IMPACTS OF MOBILE COMPUTING ON CONSTRUCTION MANAGEMENT: A COMPREHENSIVE EXPLORATION

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ABSRACT: Two decades ago, technologies that promoted information management and communication in the architecture, engineering, and construction (AEC) industry started receiving significant attention and improvement. Evidence for the impact of this improved management system was seen in the transformed design approach, coordination among the stakeholders, redefined construction cost, and timely project delivery by using building information modeling (BIM), cloud computing, and robotics, among others, as compared to the traditional method of design and construction. Recently, there has been high interest in the adoption of mobile computing in the construction industry. Although there is abundant empirical literature on mobile computing adoption in construction, a critical research gap exists regarding the current trend and impact of this state-of-the-art technology in the construction phase. This study addresses this gap by investigating how mobile computing, as part of information and communication technologies (ICTs), is revolutionizing construction site management by drawing insights from published empirical studies and conducting bibliometric analyses from 2005 to 2023. We found that there have been various attempts to develop models and road maps to select the right mobile app for construction management. The major focus was on the use of mobile computing for construction worker safety, material monitoring, and quality control. This study adds valuable insights to the understanding of the evolving dynamics between mobile computing and construction management and proposes an improved framework for mobile application selection in the construction industry. These findings provide broader insight into the evolutionary trends of mobile computing in the construction industry. In addition, the findings will inform researchers, academia, and developers of the latest updates on mobile computing capacity for the AEC industry and the importance of adopting mobile computing in construction management.

KEYWORDS: construction sites, information management, ICT, mobile application, project management.

1. INTRODUCTION

Successful construction site management relies on the timely acquisition of high-quality information and seamless communication among stakeholders, forming the foundation for informed decision-making. The construction industry has witnessed a transformative shift through the integration of information and communication technologies (ICTs), redefining the coordination and oversight of construction site activities (Chen and Kamara 2008, 8). Notably, there is increasing emphasis on the adoption of mobile computing in this dynamic industry (Kim et al. 2017, 24). Mobile computing comprises three major components: mobile devices (smartphones, tablets, laptops, and wearables), mobile networks (3G, 4G, 5G, Wi-Fi, and Bluetooth), and mobile applications (software applications specifically designed for mobile devices). The collaboration between mobile computing and construction environments is not merely an evolution but a revolution, reshaping traditional processes and providing a platform that elevates work quality, efficiency, communication, collaboration, and overall project success (Ramokgopa et al. 2023; Hannan Qureshi et al. 2023; Toyin et al. 2024). However, to fully harness the transformative power of mobile computing and unlock its benefits in terms of productivity, better-quality outcomes, cost savings, safety, and real-time decision-making, there is a pressing need for comprehensive research that explores its impacts within the construction industry (Giat and Mitelman 2023; Abdeen et al. 2022). Moreover, transformative impacts extend beyond project schedule tracking and influence the overall competitiveness and sustainability of construction firms in today's rapidly evolving market.

As noted by Rankin, Christie, and Kondratova (2005, 1) mobile computing devices facilitate real-time communication of project information within repositories or among project participants. Despite the abundance of empirical publications on mobile computing adoption in construction, there is a notable gap in the literature concerning the current trend and possible impact of these technologies. This study aims to address this gap by investigating the impact of mobile computing on construction sites. It examines how these technological advancements operate within the broader ICT framework that is currently revolutionizing and reshaping established construction management practices. The main objective of this study is to provide a comprehensive analysis of the intricate impact of mobile computing on construction sites. By exploring the transformative potential within the construction industry, this study aims to shed light on how mobile computing influences and redefines contemporary construction-management practices.

2. METHODOLOGY

This study utilized the multistep methodological approach to systematically organize and enhance the credibility and reliability of the findings. The process encompasses sequential steps, including data collection, selection/screening, and analysis, adhering to established procedures and principles for systematic review execution (Toyin and Mewomo 2023, 501). Figure 1 provides a detailed overview of article selection and study stages.

2.1. PUBLICATION TREND

Figure 2 presents the publication trends of the 111 articles retained for the bibliometric analysis and review. The publication in 2005–2010 investigated a wireless solution for mobile collaboration on construction sites, mobile technology applications, and mobile multimodal solutions for a project closeout. While recent studies have focused on using chatbots to report daily construction work using mobile messengers, mobile apps have been used for the management and control of construction site safety and integrated with building information modelling (BIM) to enhance smart safety monitoring.

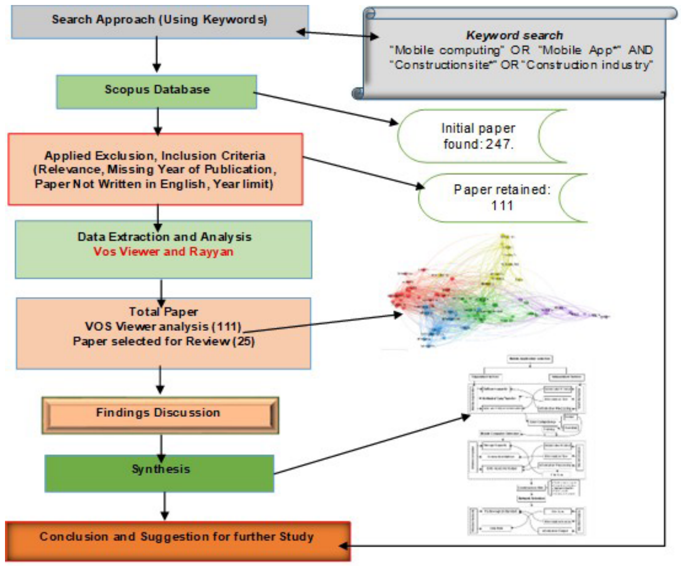

Figure 1: Schematic of the study methodology. Source: Author 2023.

Figure 2: Publication trend. Source: Author 2023.

3. BIBLIOMETRIC

Bibliometric analysis is a crucial research method that visually illustrates the trends, relationships, and interconnections among published articles through mapping. Its goal is to depict the structure of a research area by categorizing it into clusters and analyzing the data based on the credibility of the documents, contribution of journals, authors, country institutions, and keywords trends (Toyin and Mewomo 2023, 505). This analysis complements the quantitative aspects of this study and qualitative aspects of the literature review. It seeks to reveal the logical connections within a dynamic scientific knowledge system. This study presents three analyses: co-occurrence keyword, co-citation of an author, and the top contributing country.

3.1. TOP CITED COUNTRIES AND PUBLICATIONS

In this section, we break down citations and publications from the top-rated countries, as identified in the 111 bibliometric documents used for network analysis. The assessment of citations and publications per country is crucial, as it reveals the countries with the highest research interest. Of the 46 countries involved, 15 met the inclusion criteria (at least one document and a minimum of 30 citations). Figure 3 displays the citations, highlighting China as the top contributor with 16 documents, followed by the United States with 10 documents, and the United Kingdom, South Korea, and India, each with eight documents. This suggests that China is the most cited and contributing country in this study, followed by the United States. By contrast, countries such as Russia, Germany, and Singapore have fewer citations and documents. Thus, the increasing global adoption of mobile apps in the construction industry has signified growing acceptance of this technology.

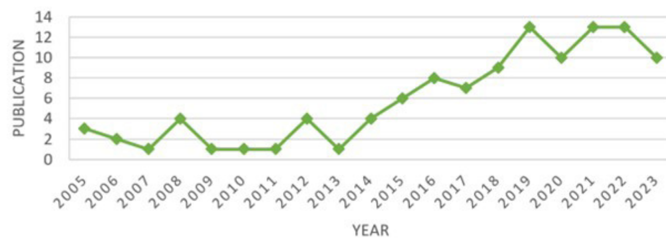

Figure 3: Top-cited countries. Source: Author 2023.

3.2. CO-OCCURRENCE KEYWORDS

The analysis used VOSviewer software to identify 1,092 keywords based on co-occurrence, applying an inclusion criterion of a minimum of three occurrences. Of these, 91 keywords met this threshold, forming a network structure, as shown in Figure 4. The figure reveals five distinct clusters, denoted by distinct colors that represent themes: human integration, project management, construction site management, information management, and safety control. These clusters contained 23, 21, 16, 16, and 15 keywords, respectively. Notably, “construction industry” is the most frequent (61 occurrences, total link strength 415), followed by “mobile applications” and “mobile computing” (43 and 23 occurrences, total link strength 266 and 169, respectively).

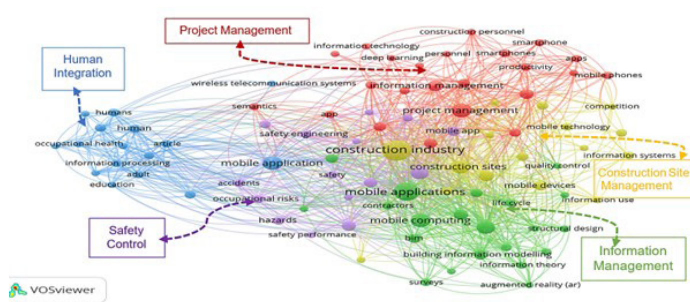

Figure 4: Co-occurrence keyword mapping. Source: Author 2023.

3.3 CO-CITATION OF AUTHOR

An author co-citation analysis was conducted to examine the development of research communities by identifying the connections between authors cited in the same articles (Toyin et al. 2024). Figure 5 illustrates the author’s co-citation network, featuring 1,538 links and a total link strength of 5514. Initially, 4,824 authors were identified in the 111 recovered documents, with inclusion criteria set at a minimum of six citations for an author. Subsequently, 80 authors were retained, and their total link strength ranged from 39 to 501.

The links signify connections between co-cited authors in one or more documents without implying indirect, cooperative relationships. The co-citation analysis resulted in grouping the authors into five clusters separated by distinct colors, as shown in Figure 5: green (cluster 1:19 authors), blue (cluster 2:15 authors), red (cluster 3:24 authors), yellow (cluster 4:12 authors), and purple (cluster 5:10 authors). Notably, Wang X. in Cluster 1 had the highest number of citations, with 501 total link strength (TLS), followed by Chen Y. in Cluster 2 with 26 citations and 375 TLS, Bowden S. in Cluster 3 with 16 citations and 236 TLS, Teizer J. in Cluster 4 with 17 citations and 260 TLS, and Wang Y. in Cluster 5 with 13 citations and 154 TLS.

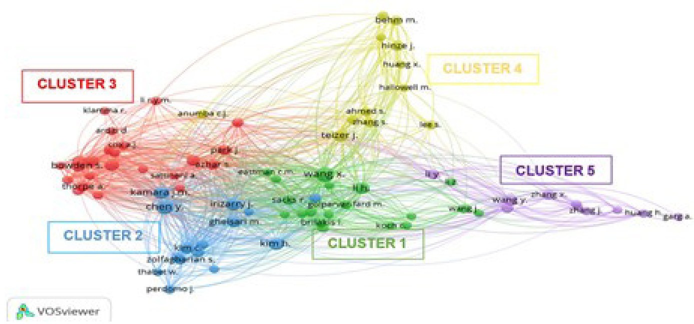

Figure 5: Author co-citations. Source: Author 2023.

4. REVIEW

This section presents a systematic overview of the published articles in this domain. As shown in Figure 1, 25 related articles were included in this review. The findings from these articles are provided in the following subsections, and a conceptual model was developed based on the study findings.

4.1. MOBILE COMPUTING FOR ON-SITE INFORMATION MANAGEMENT IN CONSTRUCTION PROJECTS

This section explores the critical factors, strategic models, and usability elements shaping the design, implementation, and usability of mobile device applications in construction settings for enhancing project productivity, transparency, and efficiency. Chen and Kamara (2008, 5) investigate how mobile computing technology can enhance on-site information management in construction projects. They identify six factors, categorizing them into "dependent factors" (mobile computer, wireless network, and mobile application) and "independent factors" (users, construction information, and construction site). The study develops a model that explores the interrelationships among these factors, influencing the design, implementation, and maintenance of mobile computing systems for on-site information management. The strategic model involves designing specific software, selecting suitable mobile computers, and establishing wireless networks. The selection of mobile applications aims to support user activities on construction sites, such as viewing drawings, editing files, making notes, and capturing images or videos. Jailani et al. (2015) proposes a set of usability elements and guidelines for developing mobile applications for the construction industry, based on ISO standards and literature review of existing models and guidelines. The authors conducted gap analysis interviews with two experts in mobile device application development to identify 13 usability elements that are suitable and relevant for the construction industry, such as effectiveness, efficiency, satisfaction, learnability, presentation, navigation, and data sourcing map.

Kim et al. (2017) explores mobile research and app development trends in construction, creating a versatile app for Android and iOS. Their app facilitates viewing of construction data, capturing and reporting photos, conducting inspections via mobile devices, and enhancing project productivity and transparency. Zhan et al. (2019) designed a mobile-based platform for construction site management in the power industry to improve quality and efficiency. Nourbakhsh et al. (2012) investigated mobile app information needs in construction, identifying key on-site objectives. They developed a user-friendly prototype that was aligned with user requirements, as confirmed by positive usability test results.

4.2. MOBILE APPS FOR SPECIFIED CONSTRUCTION PURPOSE

This section delves into the scope of mobile applications tailored for specific construction purposes, highlighting innovative solutions designed to address industry-specific challenges and enhance project efficiency. By facilitating equipment location and safety compliance to streamline material procurement and logistics tracking, these mobile apps offer targeted functionalities to meet the evolving needs of construction professionals. Irizarry and Gill (2009, 7–9) explore the design and development of two construction-focused mobile apps on the iOS platform for iPhones. The applications, *Construction Equipment Finder* and *Be Safe*, serve to locate heavy equipment rental sources and provide safety-related information, respectively. Irizarry and GIll note that the iPhone's processing power, screen size, and image management experiences, coupled with the core animation framework, support graphic project information use, including CAD drawings and BIM models. Alshuwaikh et al. (2020) developed a mobile app called SARAY to improve the procurement process of construction materials in Bahrain by reducing cost and time and enhancing communication between clients and suppliers. Vilkko, Kallonen, and Ikonen (2008, 2–5) introduce a mobile solution for electronic data collection and information exchange at construction sites with a focus on precast concrete monitoring using mobile smartphones. The authors found that the smartphone application facilitated the on-site collection and access of precast concrete element data, including state information, measurements, location, and fault reports. This electronic data collection ensures the accuracy and real-time accessibility of the project partners.

Gupta, Priya, and Ramani (2022) developed an Android app prototype for tracking construction logistics, specifically focusing on the delivery of precast elements in India. The authors developed it using Java, Android Studio Development Kit, and Firebase database. They found that the app facilitated order placement, real-time location tracking, map navigation, and delivery status updates. Through testing on emulators and real devices, the authors found the app to be well-designed, user-friendly, and aligned with the needs of the construction industry. Validation occurred in a real-world scenario with a precast hostel building project in India, demonstrating the effectiveness of the app in monitoring consignment movements, ensuring timely and quality delivery, and addressing transportation issues in the supply chain. In a recent study by Cho et al. (2023), a chatbot-based system was introduced to enhance construction daily work reports (DWR) using a mobile messenger. This innovative system enables general contractors to gather and organize data efficiently from subcontractors through interactive chatbot interactions and a companion app. It offers two user-friendly data input methods, text messaging and form-filling, and automatically organizes and stores the DWR data in a database. The system underwent successful testing at three construction sites, demonstrating substantial improvements in productivity, functionality, and usability compared to traditional methods.

4.3. MOBILE INFORMATION SYSTEM FOR CONSTRUCTION WORKERS

This section investigates the mobile information systems tailored to construction workers, exploring innovative frameworks, applications, and approaches designed to address the unique challenges faced by the industry. X. Chen (2013) introduced a framework leveraging web services and agent technologies to address information management and communication challenges faced by construction workers operating in diverse locations and utilizing numerous wireless devices. The framework was designed to meet the specific needs of construction sites, including real-time data access, information sharing, security, and customization. The author outlines the system architecture comprising four layers: presentation, mobile communication, mobile business platform, and foundation business. Ferrada et al. (2014) designed and developed a mobile application for storing previous and present lessons learned in construction projects. The authors propose a system that allows users to create, approve, evaluate, and search for lessons on their smartphones and web browsers using a cloud computing platform.

Azhar, Jackson, and Sattineni (2015, 5–8) investigated mobile apps available for design, construction, and facility management professionals. The authors found that Apple's iOS was the most popular platform, quality control was the most useful function, and most apps used were not construction specific. They ranked the top ten construction apps based on app store ratings and perceived usefulness scores from interviews. It was found that Tradie's App, a general-purpose field documentation and information access app, was the highest rated app for construction managers. Li et al. (2018, 8) examined how construction experts view knowledge-sharing behavior from two perspectives: through the lens of new institutional economics, considering informal institutions, and from psychological perspectives, such as Homan's proposition. This study focused on the challenges and opportunities of utilizing Web 2.0, mobile apps, and the Internet of Things (IoT) for sharing safety knowledge among construction workers and teams. The authors investigated how psychological and institutional factors influence practitioners' willingness to engage in knowledge sharing. This study reveals that the recent rise of mobile apps, Web 2.0, and IoT offers a fresh approach to asynchronous safety knowledge sharing among workers from different teams and levels.

4.4. MOBILE APPLICATION FOR CONSTRUCTION MANAGEMENT

This section explores the application of mobile apps for construction management, highlighting the findings of various studies on the benefits, challenges, and adoption trends within the construction industry. Barbarosoglu et al. (2016) explored the potential benefits of smartphone applications for construction-related tasks, such as project management, defect management, and equipment management. The findings highlight that the use of mobile applications enhances efficiency, productivity, communication, and information accuracy in the realms of construction, defect/damage, and equipment management. Liu, Mbachu, and Mathrani (2017) explored the varieties, uses, and perceived advantages of smartphone applications in the New Zealand construction industry. The study revealed that iPhone and Android devices were the most used, with site photos, health and safety reporting, and timekeeping ranking as the top three application areas. The respondents widely acknowledged the benefits of app usage, with "better client relationship management and satisfaction," demonstrating the strongest correlation and predictive impact on overall productivity improvement. Liu, Mathrani, and Mbachu (2019) explored the benefits and barriers of mobile app utilization in the New Zealand construction sector, focusing on perspectives from both top and middle managers. The findings reveal that both managerial levels express a positive outlook on app usage but exhibit slight differences in their preferences. Top managers prioritize apps that enhance client relationship management, whereas middle managers emphasize improving site inspection and reporting. Both groups concur on the beneficial aspects of apps for checklist management, documentation, signoffs, and time sheets. The primary obstacles identified include the industry's general reluctance to change, limited time for learning, and the expenses associated with apps and devices.

Liu et al. (2017, 8) examined smartphone preferences, challenges, and commonly used apps among construction workers in New Zealand. They discovered that 70% of construction workers used iPhones with the iOS operating system, whereas 28% used Android-based smartphones. This study identified key barriers to app adoption in New Zealand, including software and licensing costs, inflexibility in user interfaces, and the expense of training. The most widely used application was PlanGrid, a cloud-based project collaboration and management system, followed by JobFlex, Procore, and SmartBidNet. Liu, Mbachu, and Mathrani (2017) investigated the adoption of construction-related apps in small and medium enterprises within the New Zealand construction industry. The study reveals that construction workers primarily use an iPhone's iOS and Android operating systems, with document control and record keeping being the most common areas of app usage. Construction managers identified potential benefits, such as improving customer invoicing, workforce productivity, work order tracking, compliance reporting, and site inspection. Notably, top management prioritizes strategic aspects, such as client satisfaction and relationships, while middle management focuses on tactical and operational aspects, such as project-level productivity improvement. Ahirrao (2018) addresses the challenges in hazard reporting at construction sites, including low participation, inconsistency, delays, and limited accessibility. They proposed a solution using a mobile app, I-Report, which facilitates real-time, user-friendly, and paperless reporting by all stakeholders. The app demonstrated tangible and intangible benefits, including heightened hazard identification, improved reporting quality, enhanced responsibility, easy trend analysis, waste reduction, continuous safety process improvement, and a proactive safety approach.

4.5. MOBILE APPLICATION FOR QUALITY CONTROL AND REAL-TIME SAFETY MONITORING

This section explores the role of mobile applications in quality control and real-time safety monitoring in the construction industry. Kruachottikul et al. (2021) investigated how mobile applications can be used for quality control in the Thailand construction industry. The authors designed and developed an application using React Native, Expo, and AWS Amplify as the main technologies and implemented various features, such as real-time multimedia messaging, document updates, progress tracking, notification systems, and email services. Abdeen et al. (2022) explored the usability of a novel mobile augmented reality (MAR) app called Excavator Augmented Reality (EAR) for the excavation process in construction. The authors found that EAR could enhance productivity, safety, and training processes, but requires improvement in auditory and visual aspects, emergency and safety features, site complexity, and environmental changes. A SWOT and PESTEL analysis revealed the strengths, weaknesses, opportunities, threats, and challenges of EAR adoption. Ramokgopa et al. (2023) examined the usage and impact of mobile digital technologies, such as text messaging apps, cost monitoring software, and BIM, on the performance and productivity of construction projects in South Africa. The authors found that there was minimal awareness and usage of these technologies on construction sites, suggesting that the industry should leverage their benefits and invest in digital technology for construction management.

Forteza et al. (2023) introduced RisGES, a novel mobile application built upon the CONSRAT tool and an empirical model incorporating risk and organizational variables. This app was designed to evaluate on-site risk and organizational structure, offering precise criteria for interventions to enhance work quality and safety. The authors detailed the theoretical and empirical basis of RisGES, encompassing the CONSRAT instrument, the SEM model for risk and organizational variables, and the app's development and validation process. Through testing at three construction sites, the system demonstrated substantial enhancements in productivity, functionality, and usability compared with

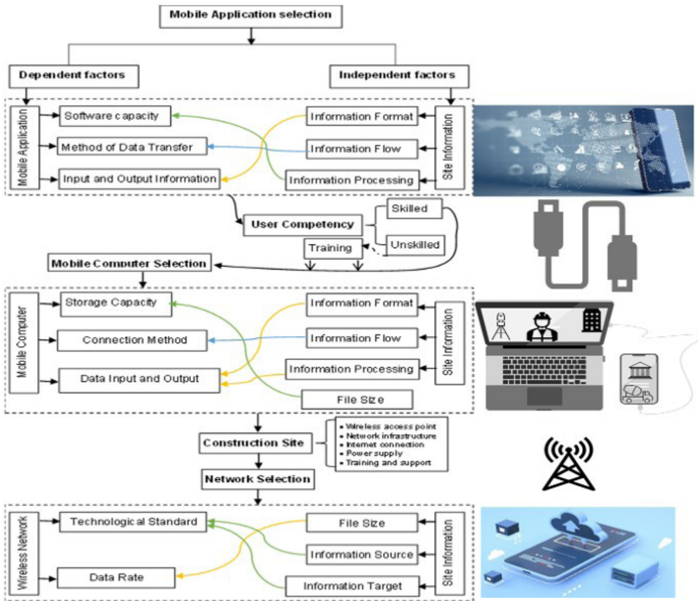

Figure 6: Proposed framework for mobile application selection. Source: Author 2023.

traditional methods. In a recent study, Hossain et al. (2023, 15–20) proposed a real-time safety-monitoring framework for construction sites. They introduced a cloud-BIM-based system utilizing an automated safety tracking mobile app. The authors designed an Android app for GPS (Global Positioning System) data collection and a cloud-based web application for visualization and alerts. The system effectively identifies hazardous locations, visually tracks workers on a virtual construction site, and notifies workers and managers of potential risks through SMS. Testing of a construction site in Bangladesh demonstrated the feasibility and suitability of the system for various indoor construction environments.

4.6. PROPOSED FRAMEWORK GUIDE FOR MOBILE APPLICATION SELECTION

The development and selection of mobile applications plays a pivotal role in enhancing various aspects of technological solutions, including productivity, quality control, and real-time monitoring, among others. The proposed framework guide for mobile application selection in this study (Fig. 6) represents a strategic approach to navigating the diverse landscape of available applications, particularly in the context of information flow management and on-site monitoring of construction sites. One notable aspect of the framework is its emphasis on information management at construction sites, which aligns with the contemporary trends in construction technology. This approach fosters a more connected and responsive system for improved collaboration, productivity, and the elimination of delays.

5. CONCLUSION

This study illustrates the transformative impact of mobile computing on construction practices. Strategic models for specialized applications and innovations in risk management. Usability guidelines for construction apps, trends in mobile research, and the development of specialized mobile applications address industry-specific challenges. Innovations in quality control, real-time safety monitoring, and risk assessment have emphasized the transformative impact of mobile technologies. Mobile technologies are reshaping onsite construction management. As the industry embraces digital advancements, the potential for continued improvements and innovations remains promising, marking a dynamic shift toward enhanced efficiency, safety, and quality in construction projects. This study proposed a guide framework for the selection of mobile applications in the construction industry, as shown in Figure 6. Therefore, this study contributes to the understanding of the evolving landscape of mobile computing, thereby paving the way for improved efficiency, safety, and quality of construction projects. These findings provide valuable insights for researchers, practitioners, and industry stakeholders in navigating the dynamic intersection of construction and mobile technology.

5.1. RECOMMENDATIONS FOR FUTURE RESEARCH

- Based on the findings of this study, researchers should collaborate with AEC experts to:
- Investigate synergies between mobile computing and emerging technologies, such as augmented reality (AR) and artificial intelligence (AI), to enhance on-site visualization, decision-making, and task automation.
- Explore advanced user-centric design principles for construction applications considering the unique needs of diverse stakeholders. Emphasize intuitive interfaces, voice interactions, and accessibility features to improve usability at construction sites.
- Develop robust security protocols for mobile construction applications, focusing on safeguarding sensitive project information, ensuring secure communication channels, and protecting against cyberthreats.
- Develop collaborative mobile platforms that enable seamless communication and information exchange among various construction project stakeholders, foster teamwork, and reduce communication gaps.
- Explore the human factors influencing the adoption of mobile technologies in construction, considering factors such as training needs, resistance to change, and the impact on job roles to facilitate smoother integration into existing workflows.

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