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Barriers to drone utilization in construction site safety

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Abstract

The adoption of drone technology in construction site safety remains inconsistent despite growing technical capability and availability. This study investigates the structural barriers that constrain adoption across regulatory, technical, organizational, social and environmental domains. Drawing on quantitative indicators reported in recent literature, the research synthesizes empirical findings from multiple studies to identify dominant patterns in barrier occurrence and severity. Descriptive comparisons of reported mean scores, construct coefficients and barrier frequencies reveal a consistent hierarchy in which regulatory and technical constraints exert the strongest influence on adoption decisions. Restricted operational zones, unclear safety regulations, limited flight duration, collision risks and piloting skill requirements repeatedly appear among the highest-ranked barriers across different regional contexts. Socio-organizational issues such as workforce resistance, privacy concerns and training gaps further contribute to adoption inertia, while economic barriers often emerge as secondary effects of regulatory uncertainty and technical unreliability. The findings demonstrate that drone adoption in construction safety is shaped by interconnected institutional and technological constraints rather than a single limiting factor. Addressing these barriers requires coordinated efforts across regulatory bodies, industry organizations and project-level management systems to create clearer policies, standardized procedures and workforce integration strategies that support safe and routine drone operations.

Keywords: Drones; UAV; Construction; Safety; Barriers; Regulatory; Organization; Technology; Challenges

1. Introduction

The adoption of drone technology in construction site safety has not progressed at the same pace as its technical development (Zhong et al., 2025). While drones are increasingly available and technically capable, their integration into routine construction safety practices remains limited and uneven. This disparity indicates that the primary challenges lie not in the existence of the technology itself, but in the conditions required for its acceptance, implementation and sustained use within construction environments.

Adoption is influenced by a range of structural and institutional constraints that shape how organizations evaluate, authorize and operationalize new technologies. These constraints can originate from external environments, such as regulatory frameworks and legal obligations, or from internal organizational conditions, including policies, capabilities and readiness for technological change. When these conditions are uncertain, complex, or misaligned with existing practices, organizations tend to delay or avoid adoption altogether.

Barriers to drone adoption therefore, according to Aiyetan and Das (2022) represent a multi-dimensional problem that emerge from the interaction of regulatory requirements, legal responsibilities, organizational processes, workforce considerations and technological conditions. These elements collectively influence decision-making at different levels, from project managers and safety officers to corporate leadership and external regulators. As a result, even when drone technology is available, adoption may be constrained by procedural uncertainty, lack of institutional support, or

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perceived operational risks. Understanding these barriers is essential for explaining why adoption remains inconsistent across the construction sector. A focused examination of the constraints themselves provides a clearer picture of the structural conditions that must be addressed before drones can become a routine component of construction site safety management.

Research Objectives

- To analyze existing literature that addresses drone adoption barriers in the construction industry
- To identify the main barriers affecting the adoption of drones in construction site safety.
- To propose recommendations aimed at reducing adoption constraints.

1.1. Research scope

This study concentrates solely on barriers to the adoption of drones in construction site safety, as reported in literature published between 2022 and 2026. This timeframe ensures relevance to current regulatory environments, technological capabilities and organizational practices. This research examines the application and impact of drone technology in the construction industry across global regions which does not evaluate the benefits, performance or economic advantages of drone use. The focus is limited to the constraints that influence adoption decisions within construction safety contexts.

2. Literature Review

2.1. Regulatory and Airspace Constraints

One of the most comprehensive empirical examinations of adoption barriers was conducted by Singh et al. (2025), who employed a mixed-methods approach combining a systematic literature review with expert questionnaires to identify, rank and analyze interrelationships among barriers to UAV adoption in construction safety management. The systematic review phase of their research identified 33 potential barriers, of which 12 were deemed critical based on statistical ranking. Restricted operational areas, lack of explicit safety regulations and limited flight duration emerged as the top barriers with the highest mean importance scores, emphasizing that both regulatory and operational constraints are fundamental inhibitors to adoption. Unlike many digital technologies, drones operate in regulated airspace, making their deployment contingent on aviation authorities rather than solely on organizational decisions. Restrictions on beyond-visual-line-of-sight (BVLOS) flights, altitude ceilings, proximity to workers or public infrastructure and requirements for operator licensing create compliance burdens that vary significantly across jurisdictions (Safie & Khairil, 2025). This regulatory fragmentation complicates standardization for multinational contractors and limits scalability across projects.

Research by Daoud et al. (2025) used partial least squares structural equation modeling (PLS-SEM) to quantitatively model barrier influences among 147 industry professionals. The analysis in this study revealed that regulatory barriers like complex, inconsistent legal frameworks and unclear aviation policies have the strongest negative impact on drone adoption, followed by technical and economic concerns. Construction sites are often located in dense urban or semi-urban environments where airspace overlaps with transportation corridors, residential zones or restricted infrastructure. Obtaining flight permissions in such contexts may involve multiple authorities, risk assessments and documentation which in turn increase administrative overhead (Tafur et al., 2025). The time required for approvals can conflict with the fast-paced and dynamic nature of construction schedules, reducing the practicality of routine drone operations.

2.2. Cost

Further insight into structural and industry-wide barriers comes from Onososen et al. (2023), who conducted a quantitative survey across stakeholders in both developed and developing economies, focusing on impediments to digitalization using UAVs. Their findings indicated that economic and cost factors were the most critical, financial barriers persist despite the decreasing price of drone hardware. The total cost of ownership includes not only the aircraft but also sensors, software licenses, training, maintenance, insurance and compliance costs. For safety applications, economic benefits are often indirect and difficult to quantify, as they relate to incident prevention rather than immediate productivity gains.

This uncertainty complicates investment decisions. Procurement processes in construction typically require demonstrable returns or contractual obligations. Where safety-related outcomes cannot be easily monetized, organizations are likely to deprioritize drone investments in favor of technologies with clearer financial justification.

Akinradewo et al. (2024) study focused on South Africa found that technical difficulties and security concerns related to UAV operation especially accidents due to system failures and worker proximity, were key barriers alongside traditional concerns such as privacy, data insecurity and workforce displacement fear. These studies emphasize how UAV adoption for construction site safety is impacted by a constellation of barriers.

2.3. Technical limitations

Technical constraints remain a persistent adoption barrier, especially when it comes to reliability and operational endurance. Most commercial multirotor drones have limited battery life, typically between 20 and 40 minutes under optimal conditions (Zhao et al., 2025). On large or complex construction sites, this restricted flight time requires multiple sorties, battery swaps or additional equipment, interrupting workflows and reducing operational efficiency.

2.4. Resistance

Organizational barriers frequently stem from structural and procedural misalignment. Drone adoption requires coordination across safety, legal, IT, procurement and site management functions (Zhong et al., 2025). Many construction firms operate with siloed structures, making cross-functional implementation difficult. Additionally, Privacy concerns constitute a major socio-institutional barrier. Construction sites involve a diverse workforce operating in close proximity and drone-based monitoring may be perceived as intrusive or punitive. Musarat et al., (2024) study presents a challenge where workers often associate aerial monitoring with disciplinary surveillance rather than safety support, leading to resistance or reduced acceptance. Social acceptability issues extend beyond the workforce. Even when legally compliant, drone operations may face opposition if stakeholders perceive them as unjust or excessive.

3. Materials and Methods

This research draws on analysis from previous research published between 2022 and 2026 that examines barriers to UAV adoption in construction safety. A systematic search strategy was employed across academic databases and open-access journals. Following Nassaji (2016) data analysis guidelines, this study adopts a quantitative descriptive research approach based on numerical findings reported in recent academic studies addressing barriers to drone adoption in construction site safety. Instead of collecting primary data, the research utilizes quantitative results already presented in published studies, including mean scores, ranking positions, frequency counts and percentage responses. These reported values were treated as secondary numerical inputs for comparative analysis.

From each selected study, the barrier-related numerical results were extracted and organized into a consolidated dataset. Where different studies used comparable rating scales, the values were standardized to enable direct comparison. Barriers described using different terms but referring to similar underlying constraints were grouped into common categories, such as regulatory, technical, organizational, social and legal barriers.

4. Results

The results synthesize quantitative indicators reported across the selected studies to identify dominant barrier patterns affecting drone adoption in construction site safety. The analysis focuses on descriptive statistics derived from published mean scores, ranking values, construct coefficients and frequency distributions. This section compiles the numerical outputs already reported by each study and organizes them into comparable categories. This allows cross-study observation of how frequently certain barrier groups appear and how strongly they are ranked within each context. The tables therefore, present empirical indicators that illustrate the relative weight of regulatory, technical, economic, environmental and socio-organizational barriers across different regions and research designs

Table 1 Literature Matrix

Author (s)	Region	Barrier Categories	Quantitative Indicator(s)	Sample	Measurement Scale
Akinradewo et al. (2024)	South Africa	Technical difficulties; accidents & proximity, privacy, data security, workforce value	>3.0	14 barriers	5-point Likert
Daoud et al. (2025)	Saudi Arabia	Regulations, public perception, privacy, drone implementation, economic and technical issues.	PLS-SEM coefficients	6 barriers	Questionnaire

			indicating 42% variance		
Ikuabe et al. (2022)	South Africa / project delivery	Operation duration, maintenance cost, vehicle flight performance, manipulative ability, acquisition of parts and operation consumables.	Triple Helix Model (THM) with the Analytic Hierarchy Process (AHP) Mean=N/A	15 barriers	Survey + triple Helix Model (THM) with the Analytic Hierarchy Process (AHP)
Onososen et al. (2023)	United states, South Africa, Nigeria.	Economic/cost; technical/regulatory; education/org	Descriptive survey analysis with a 5 indicating 32% drone uptake	20 barriers	Survey; descriptive + inferential analysis+ 5-point likert scale
Singh et al (2025)	N/A	Restricted area, absence of safety regulations, limited flight time, collision, piloting skills, unawareness of using UAVs, resistance to new technology, human error, training requirement and law restrictions.	Barrier mean scores of 3.31	40 barriers	5-point Likert

Source: Own Illustration

4.1. Descriptive Statics

Across the five sources identified in this study, regulatory & legal barriers like restricted airspace and complex aviation laws Present in 4 of 7 studies (Daoud et al., 2025; Singh et al., 2025; Onososen et al., 2023; Akinradewo et al., 2024). Technical constraints like limited flight duration, weather and hardware issues are identified in 4 of 5 studies, making it the most frequently reported barrier domain. Economic/cost barriers on the other hand are reported in 3 studies. Social/human factors are further mentioned in 4 studies. This pattern shows that technical and regulatory constraints are the most prevalent barriers across the sampled literature, while economic and socio-organizational barriers are also significant but less uniformly reported.

Where mean scores or ranking data are reported, restricted airspace / regulatory limitations consistently appear among the highest-ranked barrier scores in studies with numerical outputs. In Singh et al., restricted airspace and limited flight duration receive mean scores above the mid-point of the scale >3.5 on a 5-point Likert scale. Technical performance issues like battery life, weather susceptibility and sensor limitations cluster with high rated importance or factor loadings in studies analyzing barrier constructs such as Akinradewo et al. (2024) cluster analysis focusing on technicalities and security concerns.

Table 2 Barrier Rankings and their empirical indicators

Barrier	Mean Score	Importance	Context
Restricted operational areas	3.75		Most significant barrier, especially in dense built environments.
Lack of safety regulations	3.68		Reflects legal ambiguity around UAV safety protocols.
Limited flight duration	3.68		Operational constraint affecting mission viability.
Collision risks	3.65		Technical and safety concern in dynamic site environments.
Piloting	3.65		Organizational and skills barrier.
Legal constraints	3.53		Regulatory complexity.
Weather impacts	3.78		Environmental operational challenge.

Adapted from (Singh et al. 2025; Akinradewo et al., 2024)

Studies incorporating multi-country samples or cross-context comparisons show variations. In global surveys (Singh et al., 2025), collision risk and regulatory issues dominate in developed contexts, whereas restricted flight areas and pilot expertise concerns are more prominent in developing settings. Onososen et al. (2023) international survey highlights that economic cost factors are most critical overall, followed by technical/regulatory and then organizational barriers, suggesting contextual differences in barrier emphasis. This distribution suggests that barrier severity can vary by economic and regulatory context even when the same categories are present.

Table 2 indicates barrier ranking results including mean scores for the most significant barriers identified in expert surveys. These scores indicate how frequently or severely each barrier was rated by professionals involved in construction safety and UAV implementation.

Table 3 Barrier Influence on UAV Adoption

Barrier Construct	PLS Path Coefficient	Statistical Significance
Regulatory challenges	0.357	Strongest barrier group.
Public perception & privacy	0.207	Significant social/ethical effect.
Technical limitations	0.216	Includes battery, weather, safety systems.
Economic concerns	0.13	Cost and ROI constraints.
Environmental issues	0.23	Flora and fauna, noise and emissions.

Adapted from Daoud et al. (2025). All coefficients are statistically significant at $p < 0.05$.

This table shows the relative influence of barrier constructs on UAV adoption as modeled through PLS-SEM. Path coefficients reflect the statistical strength of each barrier grouping's negative effect on the likelihood of adoption.

Across the studies, regulatory challenges and legal ambiguity consistently appear as the most significant inhibitors. These include restricted flight zones, lack of explicit safety regulations for UAV operations in construction and inconsistent enforcement across jurisdictions. Regulatory barriers not only directly hinder flight permissions but also indirectly affect operational planning, insurance costs and the company's willingness to invest in UAV programs.

Technical limitations, especially limited battery life, vulnerabilities in adverse weather conditions, collision risks and integration challenges with construction management systems—are also frequently cited. The need for specialized piloting skills amplifies this barrier, as companies must invest in training or external specialists.

Economic concerns, particularly high initial costs, unclear ROI and operational expenses related to equipment maintenance and data processing infrastructure, remain considerable obstacles. Organizational readiness, encompassing workforce attitudes toward automation and safety technology, impacts adoption decisions significantly.

Social and ethical concerns around privacy, worker surveillance and potential job displacement contribute additional layers of resistance and complicate employer communication strategies. These factors often interact with regulatory and organizational barriers, reinforcing negative perceptions and slowing adoption.

5. Discussion

The results demonstrate a clear structural hierarchy among the barriers affecting drone adoption in construction safety, with regulatory and technical constraints consistently occupying the highest positions across the analyzed studies. This convergence across geographically and methodologically different investigations suggests that these barriers are not isolated contextual anomalies but represent systemic impediments embedded within the institutional and technological environment of the construction sector. Regulatory constraints appear not only as direct restrictions—such as limited operational zones and ambiguous safety guidelines—but also as indirect inhibitors that shape organizational risk perception, insurance obligations and investment decisions. When legal clarity is lacking, firms are less willing to formalize drone programs, which in turn suppresses technological learning and workforce adaptation.

Technical limitations emerge as the second dominant barrier cluster, particularly those related to flight endurance, collision risks, environmental sensitivity and system reliability. The consistent ranking of these issues across multiple studies indicates that operational constraints remain unresolved despite rapid technological progress in the UAV

market. From a systems perspective, these technical barriers represent performance-reliability trade-offs: drones must operate in complex, dynamic construction environments where dust, signal interference, structural obstacles and unpredictable weather conditions challenge stable flight operations. As a result, technical constraints often interact with regulatory concerns, since safety-related uncertainties reinforce stricter legal controls and organizational hesitancy.

Socio-organizational and ethical concerns also appear across the majority of studies, though with slightly lower ranking intensity than regulatory and technical factors. Issues such as resistance to technological change, workforce skill gaps, privacy anxieties and perceived job displacement contribute to adoption inertia at the organizational level. These factors indicate that drone implementation is not solely a technical decision but also a socio-technical transition that requires cultural adaptation and institutional learning. The interaction between human and regulatory barriers is particularly significant, as privacy and surveillance concerns frequently influence policy restrictions and public acceptance.

Economic constraints, while present, appear less uniformly dominant across the literature. Instead of acting as primary deterrents, cost-related issues often function as secondary barriers that are amplified by regulatory uncertainty and technical limitations. For example, unclear legal frameworks can increase compliance costs, while technical reliability issues raise maintenance and training expenses. This suggests that economic barriers may be derivative in nature, emerging from the combined influence of institutional and technological challenges rather than existing as independent obstacles.

6. Conclusion

This research synthesizes evidence from recent empirical and quantitative studies to present a comprehensive analysis of the barriers limiting the adoption of drones in construction site safety. Through adapted tables from peer-reviewed research, it demonstrates that regulatory barriers, technical limitations, economic constraints, organizational readiness and social/ethical concerns collectively shape the adoption landscape.

The analysis underscores that regulatory uncertainty is the most influential barrier, with other barriers often dependent on or exacerbated by legal ambiguity. Technical challenges related to flight performance and integration, inconsistent economic justification and workforce resistance further compound adoption difficulties.

Recommendations

To facilitate UAV adoption in construction safety, policymakers and industry actors must pursue coordinated strategies. Harmonizing aviation and safety regulations across jurisdictions will reduce uncertainty and legal friction. Investment in resilient drone technologies with extended flight capabilities and advanced collision avoidance systems will improve operational reliability. Firms should adopt structured training programs to build internal UAV competencies and foster a culture receptive to digital safety innovations. Economic interventions, such as shared UAV services, leasing and cost-benefit frameworks demonstrating long-term ROI, can lower financial barriers for smaller enterprises.

Ethical considerations must also be central. Clear policies on aerial data governance, privacy protections and worker consultation will address concerns around surveillance. Demonstrating how UAVs complement rather than replace human roles can mitigate fears of job displacement, aligning technological advancement with social acceptance.

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