

Preparing the Workforce: Skills Needed in Construction Education for Using Uncrewed Aerial Systems (UAS) in Construction

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Abstract

The construction industry is experiencing a rapid transformation as emerging technologies reshape conventional practices. Driven by advances in remote sensing, information technologies, and artificial intelligence, Unmanned Aerial Systems (UAS) are becoming increasingly popular in construction, offering wide-ranging applications at a relatively affordable cost. However, their integration also introduces challenges that extend beyond traditional construction requirements, demanding specialized technical knowledge and practical competencies not typically addressed in current construction education. While prior research has acknowledged the importance of developing UAS-related curricula to better prepare future construction professionals, little work has focused on identifying the core skills and educational content most appropriate for construction programs. To address this gap, this study examines industry expectations of current education in light of the growing adoption of UAS in construction, using a mixed-method approach that combines a comprehensive literature review with an industry survey. The results identify a set of priority knowledge areas that can serve as a foundation for curriculum development in construction management programs. This work contributes to practice by clarifying the value of UAS applications and articulating the skills most needed by employers, while also offering educators a roadmap for embedding UAS-focused content into existing courses or designing targeted learning modules. Ultimately, the findings bridge a critical gap between technological innovation and workforce readiness, positioning UAS not merely as tools of efficiency but as integral components of the construction industry's digital transformation and underscoring the importance of aligning education with rapidly evolving industry needs.

Keywords: Unmanned Aerial Systems (UAS), construction education, Curriculum development

Introduction

Unmanned Aerial Systems (UAS), commonly known as drones, have experienced considerable development over the last decade, with even more significant advances occurring in the past two years [1]. While early UAS applications were largely limited to military missions, they are now transforming numerous commercial industries, including media, agriculture, and emergency responses. The construction industry, historically considered a slow adopter of emerging technologies, has also increasingly developed new applications for UAS, as they provide unique aerial perspectives of

construction sites that are difficult or unsafe for humans to access. In the United States alone, the UAS market size was estimated at \$25.07 billion in 2024 and expected to double by 2030, driven by the increasing integration of artificial intelligence (AI) and advanced analytics that are transforming the market [2]. This trend suggests a continued growth and foreseeable acceleration in the adoption of UAS within the construction industry.

UAS has been increasingly adopted across the entire construction project lifecycle, supporting tasks ranging from surveying, mapping, and site planning during the pre-construction phase [3-4], to progress tracking [5], quality control [6], and safety inspections [7-8] during construction, and to as-built documentation and asset management in the post-construction phase [6]. The widespread utilization of UAS in construction practices highlights a growing need for construction personnel with the technical knowledge and skills required to use these technologies effectively and safely across diverse applications. However, previous studies have identified a shortage of personnel adequately prepared to use UAS in construction operations [9], and UAS-related competencies are not yet systematically addressed in most construction education programs [10]. This misalignment between rapid technological advancement and educational preparation has created a gap in workforce readiness, potentially limiting effective UAS utilization and raising concerns regarding data quality, safety, and consistency in practice. Although prior studies have acknowledged the importance of integrating UAS-related content into construction curricula, limited research has focused on identifying the core skills and educational content most appropriate for construction programs.

The challenge of integrating emerging technologies into construction education is not unique to UAS. Similar gaps have been documented in the adoption of Building Information Modeling (BIM), robotics, and automation, where industry implementation often outpaced curricular adaptation, leading to reactive rather than strategic integration [17-18]. Prior studies also highlight institutional constraints, including limited faculty expertise, resource availability, and uncertainty in defining learning outcomes, as persistent barriers to educational innovation [18]. Situating UAS integration within this broader technology adoption context underscores the need for structured, industry-aligned curricular frameworks rather than isolated course additions.

Previous research, including work by Clarkson University, has identified a clear gap in drone education within construction-related programs [11]. Many institutions have not developed comprehensive UAS courses, and prior studies rarely define clear learning objectives or specify the level of practical training required to meet industry needs [10-11]. As a result, institutions face uncertainty regarding what should be included in a well-designed drone curriculum, with decisions often driven by institution-specific constraints rather than consistent, industry-aligned guidelines [12]. This lack of clarity has discouraged some schools from initiating UAS coursework and has left others unsure how to structure effective programs. To address this issue, prior studies examined the extent of UAS education in Associated Schools of Construction (ASC) programs and proposed recommended student learning objectives [13]. The findings showed that although approximately 50% of ASC institutions offer drone-related courses in at least one department, only six schools (3.7%) provide such courses within construction management programs, suggesting that current offerings fall short of industry demand [13].

To address this gap, this study investigates how UAS is being used in the construction industry and identifies the knowledge and skills that employers expect from construction graduates working with UAS-related technologies using a mixed-method approach. The findings of this study aim to inform curriculum development and instructional design efforts in construction engineering and management education, supporting the preparation of graduates who are better aligned with evolving industry practices.

Methodology

To address the research objectives of this study, a mixed-method approach was adopted, integrating a literature review with an industry survey. The review focused on available literature related to the skills and knowledge required for using UAS, a.k.a., drones, in construction. Both scholarly and industry publications were examined, including peer-reviewed journal articles and conference proceedings, as well as industry-oriented materials such as professional reports, news articles, and blogs. As this research is exploratory in nature, an unstructured review involving cross referencing was utilized. While unstructured literature reviews have inherent limitations, they are considered appropriate for preliminary investigations [14].

Insights from the literature were then used to develop a structured questionnaire using a Qualtrics platform consisting of six sections: respondents' background, drone utilization, importance of drone-related skills, workforce readiness and skill gaps, curriculum and training preferences, and future insights into drone utilization in construction. The designed survey was distributed using a snowballing approach through professional networks and available industry contacts to reach construction professionals with experience using or managing drone technologies. The purpose of the survey was to validate, expand upon, and refine the identified skills and knowledge requirements.

Results

This section presents the findings from the industry survey conducted as part of this study, which was informed by an initial review of the literature on drone applications, skills, and knowledge requirements in construction. Given the survey was distributed to construction professionals using a snowballing approach, it was not possible to determine the total number of individuals who received the survey invitation. Therefore, the response rate could not be calculated. A total of 32 responses were collected through the Qualtrics platform. After excluding five incomplete responses, 27 fully completed surveys were retained and used for the data analysis in this section. Given the exploratory nature of this study, the findings are intended to identify preliminary industry informed trends to guide curriculum development rather than to establish statistically generalizable conclusions.

Survey Respondent Characteristics

Figure 1 provides an overview of the professional background of the survey respondents. Overall, the respondent pool reflects a highly experienced group of construction professionals, with the majority of participants (67%) reporting more than 10 years of industry experience and most respondents (92.6%) affiliated with medium to large organizations. In addition, respondents represented multiple construction

sectors, with commercial construction being the most frequently reported. Beyond the commonly represented construction sectors, three respondents indicated that their primary work involved utilities, power delivery, and government or federal public projects, including agencies and facilities such as the Federal Aviation Administration (FAA), the Department of Energy (DOE), technology facilities, and hospitals. Collectively, these results reflect a diverse respondent background spanning multiple construction sectors and organizational contexts.

It should be noted that the survey was designed to skip Sections 3.2 through 3.5 for participants who reported no direct experience with drones in construction. Of the 27 fully completed survey responses, four indicated no such experience; therefore, 23 responses were used for the analyses presented in Sections 3.2 through 3.5. All 27 responses were included in the analysis of Section 3.6, which focuses on future perspectives of the technology.

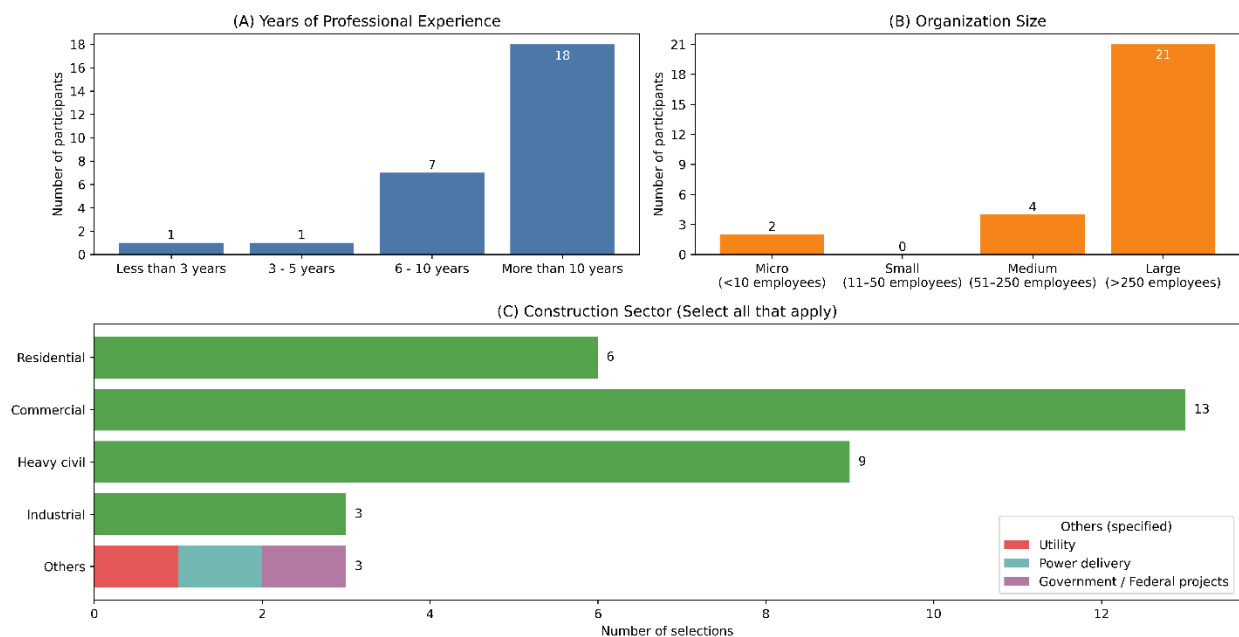


Figure 1. Background of Survey Participants (N = 27)

UAS Usage Characteristics in Construction

The survey questions in this section are designed to examine current UAS usage characteristics in construction, with a focus on how drones are deployed, operated, and applied in practice. Existing literature identifies three primary drone types commonly used in the construction industry: fixed-wing, rotary-wing, and hybrid platforms [15]. Typical payloads include RGB cameras, LiDAR scanners, and thermal cameras, selected based on application needs across different project phases [15]. These applications include land surveying and mapping during the design phase, earthwork measurement, progress tracking, quality control, and safety inspection during construction, as well as inspection and documentation during the operation and maintenance phase.

Based on the survey responses shown in Figure 2, rotary-wing platforms dominated UAS use in construction, with approximately 96% of respondents reporting experience with this drone type. This

pattern is consistent with the limited space required for takeoff and landing, which makes rotary-wing drones well suited for complex and congested construction environments. Except for respondents who were unsure of the model used, nearly all reported rotary-wing platforms were manufactured by DJI. Regarding sensor payloads, approximately 57% of respondents reported using digital (RGB) cameras, followed by LiDAR sensors (35%), while thermal cameras were reported by only two respondents. In addition, two respondents reported using Real-Time Kinematic (RTK)-enabled systems; although RTK is not a data-collection payload, it provides high-accuracy positioning to improve georeferencing and was used primarily for quantity takeoff and earthwork measurement and surveying applications.

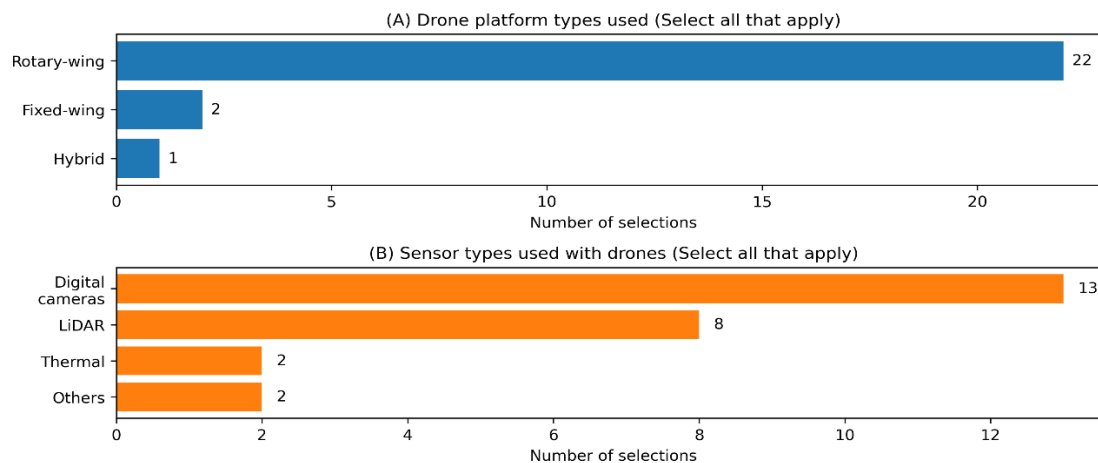


Figure 2. Participant reported drone and sensor types used ($N = 23$)

Regarding operational practices, Figure 3 shows that approximately 74% of respondents reported conducting UAS activities in-house rather than relying on third-party services, suggesting an increased emphasis on internal drone operations within construction organizations. Reported usage frequency was primarily clustered around periodic intervals, such as monthly or occasional use, rather than continuous or daily deployment.

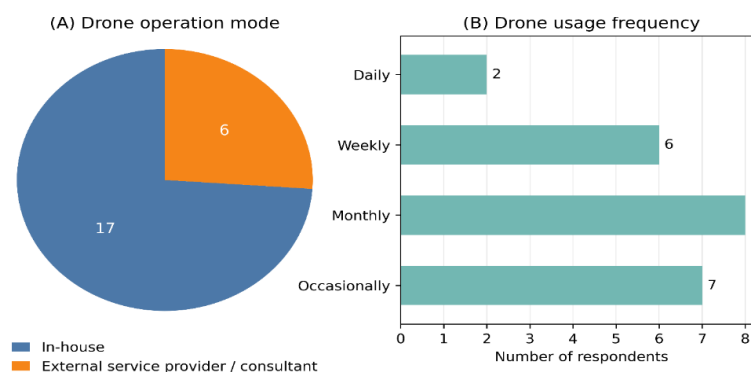


Figure 3. Participant reported drone operation mode and usage frequency ($N = 23$)

Figure 4 summarizes the UAS applications in construction reported by participants. The results indicate that drones are most commonly used to support visual oversight, spatial data capture, and communication purposes. In particular, surveying, as-built documentation, and project progress tracking were commonly reported, with progress tracking identified by more than 91% of respondents. Applications such as

quantity takeoff, earthwork measurement, and quality control were reported by fewer respondents, reflecting more specialized use of drone-derived data for measurement and evaluation tasks. Safety inspection was reported by approximately 26% of respondents, consistent with prior literature indicating more limited adoption in this area [16]. In addition, a small number of respondents reported other specialized applications, including utility mapping, damage assessment, and marketing.

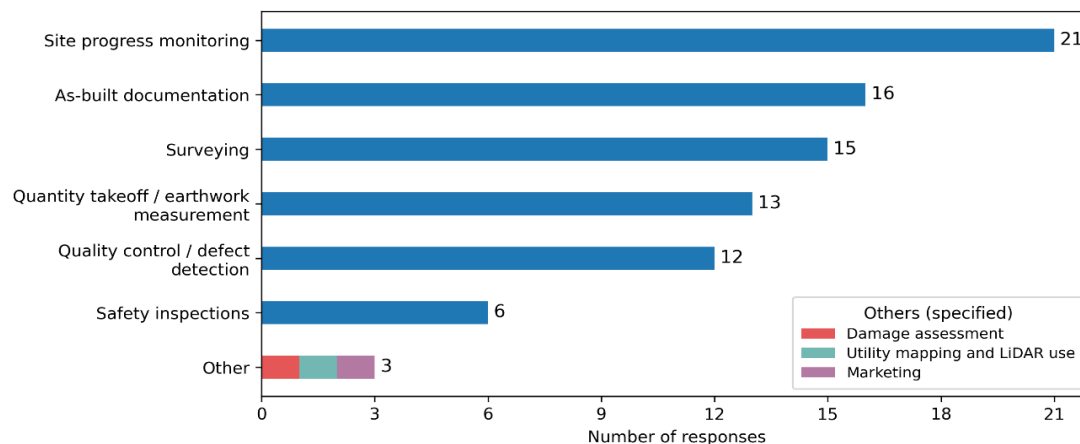


Figure 4. Participant reported drone applications in construction ($N = 23$)

Importance of UAS-related Skills

The survey questions in this section were designed to capture construction professionals' perspectives on the importance of UAS-related skills based on their industry experience. Because the existing literature does not provide a consolidated framework of UAS-related skills, the skill categories examined in this study were synthesized from prior research on UAS applications and organized into three domains: knowledge areas, operational skills, and data processing skills.

Within the knowledge domain (Figure 5), regulatory and compliance-related knowledge was rated as the most critical skill area, with a weighted average score of 4.57 out of 5 on a five-point Likert scale, where 1 indicates not at all important and 5 indicates extremely important. In addition to basic FAA regulations and airspace rules, construction-specific guidelines and best practices were also rated highly (4.04), underscoring the importance of contextual knowledge alongside regulatory awareness. Two respondents additionally identified other relevant knowledge areas, including an understanding of surveying principles and workflows when UAS are employed for surveying tasks.

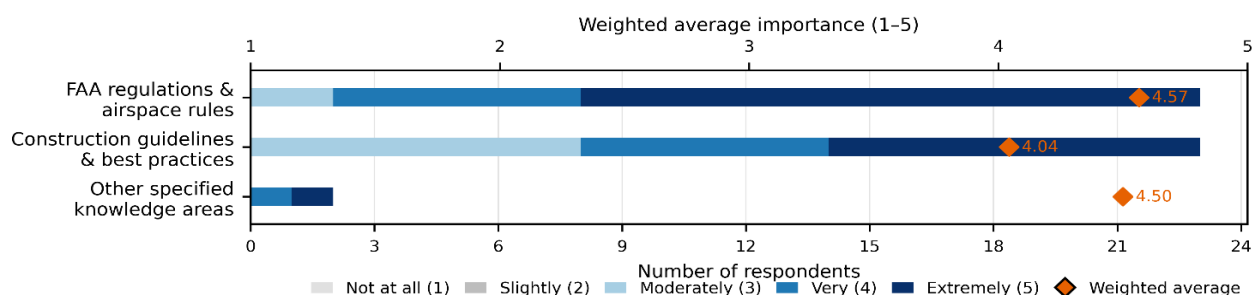


Figure 5. Participant reported Importance of UAS-related Knowledge Areas ($N = 23$)

Figure 6 presents the results related to operational and technical skills for using UAS in construction. Based on weighted average ratings, skills associated with safety procedures and risk management were identified as the most important operational competencies, followed closely by flight planning, piloting, and data acquisition. In contrast, knowledge of drone hardware and sensors, while still considered important, received comparatively lower ratings, suggesting that respondents prioritize safe and effective field operations over detailed hardware familiarity. Two respondents also identified additional skill areas not captured in the predefined categories and rated them as extremely important. These included understanding ground control workflows, which were considered part of data acquisition, and the ability to produce industry-ready deliverables, which were more appropriately classified as a final stage of data analysis.

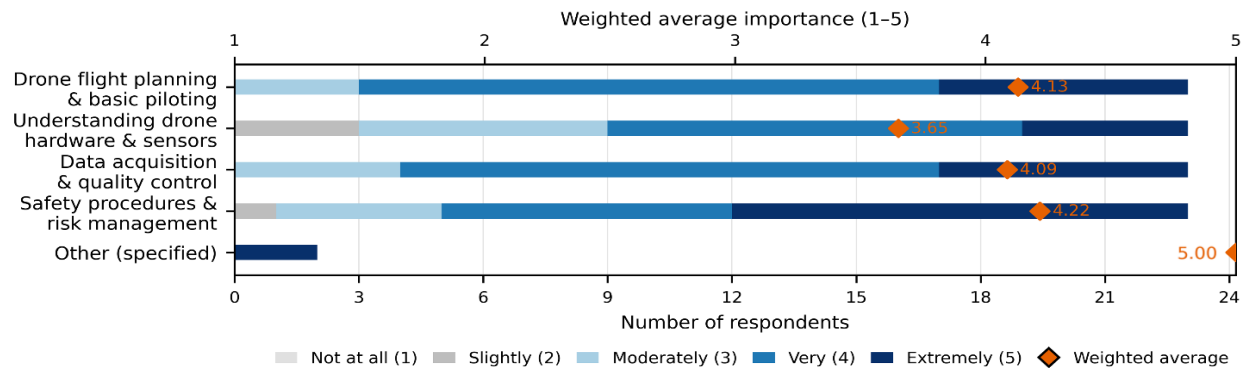


Figure 6. Participant reported Importance of UAS Technical and Operational Skills (N = 23)

In terms of data analysis skills, greater variation in ratings was observed compared to other skill categories, as shown in Figure 7. Respondents assigned higher importance to skills that directly support decision-making, such as data interpretation (4.04) and image or video processing (3.96), than to more advanced analytical or integrative competencies. Skills including photogrammetry, LiDAR-based point cloud processing, GIS mapping, and integration with BIM received comparatively lower ratings, indicating a secondary but still relevant role in current industry practice.

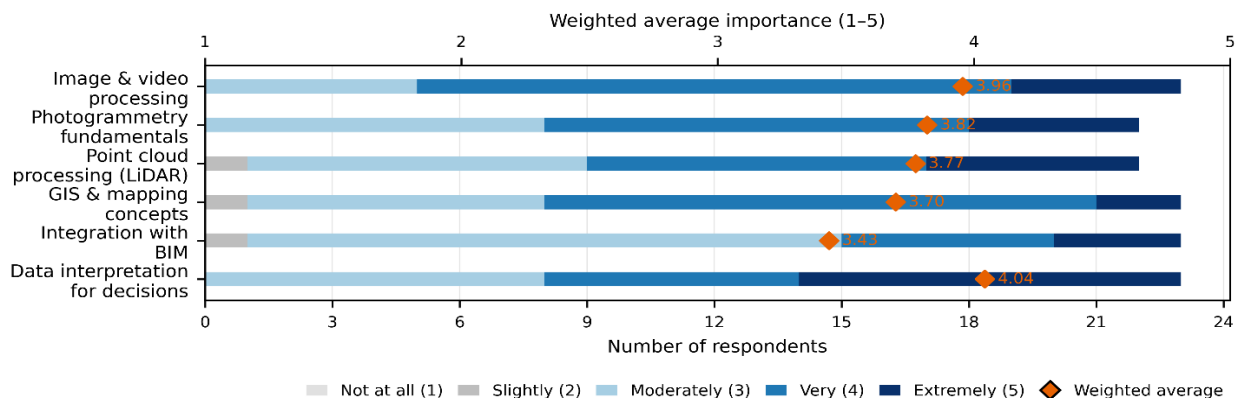


Figure 7. Participant reported Importance of UAS Data Analysis Skills (N = 23)

Workforce Readiness and Observed Skill Gaps

The survey questions in this section were designed to capture professionals' perceptions of workforce readiness and skill gaps related to UAS utilization based on their industry experience. The results indicate that respondents generally perceived construction graduates to be insufficiently prepared to apply UAS technologies in professional practice. As shown in Figure 8, most respondents rated graduates as only moderately prepared or below, with no respondents indicating that graduates were well prepared or very well prepared for drone-related applications. This distribution highlights a perceived gap between current educational outcomes and industry expectations for UAS competency.

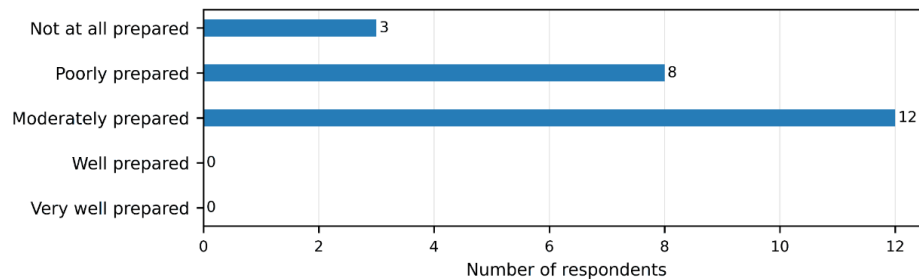


Figure 8. Participant reported Graduate Preparedness in UAS Applications (N = 23)

Consistent with the perceived lack of workforce readiness, respondents identified several key skill gaps related to UAS use in construction, as shown in Figure 9. The most prominent gaps were insufficient regulatory knowledge and limited hands-on experience, each reported by approximately 74% of respondents. Additional gaps were noted in areas such as understanding drone limitations and risks, awareness of practical applications, and the ability to integrate drone data into existing workflows, indicating challenges beyond basic technical operation. In contrast, data analysis skills were reported as a less common concern, suggesting that foundational knowledge, experiential learning, and contextual application may represent more immediate constraints than advanced analytical capabilities.

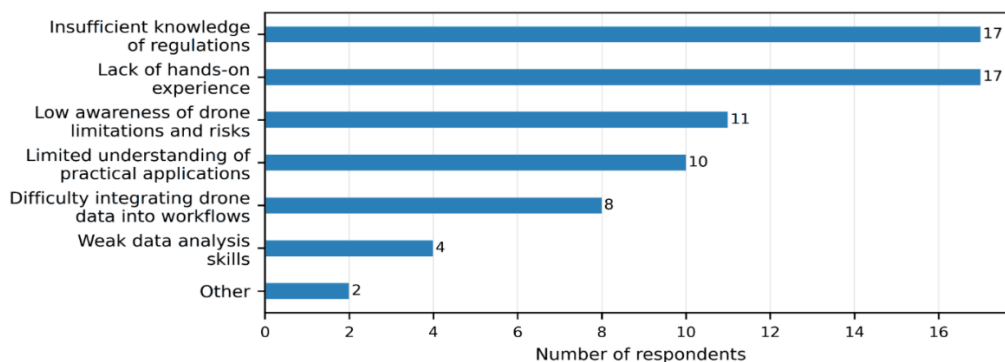


Figure 9. Participant reported Observed Skill Gaps in UAS-related Competencies (N = 23)

Curriculum and Training Preferences

This section aims to capture professionals' perspectives on how educational programs can address the skill gaps identified in the previous section. Figure 10 presents preferred approaches for incorporating drone content into construction curricula, while Figure 11 summarizes respondents' views on effective instructional formats for teaching drone-related skills.

Regarding instructional formats for incorporating UAS content into educational programs, respondents most commonly favored short modules or workshops, followed by integration into existing construction management courses and industry certification or training partnerships. Fewer respondents supported offering drone content exclusively as a stand-alone course, and none indicated that UAS education was unnecessary. Several additional suggestions were also provided. Three respondents emphasized the importance of offering FAA Part 107 exam preparation, noting that licensure would directly benefit students expected to operate drones in professional settings. Another respondent highlighted that any instructional approach that expands student knowledge of potential drone applications would be valuable.

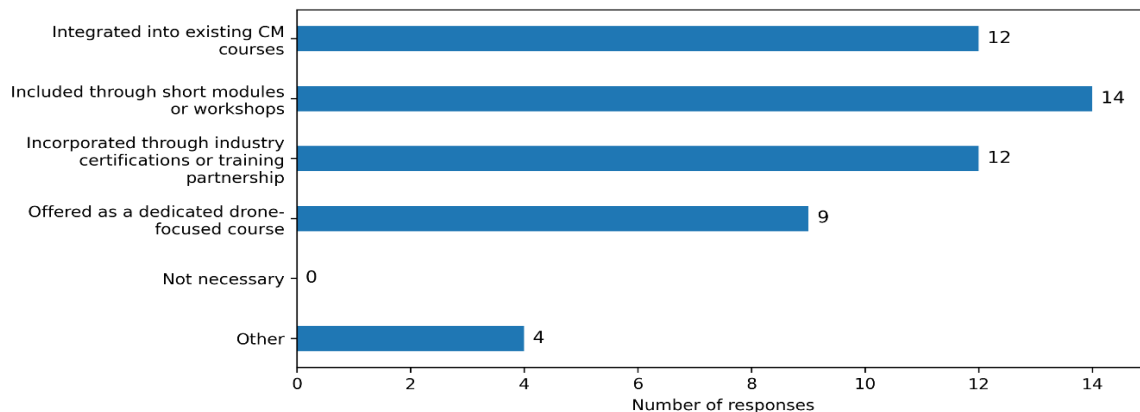


Figure 10. Participant reported Best Ways to Incorporate UAS content (N = 23, select all that apply)

Regarding instructional format, hands-on learning emerged as the most strongly supported approach. More than 70% of respondents identified hands-on laboratory activities with drones and field demonstrations as the most effective instructional methods. Case studies from real projects and guest lectures from industry professionals were also frequently selected, indicating a strong preference for instructional formats that connect technical skills to real-world construction contexts. Software-based simulations received comparatively less support. In addition, one respondent emphasized the importance of teaching the application of UAS data with AI literacy, highlighting the need for students to understand, interpret, and apply AI-assisted outputs from drone data rather than focusing solely on data collection.

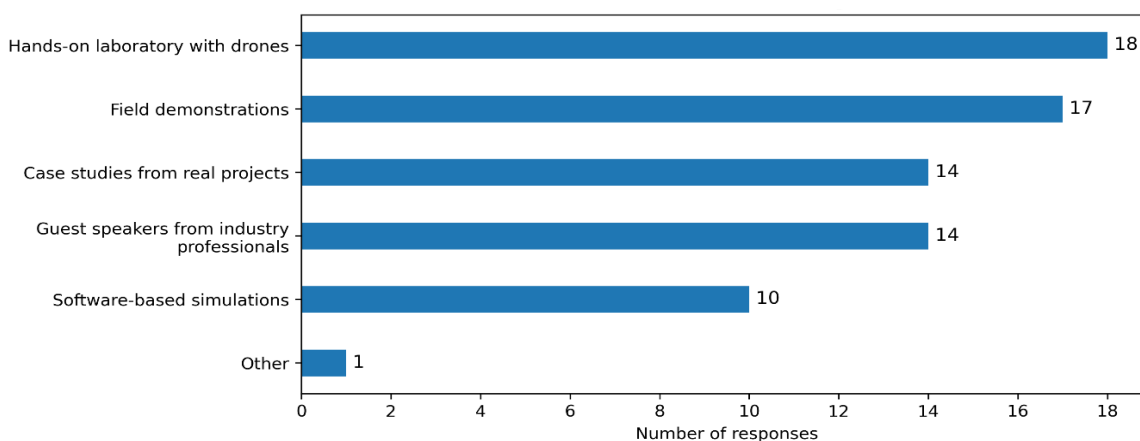


Figure 11. Participant reported Most Effective Formats for Teaching UAS Skills (N = 23, select all that apply)

Future Insights of UAS Utilization in Construction

This section was designed to capture construction professionals' perspectives on the future value of UAS technology in construction, regardless of whether they had direct experience using drones. As shown in Figure 12, survey results indicate that drone technology is widely perceived as highly valuable within the construction industry. Responses were strongly concentrated at the upper end of the rating scale, with a weighted average score of 4.15 out of 5, reflecting a clear consensus that UAS technologies provide substantial benefits to construction practice. Notably, no respondents rated drone technology as “not valuable” or “slightly valuable,” underscoring the broad acceptance and perceived maturity of UAS applications among industry professionals.

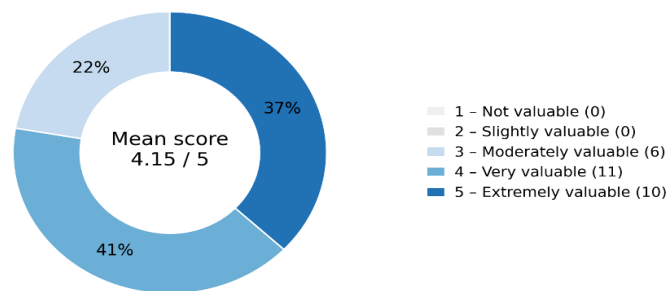


Figure 12. Perceived Value of UAS Technology in Construction (N = 27)

Despite the strong perceived value of drone technology, respondents also identified several barriers that continue to limit its adoption in the construction industry. As shown in Figure 13, regulatory and knowledge-related challenges were the most prominent, with more than half of the respondents reporting limited awareness of drone capabilities and regulatory or compliance concerns. Safety, liability, and privacy issues were also frequently mentioned. In addition, economic and organizational factors, including unclear return on investment, lack of trained personnel, costs associated with equipment and software, and organizational resistance to new technologies, were reported by a substantial portion of respondents, indicating that adoption is influenced by both workforce readiness and institutional constraints. Additional comments provided under the “Other” category further emphasized regulatory and policy uncertainty, including high initial costs combined with untested legal precedents, potential U.S. government restrictions on commonly used drone systems, and insurance requirements for commercial drone operations.

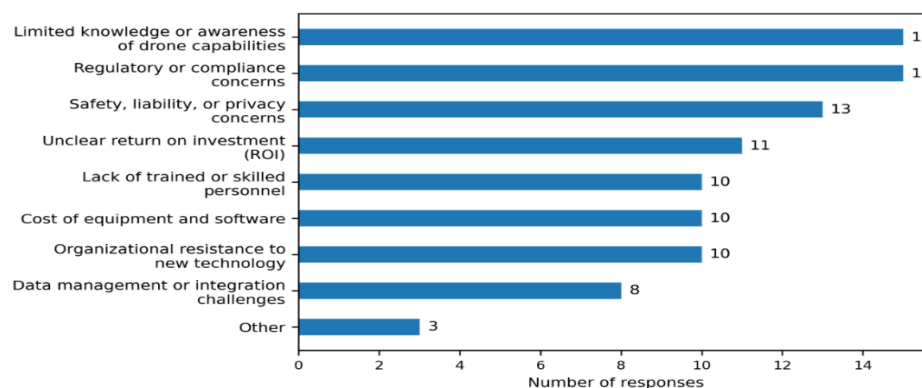


Figure 13. Participants reported Primary Barriers to UAS Adoption (N = 27)

Discussions

Overall, the results confirm that UAS is widely perceived as a valuable technology in the construction industry and is expected to become increasingly indispensable, particularly for certain types of construction activities. Several respondents explicitly noted that drone technology is likely to become the “new normal,” reinforcing the survey findings that industry acceptance of UAS has reached a mature stage. However, despite this strong perceived value, current UAS use in construction remains largely task-specific rather than fully integrated into end-to-end project workflows. As reflected in both the survey results and open-ended comments, UAS is commonly viewed as a value-added tool rather than a contractual requirement, indicating that its adoption has not yet been institutionalized across the industry.

The application patterns observed in this study further illustrate this transitional stage. Applications that rely on direct interpretation of visual data, such as site progress monitoring, were reported as the most mature and widely adopted. These applications typically allow practitioners to make immediate judgments based on images or videos, requiring minimal post-processing or advanced analysis. In contrast, applications that demand deeper analytical workflows, including defect detection and safety inspections, were reported less frequently. Importantly, lower usage does not imply lower importance; instead, it suggests that these applications remain underexplored and present significant opportunities for future development. From a workforce preparation perspective, these findings help prioritize educational content by identifying where foundational competencies can have the greatest immediate impact while also signaling areas that may grow in importance as UAS becomes more deeply embedded in construction workflows.

In terms of workforce skills, the results indicate that UAS-related competencies can be conceptualized as a progressive, multi-level structure. Knowledge-based competencies form the foundation, supported by the highest weighted importance ratings among all skill categories. This includes regulatory knowledge, airspace rules, and general understanding of UAS capabilities, suggesting that education programs should prioritize establishing a strong knowledge base, especially when instructional resources are limited. Operational skills, such as flight planning, risk management, and ensuring high-quality data acquisition, represent the second level, aligning closely with identified skill gaps related to hands-on experience. Advanced data analysis skills, including photogrammetry, LiDAR processing, and data integration, are the most advanced level. These skills are often outsourced in current practice, reflecting both their complexity and the specialized expertise required. Notably, this tiered structure aligns with observed workforce gaps, reinforcing the need for phased skill development rather than attempting comprehensive coverage at once.

Finally, the findings offer clear implications for how UAS content should be delivered within construction education. Knowledge-based instruction can be effectively introduced through modules or workshops, including preparation for certifications such as FAA Part 107, to ensure baseline regulatory and safety competency. Hands-on training remains essential but presents practical challenges related to liability, insurance, and on-site risk exposure. As a result, alternative approaches, such as controlled training environments or campus-based practice areas, may provide viable pathways to experiential

learning without the constraints of active construction sites. With respect to advanced data analysis, current industry practices suggest a gradual integration strategy, beginning with widely applicable tasks such as surveying and GIS integration before progressing toward more complex analytical applications. Together, these findings underscore the need for a staged, industry-aligned approach to workforce preparation that reflects both current UAS use and its anticipated evolution within construction practice.

Based on these findings, a preliminary conceptual framework was developed to illustrate the multi-level structure of UAS competencies and their alignment with phased curriculum delivery (Figure 14).

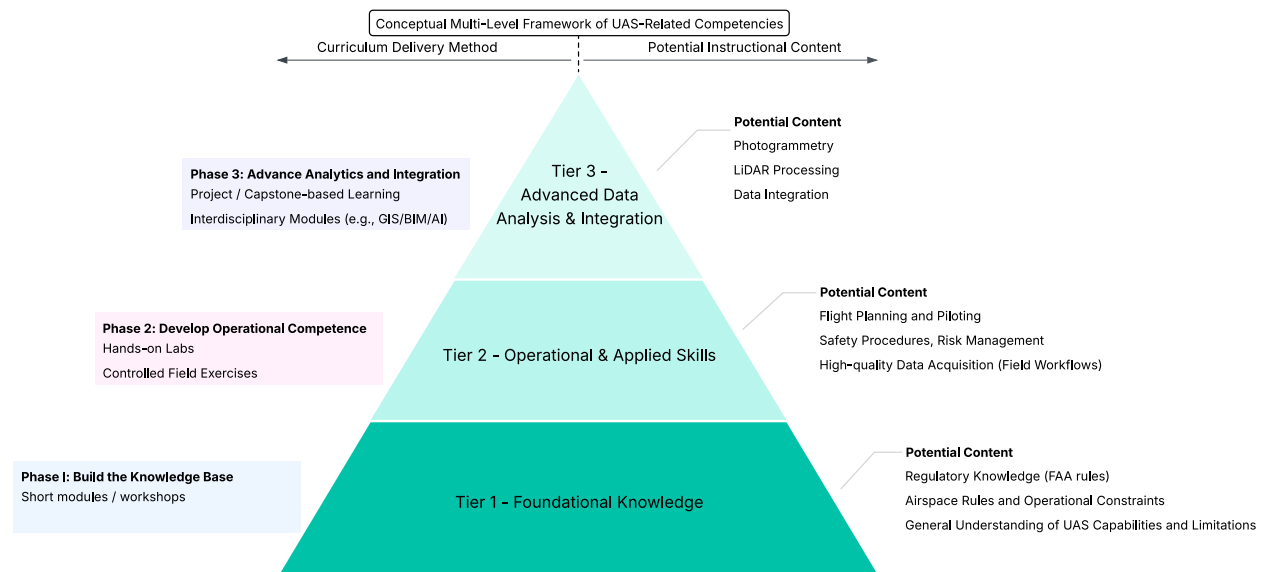


Figure 14. Conceptual Framework for Progressive UAS Competency Development

Conclusions and Recommendations

This study examined how construction education can better prepare the future workforce to use UAS by identifying industry expected skills and existing workforce skill gaps. Using a mixed-methods approach that combined a literature review with an industry survey, the study evaluated the importance of UAS-related knowledge, operational skills, and data analysis capabilities, as well as industry perceptions of graduate readiness. The results indicate a clear misalignment between industry expectations and current workforce preparation. While UAS is widely perceived as valuable, respondents consistently reported deficiencies in graduates' regulatory knowledge and hands-on experience, with additional gaps in advanced data processing and integration skills.

These results underscore the need for a staged, industry-aligned approach to curriculum development. Foundational competencies, including regulatory literacy and safety knowledge such as FAA Part 107 preparation, should be prioritized, particularly in programs with limited resources. Operational proficiency can then be developed through structured hands-on training in controlled environments, supported by industry partnerships where appropriate. Finally, advanced analytical capabilities, such as photogrammetry and GIS integration, may be incorporated progressively through project-based or capstone experiences. To synthesize these findings, a preliminary multi-level competency-curriculum

alignment framework was developed to guide phased implementation. By sequencing curriculum integration in this manner, programs can align resource availability with progressive competency development rather than attempting comprehensive adoption simultaneously. Such an approach supports targeted workforce preparation while reflecting the current and evolving role of UAS in construction practice. By sequencing implementation in this manner, programs can align resource availability with progressive competency development rather than attempting comprehensive integration simultaneously.

This study has several limitations. First, an unstructured literature review was conducted, which is considered appropriate for exploratory research; however, future studies would benefit from a more comprehensive and systematic literature review to further refine and expand the identified skill sets. Second, the survey sample size was limited and obtained through a snowball sampling approach. While the results are not intended for statistical generalization but rather to capture informed perspectives from experienced industry professionals, future research should involve larger samples and further examine how UAS skill requirements evolve as adoption increases. In addition, the proposed conceptual framework was developed by synthesizing separately collected survey data on skill gaps and instructional delivery methods. Because the survey did not directly assess the linkage between specific competencies and curriculum strategies, this alignment should be empirically examined in future studies.

Future research should move beyond expanding sample size to investigate curriculum development strategies at each competency stage and assess longitudinal outcomes of UAS integration in construction programs. Additionally, as artificial intelligence becomes increasingly integrated with drone data, further research is needed to examine how automation and analytics may reshape required competencies. Studies addressing faculty development, institutional constraints, and accreditation alignment will also be essential to support systematic and sustainable adoption of UAS education within construction programs.

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