THE ADOPTION OF UAV FOR CONSTRUCTION SAFETY MANAGEMENT: A SYSTEMATIC LITERATURE REVIEW

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Ensuring the safety of construction workers necessitates a proactive approach to identify and address potential hazards swiftly. Unmanned Aerial Vehicles (UAVs) have proven valuable in enhancing construction site safety by autonomously capturing and interpreting visual data. To fill this gap, this study conducted a systematic literature review (SLR) on UAVs in construction safety. The analysis reveals a significant surge in publications focusing on UAVs in construction safety, particularly peaking around 2022. Challenges in implementing UAVs for construction safety management include technical, safety, and legal barriers like weather conditions, collision risks, regulatory limitations, battery constraints, training, and piloting expertise. Additionally, research gaps highlight the importance of studies on integrated hazard identification systems, environmental impact assessments, comprehensive cost-benefit analyses, privacy concerns, and understanding barrier interactions. Addressing these aspects will facilitate a more effective integration of UAV technology in construction safety practices. The evolving discourse around UAVs in construction safety management underscores their potential. Overcoming challenges and research gaps is crucial for harnessing UAV capabilities to enhance safety measures on construction.

Keywords: construction safety; unmanned aerial vehicles; systematic literature review; digitalisation; hazard identification

INTRODUCTION

Studies highlight a continuous challenge in improving safety protocols within the construction sector, which has led to ongoing incidents of both non-fatal and fatal work-related injuries (Chong *et al.,* 2015; Kang *et al.,* 2017; Rubio-romero *et al.,* 2013). Individuals working within this sector often experience a lower standing in the

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socioeconomic hierarchy and face significantly more significant risks of disability and death than those employed in other fields (Roncancio, 2024). Data from the U.K. Health and Safety Executive (HSE) for 2020 showed that the construction industry reported the highest number of worker fatalities at 39, representing 27.5 percent of all occupational deaths in the U.K., making it the industry with the most significant number of occupational fatalities. In comparison, the transportation and storage sector saw 16 fatalities, which constituted 11.3 percent of the total deaths (U.S. Bureau of Labor Statistics, 2022).

Rasouli *et al.,* (2023) highlighted the crucial role of safety measures in the construction industry's success, underscoring the urgent need for enhanced safety and health practices in what is recognised as one of the most dangerous professions, marked by a high frequency of workplace incidents. The importance of occupational safety and health for workers is further underlined by findings from the 2022/23 Labour Force Survey (LFS). This survey revealed that over half a million workers, precisely 561,000, reported experiencing non-fatal injuries within that period, according to the Health and Safety Executive 2022/23. Beyond boosting efficiency and competitiveness, minimising disputes and conflicts, and enhancing profitability more rapidly, enhancing safety conditions in construction yields numerous additional benefits. These improvements directly result in such advantages (Li and Poon, 2013). Consequently, it falls upon construction firms to make their workers' health and safety a top priority (Yadav *et al.,* 2022).

Enhancing safety management on construction sites necessitates the introduction of an innovative approach, tool, or safety management framework that not only significantly lowers incident rates but is also efficient, cost-effective, and easy to deploy (Zhou *et al.,* 2015). This effort seeks to advance the oversight of safety practices at construction sites. The deployment of unmanned aerial vehicles (UAVs), also known as drones, could play a crucial role in achieving this objective, offering a promising solution in the area (Gheisari and Esmaeili, 2016).

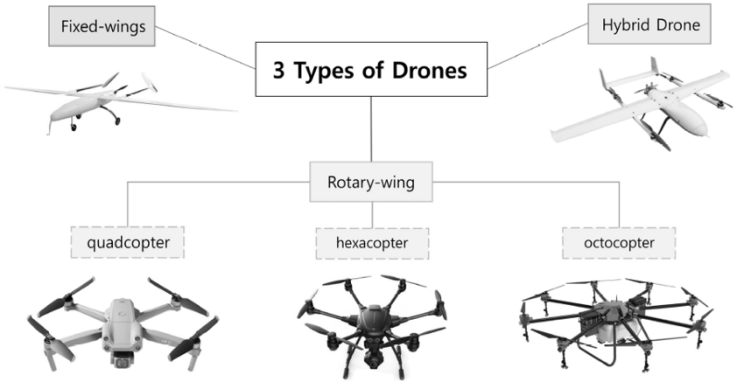
UAVs, which are increasingly utilised in construction site safety management, are growing in prominence (Aiyetan and Das, 2022). Drones utilised in construction for safety monitoring follow a structured process involving planning, deployment, data collection, analysis, and reporting. Their versatility extends beyond construction, finding applications in infrastructure management, traffic monitoring, material transport (including food and medical supplies), search and rescue operations, and security surveillance (Albeaino and Gheisari, 2021).

Variations among studies may highlight different methodologies, focus areas, and findings regarding drone efficacy in safety oversight. Research explores operator competence, technological capabilities, and regulatory adherence as pivotal factors shaping drones' role in enhancing safety practices on construction sites. A 2021 study by Jeelani and Gheisari highlighted that the construction sector leads in adopting UAV technology across civilian uses (Jeelani and Gheisari, 2021).

The surge in UAV deployment for construction safety management, as explored by Albeaino and Gheisari in 2021, can be attributed to several advantages: cost-effectiveness, enhanced navigational technology, the capability for autonomous flight, longer battery durations, and an array of integrated sensors (Albeaino and Gheisari, 2021). Furthermore, UAV technology has been identified as a key element in the digitisation of the construction industry (Onososen *et al.,* 2022). Based on past studies, existing drones have been used in construction site surveillance and safety

practices to provide visual context and enhance understanding of their utilisation in the field, as depicted in Figure 1.

Figure 1: Different types of drones



This review addresses research gaps in the use of unmanned aerial vehicles (UAVs) to enhance safety management in construction. It identifies key deficiencies, such as the lack of integrated hazard identification systems and environmental impact assessments. The review aims to comprehensively map current research, explore adoption challenges, identify gaps, and propose future directions. Ultimately, it seeks to guide construction managers in developing effective hazard identification systems, conducting environmental assessments, and navigating UAV adoption challenges to enhance safety and resource use in construction environments.

METHOD

To comprehensively explore the integration of Unmanned Aerial Vehicles (UAVs) in construction safety management, a systematic literature review (SLR) was conducted using a rigorous and systematic approach. The study aimed to assess the existing knowledge, identify research gaps, and evaluate pertinent academic articles employing specific search terms such as "UAV," "unmanned aerial vehicle," "drone," and "construction safety." The review progressed through several methodical stages, including initial selection of search strategies and keywords, utilisation of appropriate search engines, and meticulous review and selection of literature. Each stage was meticulously planned to ensure the inclusion of significant and authoritative studies aligned with the study's scope.

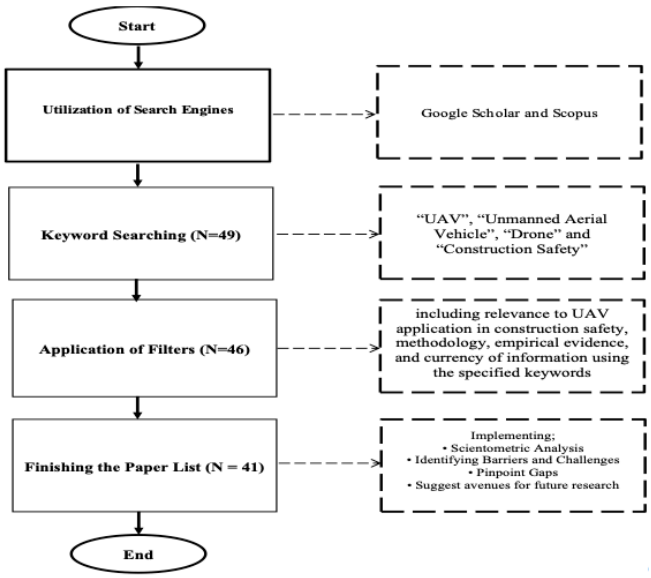
This SLR methodology was enriched by incorporating bibliometric analysis, which involves a quantitative examination of academic literature to uncover patterns and trends. This approach was favoured over the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol due to its capacity to provide a comprehensive quantitative overview of the literature landscape. It facilitated the identification of research themes, influential publications, and collaborative networks within the domain of UAVs in construction safety. This methodological framework offers a detailed insight into the step-by-step process employed to achieve the study's objectives. Additionally, Figure 2 visually represents the structured approach applied in the literature review, highlighting the systematic steps taken to investigate UAV integration in construction safety management thoroughly.

Initial Search Strategy and Keyword Selection

A detailed literature review focusing on the utilisation of UAVs—also known as unmanned aerial vehicles or drones—in construction safety was undertaken using a

systematic method. This involved an in-depth search across well-regarded scholarly databases, with a particular emphasis on Google Scholar and Scopus. The process included the careful choice of keywords and phrases like "UAV," "unmanned aerial vehicle," "drone," and "construction safety" that are directly related to the implementation of UAV technology in managing construction site safety. This approach ensured that a wide range of relevant and significant sources were considered.

Figure 2: Research Methodology Flowchart



Utilisation of Search Engines

The selection of Google Scholar and Scopus as the primary search platforms was made due to their broad spectrum of academic content across different disciplines. These databases were preferred for their effectiveness in furnishing peer-reviewed articles, conference proceedings, and other relevant documents around UAVs and construction safety management, guided by the chosen keywords.

Screening and Selection Process

The selection and screening phase was carefully conducted to ensure articles that matched the study's focus on UAV utilisation in construction safety management were chosen. After the initial search, 41 articles were identified through their titles and abstracts by applying specific keywords. To ensure a transparent and exhaustive review, the next step involved a detailed analysis of these articles' full texts. This in-depth review of the content, methodologies, and outcomes of each article aimed to refine the selection, prioritising works that intricately discuss the intricacies of UAV adoption while making substantial contributions to the overall conversation on managing safety in construction.

Criteria for Relevance

Articles were evaluated against set standards, focusing on their pertinence to the use of UAVs in enhancing construction safety, the rigor of their methodology, the presence of empirical data, and the timeliness of the information, all aligned with the specified search terms.

Selection and Refined Subset

The selection methodology began by pinpointing articles through the designated keywords, initially filtering them by their titles and abstracts. This process led to a narrowed-down group of 14 articles deemed highly relevant to the study's goals, satisfying the established criteria for this review's inclusion.

This approach is in harmony with the review's broader aims to develop an extensive scientific overview of the current knowledge landscape, uncover obstacles and challenges, identify existing research gaps, and propose directions for future investigations concerning UAV implementation in construction safety management.

FINDINGS AND DISCUSSION

Result of Science Mapping

Citation Analysis by Journal

The citation analysis of journal articles reveals a significant number of references related to construction within the engineering sector, as shown in Figure 3 (a). This highlights a distinct link between the construction industry and engineering as a field. The areas of civil engineering and construction automation mainly show how closely unmanned aerial vehicles are related. An examination of journal citations shows that the articles reviewed for this study are relevant to the research topic at hand.

Co-Authorship Analysis by Country

The results of the co-authorship analysis show that a significant portion of the papers come from the United States, as shown in Figure 3 (b). Additionally, it becomes clear that the primary emphasis of these articles is on the application of Unmanned Aerial Vehicles (UAVs) in developed nations, including the United States, United Kingdom, and Australia. There is a noticeable gap in the academic literature regarding the exploration of emerging technologies in developing countries.

Co-Author Network

The analysis of the co-author network highlights Dr. Gheisar as the leading contributor on this subject, evidenced by the largest quantity of high-quality publications authored, as shown in Figure 3 (c). Following Dr. Gheisar, Dr. Irisarry is recognised for substantial contributions in this area. Prominent authors in the field also include Jeelani I., Esmaeili B., Kim S., and Costa D. B.

Trend of Publications

The analysis of publication trends from 2012 to 2023 sheds light on the evolving focus on the use of Unmanned Aerial Vehicles (UAVs) to improve safety practices in the construction sector, as shown in Figure 4. The findings indicate a significant growth in the volume of related publications, with a pronounced spike occurring in 2022. This increase points to a marked expansion in academic interest and discussion during this time. The peak in publications could be attributed to several factors, including advancements in UAV technology, greater implementation within the industry, or key discoveries in research. These elements likely spurred an uptick in research activities, positioning 2022 as a key year for investigating the role of UAVs in enhancing construction safety management.

Outcomes of Content Analysis

Identification of Barriers

The emergence of UAVs in construction safety presents hurdles that can hinder the progress of safety management. Identifying and addressing challenges, including technical issues, safety concerns, and legal constraints, is crucial for advancement. Key obstacles cited include adverse weather, collision risks, legal limitations, battery constraints, training requirements, and piloting skills. While these technical issues do not expose personnel to increased potential for harm on construction sites, they must be managed to ensure the effective integration of UAVs in construction safety practices.

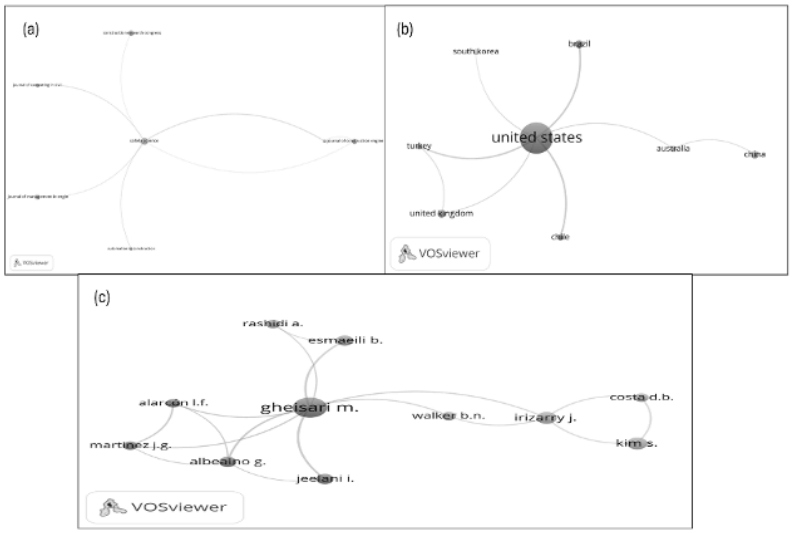


Figure 3: Analysis: (a) Journal contributions; (b) Co-authorship Analysis by Country (c) Co-Author Network

Figure 4: Trend of Publications

Figure 5: Barriers and Sub-Barriers of UAVs' Adoption (Jeelani and Gheisari (2021), Gheisari and Esmaeili (2019), Melo, R R et al., (2017), Khan, M et al., (2023), Ahn, H et al., (2023), Ilić, et al., (2022), Wang, X et al., (2023), Nwaogu, J M et al., (2023), Onososen, A O et al., (2023), Hassandokht Mashhadi, A et al., (2022), Aiyetan, A O and Das, D K (2022), Umar, T (2020), Martinez, J G et al., (2021), Albeaino, G and Gheisari, M (2021)

Existing gaps and potential future works

Current research on Unmanned Aerial Vehicles (UAVs) in construction safety management has revealed several uses and challenges, but many areas remain unexplored. While previous research has shed light on UAV use and problems, numerous critical aspects need more study. These deficiencies present an opportunity to improve UAV deployment and emphasize the need for future research to remedy them, enabling the full integration of UAV technology into construction safety management methods. This analysis found two main gaps in UAV research on construction safety management that could benefit from future efforts. First, while prior studies monitor worker movements in real-time, they do not include an integrated system for hazard detection. Future research could use AI or machine learning to spot hazards immediately by evaluating worker conduct and environmental context, fostering a proactive safety culture. The existing literature does not adequately address drones' environmental impact on buildings. Future drone environmental impact evaluations could include carbon footprints, noise levels, and animal impacts to promote sustainable construction.

Drone integration into safety protocols requires extensive cost-benefit studies to determine economic and long-term financial gains. Future research should also examine drones' potential as safety trainers, helping workers develop safety awareness. The literature also doesn't explore how construction UAV deployment barriers interact. Humidity and severe temperatures affect UAV operations, but little is known about how they affect battery technology and sensor sensitivity (Xu and Turkan, 2022). Privacy concerns about constant drone surveillance in construction have been ignored. For safety surveillance drone deployment, future studies should address worker privacy and data security techniques and rules.

CONCLUSION

The review underscores the potential of unmanned aerial vehicles (UAVs) to enhance construction safety practices. It outlines challenges and avenues for future development, mapping out the intricate connections between construction, engineering, and safety management. Major obstacles include technical issues, legal regulations, and safety concerns. Addressing these challenges and research gaps is crucial for integrating UAVs effectively and safely into construction protocols. The review emphasizes the need for an integrated approach, considering environmental impacts and adopting advanced algorithms for hazard detection. It also calls for cross-disciplinary collaboration and global perspectives to promote safer construction practices.

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