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Evaluating Software Ecosystems in Large-Scale Commercial Construction Projects and Implications for Construction Management Education

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This paper examines the software ecosystems used by construction field personnel for daily tasks, with a focus on perspectives from both subcontractors and general contractors on large-scale commercial construction projects. The study analyzed current software ecosystems, associated hardware, and firm interconnections, collecting data from one case study of a large-scale construction project in Nashville, Tennessee. Through a survey questionnaire, insights were gathered on the essential software functionalities for on-site tasks, stakeholder communication, and current training formats. The study involved 23 participants who collectively provided 109 responses, representing an average of 6 years of experience in diverse job-site roles. The findings reveal that ProCore® is the predominant software used to enhance communication and coordination between general contractors and subcontractors. Tablets emerged as the most popular on-site hardware, reflecting a shift toward mobile, flexible digital solutions. However, the study also uncovered a significant reliance on informal training methods, such as on-the-job training, highlighting a gap in structured training opportunities. The paper offers actionable recommendations for construction management curricula to address this gap.

Keywords: Construction Field Software Ecosystems; Digital Transformation; Software Interoperability; Construction Education; Construction 4.0

Introduction

The construction industry's digital transformation is being driven by the Fourth Industrial Revolution, often referred to as Construction 4.0. This shift has brought the integration of diverse software ecosystems that enhance project management, efficiency, and team collaboration. As this technology continues to emerge, software providers are developing new tools, functionalities, and features to meet the industry's evolving demands. However, challenges have arisen around the selection and implementation of software systems—whether used on-site or off-site—raising concerns among professionals about optimal choices for specific tasks, including collaboration, data storage, and data sharing (Ahmad & Azhar, 2023). These issues also impact academia, where future professionals are trained on various software tools to prepare them for leading projects in a digitally transformed construction landscape.

However, the industry faces challenges in adopting these technologies, including social and technical factors (Alaloul et al., 2020). Management and strategic issues also play a crucial role in Construction 4.0 implementation beyond just technological aspects (Nagy et al., 2021). The adoption of Industry 4.0 in construction requires consideration of both technological and human-related factors, emphasizing data-driven approaches, privacy, ethics, and integration (Soltani et al., 2023). While academia shows higher familiarity with C4 concepts, there is a lack of collaboration between academia and industry in this domain (Ahmad & Azhar, 2023).

This study investigates the current on-site utilization of the software ecosystem options of large-scale construction projects by field personnel from the general contractor and subcontractors' perspectives. Using a mixed-methods approach, combining qualitative and quantitative data collection and analysis, the research aims to understand and describe these software options. The findings aim to offer insights and recommendations for refining construction management curricula, enhancing education to better align with industry needs.

Literature Review

The construction industry has increasingly embraced software solutions to boost efficiency and productivity across various stages of project delivery. Programs such as Procore, Bluebeam, and ASTA Powerproject cater to distinct functions, including project management, document markup, and scheduling, thereby streamlining workflows and improving communication in construction management (Bien, 2017). Among these advancements, Building Information Modeling (BIM) has emerged as a critical tool, offering significant advantages such as enhanced collaboration, risk reduction, and data-driven decision-making throughout a project's lifecycle. Despite these benefits, BIM adoption faces persistent challenges, including data interoperability issues and a shortage of skilled professionals, largely due to limited access to comprehensive training opportunities (Alathamneh et al., 2024).

Recent research highlights the need for construction management education to align with industry practices, particularly in software utilization. A survey revealed that On-Screen Takeoff, Bluebeam, and Microsoft Excel are commonly used for estimating tasks, while smartphones are preferred over tablets for most field observations (Collins & Redden, 2022; Palmquist, 2017). Advanced field data capture technologies, such as laser scanners and drones, further enhance accuracy and reliability compared to manual methods, underscoring the importance of training students in these technologies (Yucel et al., 2024).

Current trends also reflect a paradigm shift in the adoption of construction software ecosystems. Cloud-based solutions have gained prominence for their scalability, real-time collaboration capabilities, and remote accessibility, significantly enhancing productivity and decision-making for distributed project teams (Vaidyanathan et al., 2020). Concurrently, artificial intelligence (AI) and machine learning (ML) are being integrated into construction workflows, leveraging large datasets to identify patterns, forecast project outcomes, and optimize resource allocation. These innovations hold immense potential to transform project planning, scheduling, and risk management practices (Pan & Zhang, 2023).

To date, research has largely focused on software utilization in general or within specific areas of the preconstruction management phase. However, no studies have specifically examined software use among on-site field crews, including the unique functionalities utilized by general contractors and their subcontractors. This gap highlights the need for a focused study on software applications at construction job sites to better understand the most commonly used features and tools. Additionally, there's a need

to highlight how the on-site practices could be reflected in construction education curricula aiming to enhance graduate competencies, equipping new professionals with the practical skills needed for on-site roles.

Research Methodology

The aim of this research was to investigate the current on-site utilization of the software ecosystem options of large-scale construction projects by field personnel from the general contractor and subcontractors' perspectives. This research employs a mixed-methods approach, combining qualitative and quantitative data collection and analysis. The primary objective is to understand and describe these software options, offering insights and recommendations for refining the curriculum to enhance education within construction management programs.

Research questions:

- (1) What are the most commonly used software tools on the job site by field personnel?
- (2) What functionalities of each software are utilized, and for which specific scopes of work?
- (3) What training resources are available for each software, and what formats of training are field personnel receiving for each software and its functionalities?

Data Collection

The target population for this study was the field staff of a large-scale construction project: a 17-story, 470,000-square-foot healthcare tower in downtown Nashville, TN. Participants were recruited through convenience sampling, utilizing the author's industry contacts and partnerships. Informed by findings from the literature review, a survey questionnaire was developed to gather detailed information on the software ecosystems currently used in construction projects. The survey was administered in person during group meetings using a paper-based format.

The survey questionnaire was structured in two parts to comprehensively assess participants' demographics, software usage patterns, and experiences. The first part, completed once by each participant, gathered demographic information, including (1) Employer name. (2) Current job or position title. (3) Years of experience in the current position. (4) Scope of work on the current project. (5) Average number of different software tools used daily. (5) Self-assessed proficiency in overall software options. In the second survey section, participants completed a separate response form for each software application they used, linking these responses to demographic data from the first part to create a dependent data structure for comprehensive analysis. For each software, participants provided responses to six quantitative questions aimed at enabling potential correlation analysis between software usage and demographic variables, along with two open-ended questions for gathering qualitative insights. The questions covered software name, frequency of use (e.g., daily, weekly), duration of use (in years), type of device (mobile, tablet, laptop, desktop), company mandate for software use (e.g., every project), and satisfaction with the software's performance on a Likert scale from 1 to 5. Additional inquiries addressed the primary use of the software and the availability and format of training resources.

Data Cleaning and Categorization

The data cleaning and categorization process began with coding and initial recording of each response in its original form on a spreadsheet. This was followed by correcting common typographical errors and abbreviations to ensure consistency across responses. To maintain uniformity, key terminology was standardized in specific areas: position titles were unified across responses, work scope entries (such as Fire Protection, MEP, and Plumbing) were categorized under standard labels, and varying expressions

in training descriptions (e.g., "Self-Taught," "None," "0," and "Easy") were consolidated into consistent labels like "Self-Taught," "No Training," and "Brief Training." Additionally, irrelevant data were removed based on predetermined criteria. Duplicate entries were verified as absent from the dataset, and inclusion criteria focused on completion rates; responses with 100% completion were included, while responses with at least 87.5% completion (7 out of 8 answers) were accepted in specific cases. Further categorization included grouping responses by training format, such as "College/University" or "YouTube/Online Videos." Lastly, responses were organized through thematic coding based on core functionalities, like safety observations, document management, and scheduling, which facilitated the development of thematic categories and sub-categories for more comprehensive analysis. This structured approach allowed for greater clarity in the dataset.

Data Analysis Methods

The analysis began with a demographic and sample assessment to understand the composition of the respondents. Frequency analysis was conducted to gauge the prevalence of various responses, examining areas such as scope of work per respondent, frequency of software use, devices employed by field personnel, availability and format of training resources, and satisfaction rates with each software. Thematic analysis was performed to categorize software functionalities and detect trends in usage. Additionally, it identifies relationships between software usage and other variables, including software use by trade, functionalities, and position titles associated with software use, highlighting best practices and areas for potential improvement within current software systems.

Results

Participants Demographics

The authors collected 23 responses from the field case study at the interior finishes and envelop stage, reporting 115 software options. Two entries were removed due to missing demographic linkage data, and four additional responses were excluded for not meeting the 87.5% completeness threshold, as per the study's inclusion criteria. Following these adjustments, the final data set consisted of 109 valid responses from 23 participants. On average, participants had six years of experience in their current roles and provided roughly five responses each. The study included participants from 10 companies—one general contractor with 15 participants and nine subcontractors with 11 participants—offering a comprehensive view of software usage across various organizational contexts in the construction industry (see Table 1).

Table 1. Participants Demographics

Aspect	Detail
Total number of participants	23 participants from field case study
Total Software Options Reported	115 software options reported
Exclusions	2 software sheets were removed (missing demographic linkage data); 4 responses were excluded (did not meet the 87.5% completeness threshold)
Final Dataset	109 responses from 23 participants meeting the inclusion criteria
Average Experience	6 years in current positions
Average Responses per Participant	Approximately 5 responses
Companies Represented	10 companies: 1 general contractor (15 participants) and 9 subcontractors (11 participants)

Participants held various roles, predominantly in positions related to project management, supervision, and specialized trade management, reflecting a diverse range of expertise. Roles included Project Engineer, Superintendent, Foreman, Safety Manager, Construction Coordinator, and Assistant Superintendent. Participants also represented a broad scope of work within the construction field, covering General Contracting (GC), Mechanical, Electrical, and Plumbing (MEP), framing, finishes, masonry, safety, and other key areas such as fire protection, curtain wall installation, and waterproofing. This diversity in roles and responsibilities provides a comprehensive view of software usage practices across different specialties and experience levels on construction sites.

Scope of work of each response

The data in (Figure 1) represents the scope of work areas selected by survey participants, where each number corresponds to the frequency of responses per scope. Respondents could choose multiple areas, reflecting their involvement in various aspects of construction. "General Contracting" (26 responses) emerged as the most common scope, indicating that a significant portion of participants are engaged in overarching project responsibilities. Other commonly selected scopes include "MEP" (18), and "Exterior Skin" (10), suggesting strong involvement in structural and mechanical aspects of projects. In contrast, more specialized scopes like "HVAC" (3) and "Drywall" (4) had fewer responses, hinting that fewer participants are focused on these areas. Overall, the data indicates a diverse range of expertise among respondents, with a tendency toward roles with broader or structural responsibilities.

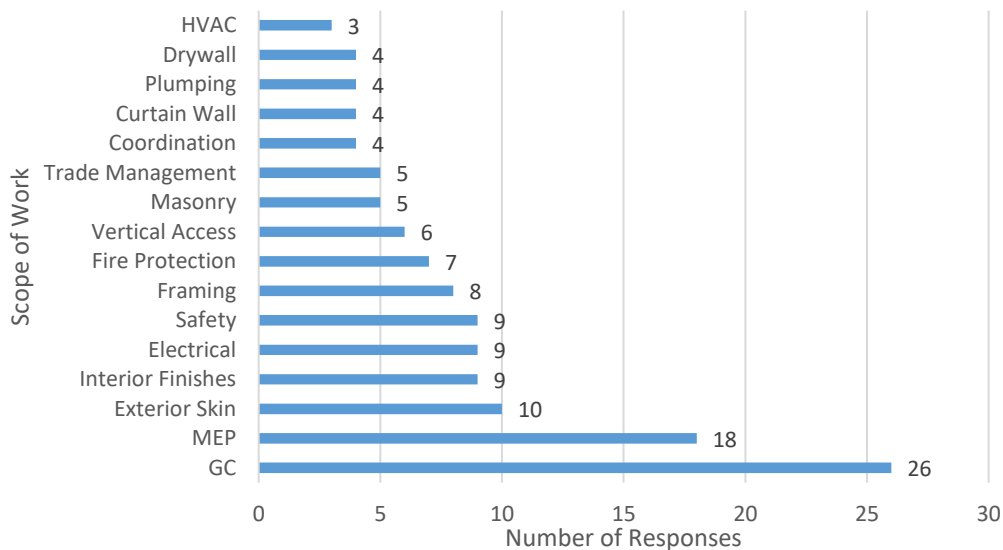


Figure 1. Number of Responses per Scope of Work

(1) *What are the most commonly used software tools on the job site by field personnel?*

The software being used by Field personnel

The software usage frequency data in (Figure 2) shows that Procore (19 responses) is the most widely used tool among participants, underscoring its role as a leading project management platform in

construction. Other commonly used software includes Genda (16), Bluebeam (11), Email (11), and Autodesk Construction Cloud (ACC) (4), highlighting the importance of communication, document management, and field coordination in participants' workflows. Less frequently used tools, such as Concur SAP and Navisworks, and specialized applications, like Leica Icon, received only one response each, indicating that they are utilized by a smaller subset of participants for specific tasks. Overall, the data reveals a preference for versatile project management and collaboration software, with Procore and ACC emerging as key tools while specialized applications are used selectively.

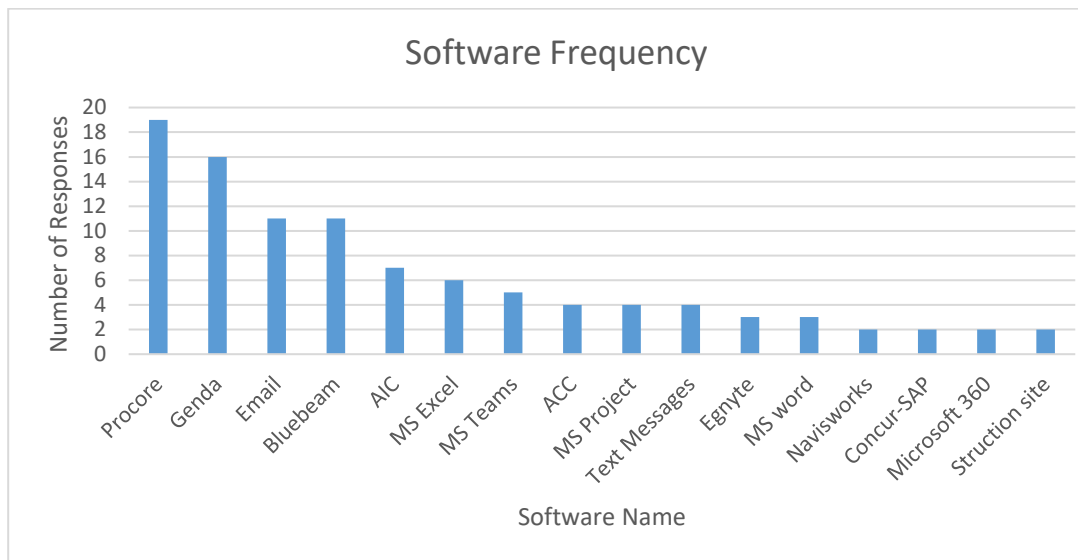


Figure 2. Software Frequency

The devices being used by Field personnel

The devices used by field personnel on a daily bases regarding their job were mainly tablets, laptops and mobile phones. Tablet devices are the most frequently used device, with 77 instances, followed closely by laptops at 72 and mobile phones at 68. This distribution indicates a preference for tablets and laptops, likely due to their larger screens and more robust capabilities for handling field data, while mobile phones, although slightly less common, still play a significant role in field operations. This trend suggests a balance between mobility and functionality in the tools field personnel rely on for their tasks.

(2) What functionalities of each software are utilized, and for which specific scopes of work?

Figure 3 highlights the relationships between Scope of Work, Software, and Functionalities. Procore, Genda, and Bluebeam show numerous connections, indicating their broad applicability across diverse on-site roles and functions. On the other hand, Autodesk Construction Cloud (ACC) is used by subcontractors for internal purposes, primarily through PlanGrid, yet notably, the general contractor does not integrate with it directly. Additionally, field crew are using the Genda platform specifically for field communication and managing on-site deliveries, reflecting a more advanced and centralized approach to real-time communication and logistics.

Procore emerges as the most widely integrated platform, linking diverse roles within construction teams, including general contractors (GCs) and subcontractors. It supports essential functionalities such as on-

site document access, internal communication, markup and annotation sharing, as well as reviewing and submitting RFIs and submittals. These functions make Procore a key tool for collaborative project management and real-time communication on-site. Bluebeam Revu, the second most-used software, is primarily utilized for document review and drawing markups. Though often seen as a PDF management tool, its overlap with Procore’s functionality highlights its role in supporting collaborative document handling and design review.

Genda, a relatively new tool to many participants, is frequently accessed on mobile phones and tablets by GCs and trades alike. It facilitates daily scheduling, coordination among trades, site logistics, delivery scheduling, and booking vertical access via hoists. Genda’s popularity among on-site workers underscores its value in streamlining day-to-day operations. Email remains the primary formal communication channel for GCs and subcontractors, often used for setting up meetings and requesting information, despite the availability of more integrated platforms. Autodesk Construction Cloud offers similar capabilities to Procore, such as model and plan review, though it has lower adoption rates in this sample. Additionally, Microsoft Excel remains widely used for financial management and resource tracking, reflecting the continued reliance on spreadsheets for essential project management tasks. The diagram in Figure 3 also highlights other software tools, showcasing the specific functionalities utilized by each role to support construction operations.

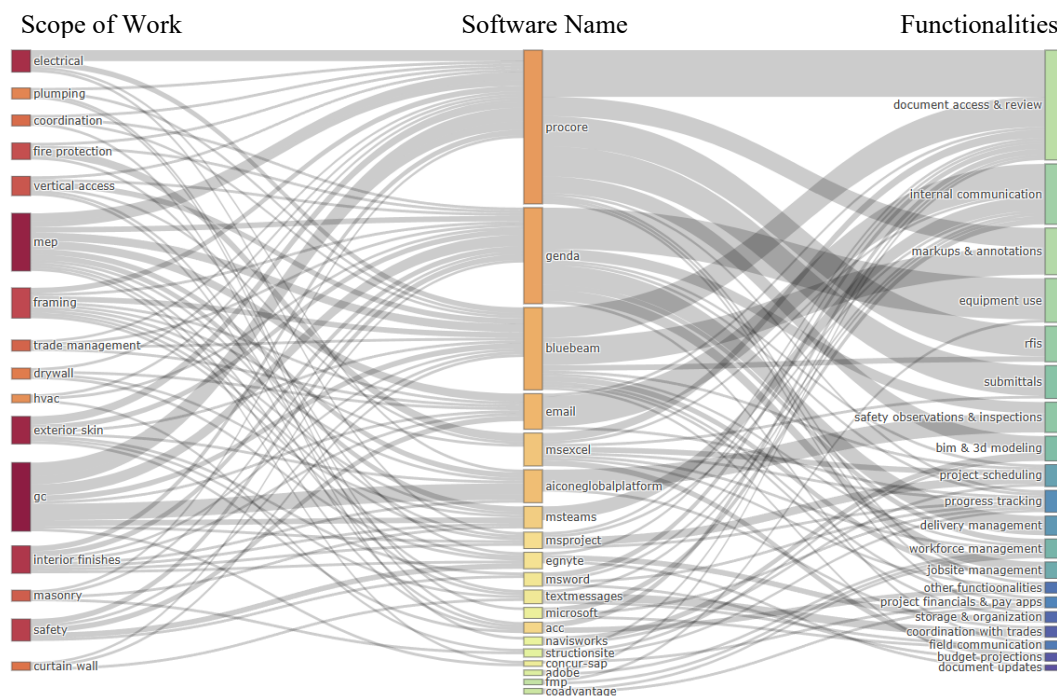


Figure 3. Scope of work vs Software vs Functionalities

(3) What formats of training have the field personnel received for each software and its functionalities?

Figure 4 illustrates the various training formats available for different software tools and their specific applications, revealing that a significant number of users have received no formal training. The most common formats are "no training" and "on-the-job training (OJT)," with OJT often associated with

functionalities such as document access, internal communication, and markups/annotations. In contrast, more complex functionalities, like BIM 3D modeling, equipment use, and quality inspections, tend to require structured training to enhance competency. Among respondents, 37% (44 responses) reported no formal training, while 29% (34 responses) relied primarily on OJT, gaining skills in real job settings with guidance from experienced colleagues. Less common formats included brief training sessions (5%, 6 responses), self-teaching (4%, 5 responses), and online videos (8%, 10 responses). Formal employer-provided training and sessions from software providers each accounted for 6% (7 responses), and only 5% (6 responses) mentioned higher education courses. The limited availability of formal educational resources highlights a need for expanded training, particularly for advanced or specialized functionalities.

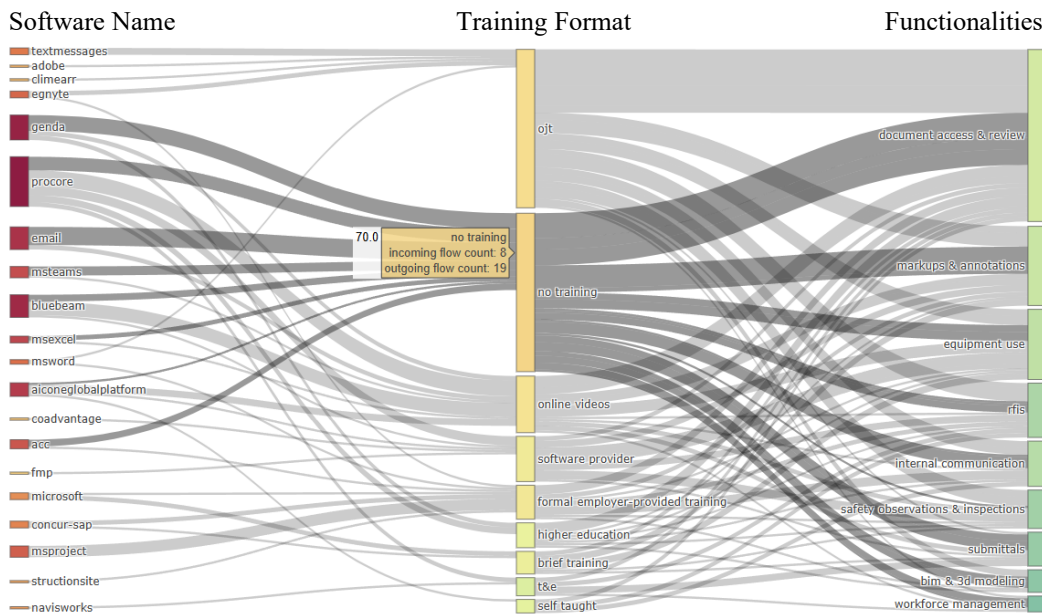


Figure 4. Training availability and format across different software options and functionalities

Discussion of Results

The survey data illustrated that a high percentage of personnel used Procure for tasks such as real-time document access, markup sharing, and communication, reinforcing Procure’s reputation as an effective platform for project management and contractor-subcontractor collaboration. These functionalities align well with Construction 4.0 goals of improving efficiency through digital collaboration. The training methods and availability reveal an urgent need for more structured educational approaches in software skill acquisition for construction professionals. Our study found that most participants relied on non-formal training methods, such as on-the-job training (OJT). Given that 37% of participants reported receiving no formal training and an additional 29% relied on OJT, this reflects an apparent skills gap in software utilization that could be addressed through more comprehensive education programs in construction management curricula.

The hardware usage trends among field personnel are particularly noteworthy. Tablets emerged as the most utilized device on job sites, closely followed by laptops and mobile phones. The preference for tablets may reflect the construction industry’s gradual shift towards mobile devices that combine the convenience of portability with the functionality of larger screen displays, essential for reviewing plans

and schedules on-site. This trend also suggests that as construction projects increasingly adopt digital tools, software providers might need to optimize their applications for tablet interfaces to meet field personnel's needs more effectively.

Lastly, this study highlights the implications of our findings for construction management education. The limited formal training available to field personnel points to a pressing need for curricula to include specialized software training that goes beyond basic proficiency to focus on the integration and application of these tools in practical settings. For instance, given the widespread use of Procore and Bluebeam among participants, incorporating hands-on training modules in these platforms could provide future professionals with the practical skills required to meet industry expectations. Additionally, introducing case-based learning that simulates real-world scenarios involving different scopes of work would better equip students to handle the complexities of digital collaboration on-site.

Conclusion

This study provides insights into the software ecosystems currently used by field personnel on large-scale commercial construction sites. By analyzing the tools and technologies employed by general contractors and subcontractors, this research highlights the prominent role of platforms like ProCore® and Bluebeam in facilitating on-site collaboration and document management. The reliance on mobile devices, particularly tablets, reflects a broader industry trend toward flexible, digital solutions for construction management. However, the findings also underscore a significant gap in formalized training for these software tools, pointing to a critical need for construction management curricula to incorporate comprehensive training on these platforms. Bridging this educational gap will equip future professionals with the necessary skills to navigate and optimize digital ecosystems in the rapidly evolving construction landscape.

Future research should focus on developing and evaluating structured, role-specific training programs for construction management software, particularly for field personnel. Given the heavy reliance on informal training methods highlighted in this study, investigating the impact of structured training—delivered through simulations, role-based modules, or virtual reality environments—on skill acquisition and on-site performance. Additionally, research should explore the long-term effects of such training on productivity, safety, and software adoption rates across diverse roles, from project engineers to trade supervisors. Collaborative partnerships between academia and industry could be instrumental in co-creating training curricula tailored to specific software functionalities, enhancing the alignment of construction education with industry needs. The current absence of artificial intelligence within job site software ecosystems also presents a significant research opportunity. Future studies could explore how AI might streamline on-site tasks and enhance decision-making. Additionally, exploring AI's potential to provide personalized, role-specific learning experiences, potentially transforming on-site operations and upskilling practices in construction management.

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