-access participants. While effective and efficient where no formal sampling frame exists, this method may introduce bias and limit generalisability (Goodman 1961). Challenges may also include time and budget constraints, as well as limited availability of PWA-specific UX data. However, the researcher's professional network will support recruitment without compromising objectivity.

The study will adhere strictly to ethical research principles, including informed consent, confidentiality, and participant protection (Saunders et al., 2023; Bell et al., 2022). No sensitive personal data will be collected (Cannella and Lincoln 2011), and all responses will be recorded securely, respecting participant privacy (Resnik 2015). The research avoids controversial topics and complies with ethical standards for internet-based and mobile app research (Iphofen and Tolich 2018). Guidance from professional bodies and ethical codes, such as [The Ethics Guide 2015: Advice and Guidance](#), will ensure the study maintains integrity (Tolich, Iphofen et al. 2020) and aligns with Goal 9 - Sustainable Development Goals (SDGs) - <https://sdgs.un.org/goals/goal9>.

7. Conclusion

Optimising PWAs offline capabilities provides a strategic edge for international e-commerce by mitigating connectivity challenges, enhancing site performance, and ensuring compliance with diverse global regulations; ultimately improving user experience across borders (Aguirre, Delía et al. 2020). As digital commerce continues to globalise, such optimisation becomes crucial for multinational enterprises (MNEs) to maintain competitiveness (Love 2018). As illustrated in Figure 2, this study will contribute methodologically by highlighting the value of qualitative research and theoretically by filling knowledge gaps and proposing refined or new frameworks. It will also offer practical guidance for SMEs in the retail e-commerce sector, with findings disseminated through academic and industry channels to reach scholars, practitioners, and policymakers (Bell et al., 2022).

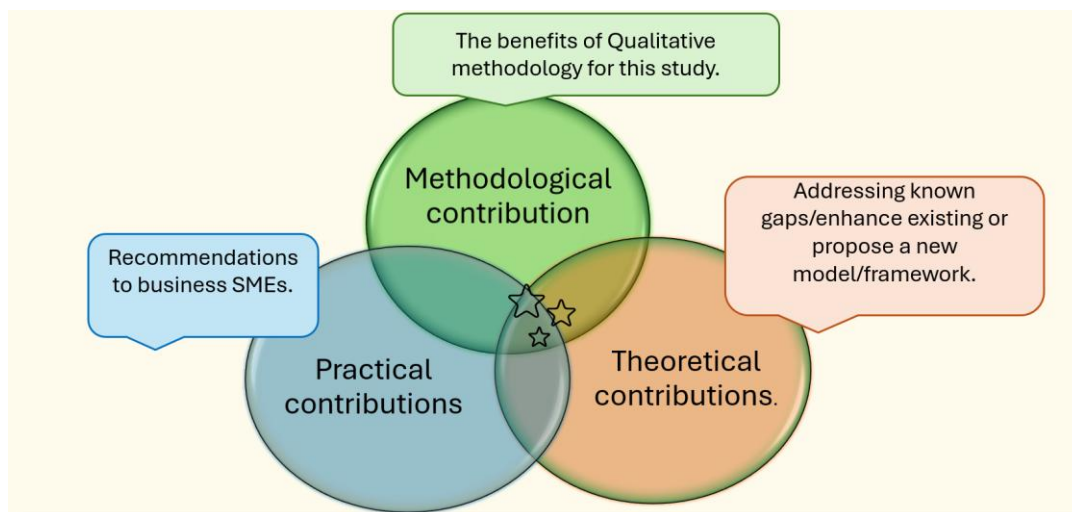


Figure 2 - Intended Contributions

References

Acs, Z. J., et al. (2021). "The evolution of the global digital platform economy: 1971–2021." *Small Business Economics* 57: 1629-1659.

Aguirre, V., et al. (2020). PWA and TWA: recent development trends. *Computer Science–CACIC 2019: 25th Argentine Congress of Computer Science, CACIC 2019, Río Cuarto, Argentina, October 14–18, 2019, Revised Selected Papers 25*, Springer.

Bell, E., et al. (2022). *Business research methods*, Oxford university press.

Biørn-Hansen, A., et al. (2017). Progressive web apps: The possible web-native unifier for mobile development. *International Conference on Web Information Systems and Technologies*, SciTePress.

Biørn-Hansen, A., et al. (2018). Progressive web apps for the unified development of mobile applications. *Web Information Systems and Technologies: 13th International Conference, WEBIST 2017, Porto, Portugal, April 25–27, 2017, Revised Selected Papers 13*, Springer.

Cannella, G. S. and Y. S. Lincoln (2011). "Ethics, research regulations, and critical social science." *The Sage handbook of qualitative research* 4: 81-90.

Easterby-Smith, M., et al. (2012). "The philosophy of management research." *Management research*: 55-77.

Goal 9 - Sustainable Development Goals (SDGs) URL - <https://sdgs.un.org/goals/goal9>, Accessed on 19/05/2025 @17:00

Goodman, L. A. (1961). "Snowball sampling." *The annals of mathematical statistics*: 148-170.

Goyal, S., et al. (2019). "Literature review of emerging trends and future directions of e-commerce in global business landscape." *World Review of Entrepreneurship, Management and Sustainable Development* 15(1-2): 226-255.

Griffith, C. (2017). *Mobile App Development with Ionic, Revised Edition: Cross-Platform Apps with Ionic, Angular, and Cordova*, " O'Reilly Media, Inc."

Guest, G., et al. (2006). "How many interviews are enough? An experiment with data saturation and variability." *Field methods* 18(1): 59-82.

Hancock, D. R., et al. (2021). "Doing case study research: A practical guide for beginning researchers."

Hume, D. (2017). *Progressive web apps*, Simon and Schuster.

Iphofen, R. and M. Tolich (2018). *The SAGE handbook of qualitative research ethics*. London, SAGE Publications Ltd.

Jackson, K., et al. (2019). *Qualitative data analysis with NVivo*, Sage.

Karapanos, E., et al. (2009). User experience over time: an initial framework. *Proceedings of the SIGCHI conference on human factors in computing systems*.

Lama, N. (2019). "Providing native experiences in mobile with PWA."

Lawrence, J. E. and U. A. Tar (2010). "Barriers to e-commerce in developing countries." *Information, society and justice journal* 3(1): 23-35.

London, T. and S. L. Hart (2004). "Reinventing strategies for emerging markets: beyond the transnational model." *Journal of international business studies* 35: 350-370.

Love, C. (2018). *Progressive Web Application Development by Example: Develop fast, reliable, and engaging user experiences for the web*, Packt Publishing Ltd.

Majchrzak, T. A., et al. (2018). "Progressive web apps: the definite approach to cross-platform development?".

Miles, M. B., et al. (2020). *Qualitative data analysis: a methods sourcebook*. Thousand Oaks, California, Sage.

Naderifar, M., et al. (2017). "Snowball sampling: A purposeful method of sampling in qualitative research." *Strides in development of medical education* 14(3).

Noy, C. (2008). "Sampling knowledge: The hermeneutics of snowball sampling in qualitative research." *International Journal of social research methodology* 11(4): 327-344.

Parker, C., et al. (2019). "Snowball sampling." *SAGE research methods foundations*.

Resnik, D. B. (2015). *What is ethics in research & why is it important*.

Rutter, R., et al. (2007). *Web accessibility: Web standards and regulatory compliance*, Apress.

Saunders, M. N. K., et al. (2023). *Research methods for business students*. Harlow, England, Pearson.

Sheppard, D. and D. Sheppard (2017). *Beginning progressive web app development*, Springer.

Taherdoost, H. (2022). "What are different research approaches? Comprehensive review of qualitative, quantitative, and mixed method research, their applications, types, and limitations." *Journal of Management Science & Engineering Research* 5(1): 53-63.

Tandel, S. and A. Jamadar (2018). "Impact of progressive web apps on web app development." International Journal of Innovative Research in Science, Engineering and Technology 7(9): 9439-9444.

The Ethics Guide 2015: Advice and Guidance - <https://charteredabs.org/publications/ethics-guide-2015-advice-guidance/> - Accessed on 19/05/2025 @17:30

Tolich, M., et al. (2020). Ethics of qualitative research. London, SAGE Publications Ltd.

Zulfa, M. I., et al. (2020). "Caching strategy for Web application—a systematic literature review." International Journal of Web Information Systems 16(5): 545-569.

Acs, Z. J., et al. (2021). "The evolution of the global digital platform economy: 1971–2021." Small Business Economics **57**: 1629-1659.

Aguirre, V., et al. (2020). PWA and TWA: recent development trends. Computer Science–CACIC 2019: 25th Argentine Congress of Computer Science, CACIC 2019, Río Cuarto, Argentina, October 14–18, 2019, Revised Selected Papers 25, Springer.

Bell, E., et al. (2022). Business research methods, Oxford university press.

Biørn-Hansen, A., et al. (2017). Progressive web apps: The possible web-native unifier for mobile development. International Conference on Web Information Systems and Technologies, SciTePress.

Biørn-Hansen, A., et al. (2018). Progressive web apps for the unified development of mobile applications. Web Information Systems and Technologies: 13th International Conference, WEBIST 2017, Porto, Portugal, April 25–27, 2017, Revised Selected Papers 13, Springer.

Cannella, G. S. and Y. S. Lincoln (2011). "Ethics, research regulations, and critical social science." The Sage handbook of qualitative research **4**: 81-90.

Easterby-Smith, M., et al. (2012). "The philosophy of management research." Management research: 55-77.

Goodman, L. A. (1961). "Snowball sampling." The annals of mathematical statistics: 148-170.

Goyal, S., et al. (2019). "Literature review of emerging trends and future directions of e-commerce in global business landscape." World Review of Entrepreneurship, Management and Sustainable Development **15**(1-2): 226-255.

Griffith, C. (2017). Mobile App Development with Ionic, Revised Edition: Cross-Platform Apps with Ionic, Angular, and Cordova, " O'Reilly Media, Inc."

Guest, G., et al. (2006). "How many interviews are enough? An experiment with data saturation and variability." Field methods **18**(1): 59-82.

Hancock, D. R., et al. (2021). "Doing case study research: A practical guide for beginning researchers."

Hume, D. (2017). Progressive web apps, Simon and Schuster.

Iphofen, R. and M. Tolich (2018). The SAGE handbook of qualitative research ethics. London, SAGE Publications Ltd.

This handbook is a much-needed and in-depth review of the distinctive set of ethical considerations which accompanies qualitative research. This is particularly crucial given the emergent, dynamic and interactional nature of most qualitative research, which too often allows little time for reflection on the important ethical responsibilities and obligations. Contributions from leading international researchers have been carefully organised into six key thematic sections: Part One: Thick Descriptions Of Qualitative Research Ethics Part Two: Qualitative Research Ethics By Technique Part Three: Ethics As Politics Part Four: Qualitative Research Ethics With Vulnerable Groups Part Five: Relational Research Ethics Part Six: Researching Digitally This Handbook is a one-stop resource on qualitative research ethics across the social sciences that draws on the lessons learned and the successful methods for surmounting problems - the tried and true, and the new.

Jackson, K., et al. (2019). Qualitative data analysis with NVivo, Sage.

Karapanos, E., et al. (2009). User experience over time: an initial framework. Proceedings of the SIGCHI conference on human factors in computing systems.

Lama, N. (2019). "Providing native experiences in mobile with PWA."

Lawrence, J. E. and U. A. Tar (2010). "Barriers to e-commerce in developing countries." Information, society and justice journal **3**(1): 23-35.

London, T. and S. L. Hart (2004). "Reinventing strategies for emerging markets: beyond the transnational model." Journal of international business studies **35**: 350-370.

Love, C. (2018). Progressive Web Application Development by Example: Develop fast, reliable, and engaging user experiences for the web, Packt Publishing Ltd.

Majchrzak, T. A., et al. (2018). "Progressive web apps: the definite approach to cross-platform development?"

Miles, M. B., et al. (2020). Qualitative data analysis : a methods sourcebook. Thousand Oaks, California, Sage.

Naderifar, M., et al. (2017). "Snowball sampling: A purposeful method of sampling in qualitative research." Strides in development of medical education **14**(3).

Noy, C. (2008). "Sampling knowledge: The hermeneutics of snowball sampling in qualitative research." International Journal of social research methodology **11**(4): 327-344.

Parker, C., et al. (2019). "Snowball sampling." SAGE research methods foundations.

Resnik, D. B. (2015). What is ethics in research & why is it important.

Rutter, R., et al. (2007). Web accessibility: Web standards and regulatory compliance, Apress.

Saunders, M. N. K., et al. (2023). Research methods for business students. Harlow, England, Pearson.

Sheppard, D. and D. Sheppard (2017). Beginning progressive web app development, Springer.

Taherdoost, H. (2022). "What are different research approaches? Comprehensive review of qualitative, quantitative, and mixed method research, their applications, types, and limitations." Journal of Management Science & Engineering Research **5**(1): 53-63.

Tandel, S. and A. Jamadar (2018). "Impact of progressive web apps on web app development." International Journal of Innovative Research in Science, Engineering and Technology **7**(9): 9439-9444.

Tolich, M., et al. (2020). Ethics of qualitative research. London, SAGE Publications Ltd.

Qualitative research ethics are more complex than biomedical research ethics. Qualitative research's starting point is not found in implied informed consent and ethical assurances that limit a researcher/subject relationship to the few moments beyond completing a survey. Quite the opposite: when subjects agree to participate in a qualitative research project, either by signing a consent form or by consenting orally, they establish a convoluted set of ethical assurances that are not fleeting. By signing a consent form to take part in a qualitative research project, the subject accepts a set of ethical assurances offered by the researcher that are enduring; these assurances are diverse and technique-specific, each with their own variant of ethical issues. Two of the most common techniques qualitative researchers use are one-to-one unstructured interviews and focus groups. Both techniques ask open-ended questions and often collect data via audio recording, yet their ethical practice is dissimilar. Whereas one-on-one interviews can offer strong ethical assurances since the interviewee has

opportunities to withdraw remarks during the interview, focus group participants' opinions are made in public and cannot be unsaid. Qualitative research's unique emergent research design and diversity of practice (e.g., photovoice, autoethnography, narrative) are so individualised they prove problematic for how institutional review boards appraise them, evaluating only the procedural ethical considerations of a project, not its emergent ethics in practice. The immersive nature of their research requires emotional, political and personal responsiveness often expressed by the exhortation to "reflexivity."

Zulfa, M. I., et al. (2020). "Caching strategy for Web application—a systematic literature review." International Journal of Web Information Systems **16**(5): 545-569.