Challenges and Enablers for Drone Application in the Construction Industry

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Abstract:
Drones are employed for various applications such as inspections, surveying, mapping, and monitoring work progress. These application areas are core aspects of construction activities, thus, increasing drone adoption in the construction industry over the years. However, with the adoption of digital technologies comes factors that influence their use. This study determines the challenges and enablers of using drones in construction by reviewing existing literature and social media discussions. A total of 128 peer-reviewed articles and 460 tweets related to drone adoption in the construction industry were retrieved from the Scopus and Twitter databases, respectively. The data were analysed quantitatively and qualitatively, and themes were developed. The results showed that drone adoption challenges are related to policy issues, safety concerns, and knowledge and awareness. In comparison, the enablers include efficiency and cost reduction. By identifying the factors influencing drone adoption, strategies can be developed to effectively provide construction organisations with the best opportunities to use drones for their construction processes.

Keywords:
Drone, UAVs, Challenges, Enablers, Construction Industry, AEC.

1 Introduction

The use of drones for construction activities has increased over the years, with a more than 200% increase in one year, making the construction industry the fastest adopter of commercial drones (Jeelani and Gheisari, 2021). Commercial drones differ from military drones because they are more cost-effective and portable for civil applications such as entertainment and industrial use (Li and Liu, 2019). Drones have become an important part of industrial processes such as construction and infrastructure because of their ability to collect data faster, more economically and reach hard-to-access areas than other techniques (Greenwood et al., 2021). Depending on how a drone is operated, a number of terms are used to describe it. The terms include Unmanned Aerial Vehicles (UAVs), Unpiloted Aircraft System (UAS), and Remote Piloted Aircraft System (RPAS). UAV refers to any aerial vehicle that does not depend on an onboard pilot for flight; it can either be controlled autonomously by software or remotely (Golizadeh et al., 2019, Adepoju, 2022). However, for simplicity, the term drone is used in this paper.

Drones are equipped with high-resolution cameras, Global Positioning System (GPS), radio-frequency identification readers, laser scanners, and remote sensors, which facilitate their use for collecting data in industrial settings (Adepoju, 2022). Drones have found various uses in the construction industry. They are used to perform construction activities such as security and safety monitoring, traffic monitoring, survey mapping, site navigations, pre-construction site assessment, aerial surveying, monitoring site progress, and various forms of inspection (Adepoju, 2022). Despite their benefits and promotion among the academic community, they have drawbacks. Jeelani and Gheisari (2021) noted that drones pose new risks to the workplace. For instance, they are a source of safety concerns on construction sites and privacy concerns to the community. Their drawbacks form challenges to use and retention within the construction industry. Although there are many studies on drone adoption, areas of use and benefits within the construction industry, there is a dearth in studies examining the challenges and enablers to adoption or use within the construction industry from a sentimental analysis perspective.

Jeelani and Gheisari (2021) examined the safety challenges and risks that drones pose to people working on construction sites using an empirical survey. Golizadeh et al. (2019), using a systematic review, focused on the barriers to using drones. This study intends to fill the gap by reviewing the existing literature and social media discussion to determine what forms the challenges and enablers of drone use. To determine the aim, the objectives of the study are: (i) to determine the motivators and drawbacks of drone use; and (ii) to determine the sentiments of drone users within the construction industry. This paper analyses how drone application is conceived and consented by using academic literature and Twitter data. It contributes to the drone in construction literature in several ways. It explores Twitter Analytics to shed light on how and why the drone application is debated on one of the most influential social media platforms. It further reinforces the need for scrutiny of drone use to enable attention to what form drawbacks in order to fix them for drone adoption and retention within the construction industry. Scopus database was consulted for the data retrieval because they are the largest database for peer-reviewed studies within the field of construction and engineering (Nwaogu et al., 2020). Also, Twitter was preferred because it is the most popular social media platform with the largest free and open data source (Sharma and Ghose, 2020).

2 Literature Review

Jeelani and Gheisari (2021) examined the risks posed by drones on people working with them or around them on construction sites as well as enabled an understanding of economic, social, and personal costs associated with such risks. The identified risks were physical risks, attentional costs, and psychological impacts. Physical risks arise from errors in the drone hardware or software; errors from the flight team during navigation and flight planning (Jeelani and Gheisari, 2021). Attentional risks arise from distraction from drone noise and sightings, which can have secondary safety implications. Psychological impacts are attributed to anxiety and stress that arises from the feelings of being watched (Jeelani and Gheisari, 2021). Golizadeh et al. (2019), examining barriers to drone use, categorised them as technical difficulties, restrictive regulatory environment, site-related problems, weather and organisational.

Despite the shortcomings of drones, their benefits or advantages motivate or enable people to use them. Drones have been deduced to be used for various activities, such as security and safety management, quality management, time management, traffic monitoring, survey mapping, site navigations, site assessment, aerial surveying, monitoring site progress, and inspection (Adepoju, 2022, Greenwood et al., 2019, Li and Liu, 2019). This study defines challenges as reasons or drawbacks that prevent the use of drones for construction activities. Motivators or enablers refer to catalysts, reasons, or factors that enhance the use of drones within the construction industry.

3 Research Methodology

3.1 Scientometric review

A scientometric review of journal articles published from 1980 to 2021 was conducted. The networks were constructed through two types of analysis: co-occurrence of keywords and cluster analysis. Scientometric analysis is a quantitative technique that aids in mapping and synthesising literature in a specific field (Ali et al., 2021). Co-occurrence keyword analysis indicates the research areas explored and provides a good picture of the conceptual structure of a research field (Nwaogu et al., 2020). Cluster analysis is used to identify the intellectual base and research front within a particular unit of analysis (Nwaogu et al., 2020, Olawumi and Chan, 2018). In scientometric analysis, the node or link size reflects an item's importance or influence (Nwaogu et al., 2020). Therefore, the larger the node, the larger the influence or importance of the item. VOSviewer uses two standard attributes to determine importance: Links and Total Link Strength (TLS). The *Links* indicate the number of links of an item with other items, and *TLS* indicates the total strength of the links of an item with other items (Van Eck and Waltman, 2013).

3.1.1. Retrieval of Literature from Scopus database

Scopus database was systematically searched using search syntax (TITLE-ABS-KEY ("UAV" OR "Unmanned Aerial Vehicle" OR "drone" OR "UAS" OR "Unmanned aerial systems" OR "RPAS" OR "Remotely piloted aircraft systems") AND TITLE-ABS-KEY ("construction industry" OR "engineering" OR "AEC" OR "construction sector"). The inclusion criteria at the stage of the search were limited to: articles published between 1979 and 2022, only articles at the final publication stage, and written in the English language. The initial search produced 6408 documents. The search was refined by limiting the search with the inclusion criteria. Therefore, 960 peer-reviewed journal articles were automatically retained. To ensure that only articles relevant to AEC and the construction industry were retrieved, the abstracts of the articles were read. It was deduced that only 132 articles focused on the AEC industry. The articles were read, and only 128 met the inclusion criteria. The 128 articles were subjected to scientometric analysis and review, and the findings are discussed below.

3.2 Social Media Review

The purpose of the social media review was to perform sentiment analysis which may help to address future research directions by comparing the opinions of drone users or promoters with academic research. An online search via the Twitter database was undertaken; thus, the results might not cover the sentiments of drone users in the construction industry on all social media platforms. Sentiment analysis is the study of people's opinions, emotions, appraisals, and attitudes towards something, e.g., product, service, organisation, individual, topic, or event (Zhang et al., 2018).

The search terms used on Twitter were "drone" "construction", "drone" "construction industry". The tweets were limited to those written in the English Language. The Twitter data was collected and analysed using MAXQDA. However, MAXQDA only allows the retrieval of data within one week (De Lima, 2022). To facilitate capturing older data during the data search, all the conversations found were retweeted to the time frame in order to analyse them. The search frame was 2nd September 2022 and 9th July 2022 and contains tweets from 2020 to 9th September 2022. The tweets imported to MAXQDA were analysed using the autocode hashtags and sentiments in the MAXQDA software. The hashtag function in Twitter and other social media platforms allows people to easily follow discussions, and often, trending topics stem from hashtagged words (De Lima, 2022). Hence, the hashtag is used to determine the relevant topics or keywords in discussions related to drone use within the construction domain.

Sentiment analysis in MAXQDA uses a polarity lexicon and a set of rules to identify the sentiments of tweets (De Lima, 2022). The tweets' polarities are calculated and based on the weight, and the sentiments are classified as no sentiment, negative, slightly negative, neutral, slightly positive and positive. This classification helps to understand people's views about drone use within the construction industry. The vocabulary in the tweet is used to characterise the perception of the tweeps towards the drone concept. For hashtag and sentiment analysis, the code

4 Findings and Discussion

4.1 Findings

4.1.1 Co-occurrence Keyword Word Analysis based Scientometric Analysis

The minimum number of occurrences for keywords was set at 5; with 1453 keywords in the documents, 43 keywords met the threshold. However, to determine keywords unique to the studies, terms (including search terms) generic to the construction industry were eliminated. The keywords unique to the studies and their clusters are detailed in Table 1. The cluster theme was deduced by reading the keyword with respect to the articles in which they appeared. The network of the keywords in Table 1 had 5 clusters, 143 links, and 282 TLS (see Figure 1). The clusters signal the hotspots or research areas for drone application within the construction industry, and they were categorised into inspection and mapping, data processing and management, safety and health management, challenges and risks of drone use, and training aid.

The network frequency revealed that antennas, inspection, photogrammetry, safety engineering, accident prevention, aircraft detection, and robotics are the most co-occurring keywords in the literature related to drone use in the construction industry. The overlay visualisation further revealed that these keywords have an average publication year 2020, signalling increased consideration to use drones for safety management of on-site personnel.

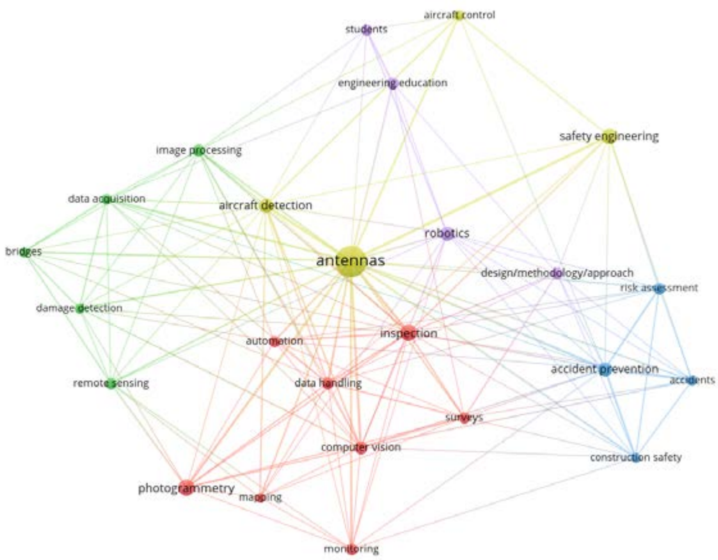

Figure 1. Research areas of drone application within the AEC industry based on keyword analysis

Table 1. Research areas where drones are applied based on keywords co-occurrence analysis

Cluster	Themes	Keyword	Occurrences	Total Link Strength	Avg. Pub. Year
1	Inspection and Mapping	Inspection	14	35	2019
		Computer Vision	9	29	2019
		Data Handling	8	25	2019
		Photogrammetry	14	21	2019
		Surveys	7	19	2019
		Monitoring	7	15	2020
		Automation	7	14	2019
		Mapping	5	12	2019
2	Data Processing and Management	Data Acquisition	6	20	2019
		Damage Detection	5	16	2019
		Image Processing	8	16	2018
		Bridges	5	15	2019
		Remote Sensing	7	14	2019
3	Safety and Health Management	Accident Prevention	11	37	2019
		Accidents	6	18	2020
		Construction Safety	5	19	2020
		Risk Assessment	7	16	2019
4	Challenges and Risks of Drone Use	Antennas	50	109	2020
		Safety Engineering	13	20	2020
		Aircraft Detection	11	34	2020
		Aircraft Control	6	12	2019
5	Training Aid	Robotics	10	19	2019
		Design/Methodology/Approach	8	12	2019
		Engineering Education	8	11	2020
		Students	7	10	2019

4.1.2 Hashtag/keyword analysis based on Twitter Data

A total of 460 tweets were retrieved from the Twitter database. Using the analyse tweet function, it was deduced that the tweets had 169 hashtags. Table 2 shows the most popular hashtags used in the 460 tweets. Among the topmost hashtags (#bullettrain, #mahsr, #nhsrcl) were related to rail project awareness in India. Aside from these hashtags and generic/search terms (drone, drones, construction, construction industry), the most popular hashtag includes "safety"; # safety was used 35 times. These hashtags represent the core topics of interest in drone use discussion on Twitter. By autocoding the tweets using 20 hashtags selected from the 169 hashtags, some topics and respective discussions within the Twitter database regarding drone applications in the construction industry could be indicated. By comparing the results from the Twitter analysis and scientometric review, it can be inferred that topic areas include drone application areas, e.g., surveying, mapping, progress monitoring, and safety. Figure 2 illustrates some exemplar tweets under the #safety.

Table 2. Most frequently used hashtags in the drone in construction discussion on Twitter

Hashtags	Frequency	Percent	Percent (without other)
#construction	134	10.11	19.94
#drone	97	7.32	14.43
#bullettrain	78	5.88	11.61
#mahsr	78	5.88	11.61
#nhsrcl	78	5.88	11.61
#drones	52	3.92	7.74
#safety	35	2.64	5.21
#building	23	1.73	3.42
#architecture	20	1.51	2.98
#uav	17	1.28	2.53
#engineer	15	1.13	2.23
#technology	15	1.13	2.23
#constructionindustry	11	0.83	1.64
#innovation	10	0.75	1.49
#ai	9	0.68	1.34
TOTAL (without other)	672	50.68	100.00
OTHER	654	49.32	-
TOTAL	1326	100.00	-

Note: "Other" consist of keywords with a frequency of less than 8

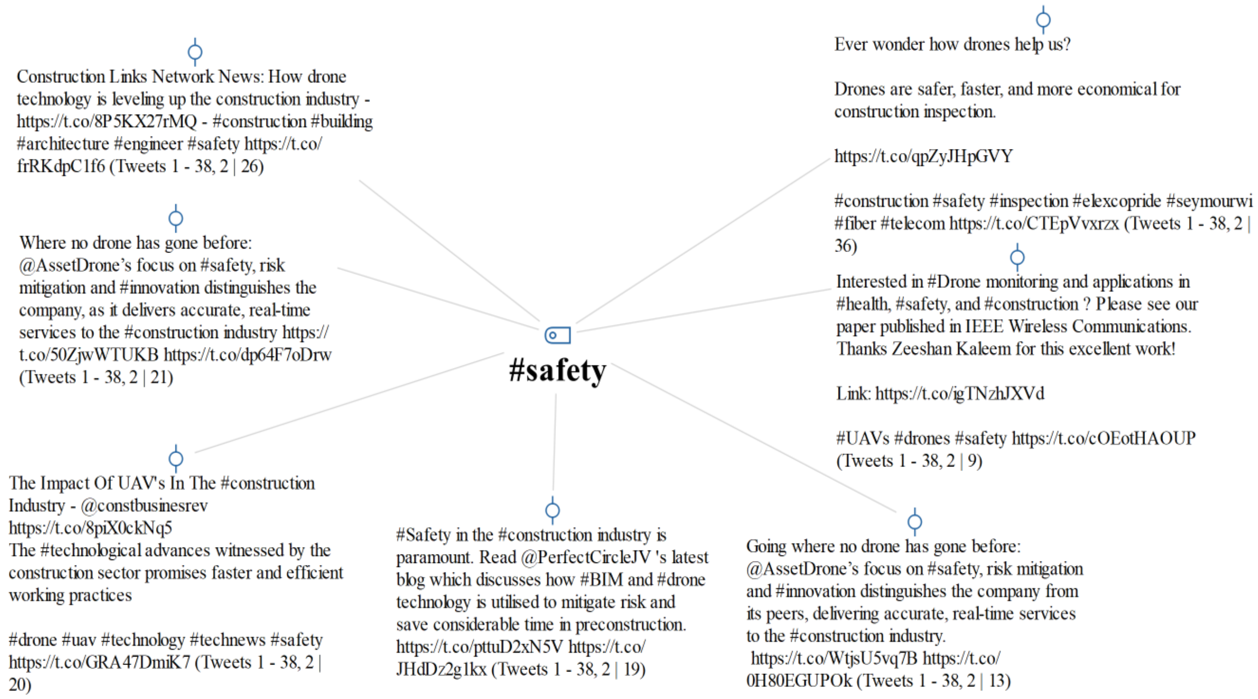

Figure 2. Screenshot of #safety and some corresponding tweets

4.1.3 Sentiment Analysis

Figure 3 shows the sentiment analysis results regarding drone discussions on Twitter. Approximately 54% (249) of 460 tweets revealed slightly positive sentiment, 39% (180 tweets) neutral sentiment, 5.7% (26) with slightly negative sentiment, and 0.2% (1) with negative sentiment. Finally, 0.9% (4) tweet has positive sentiment. Overall, the results highlight that the opinion expressed through Tweets shows that people demonstrate a positive attitude toward drone application within the construction industry. For example, as illustrated in Figure 4, some Twitter users have emphasised that drone applications can help improve health & safety monitoring within the construction industry.

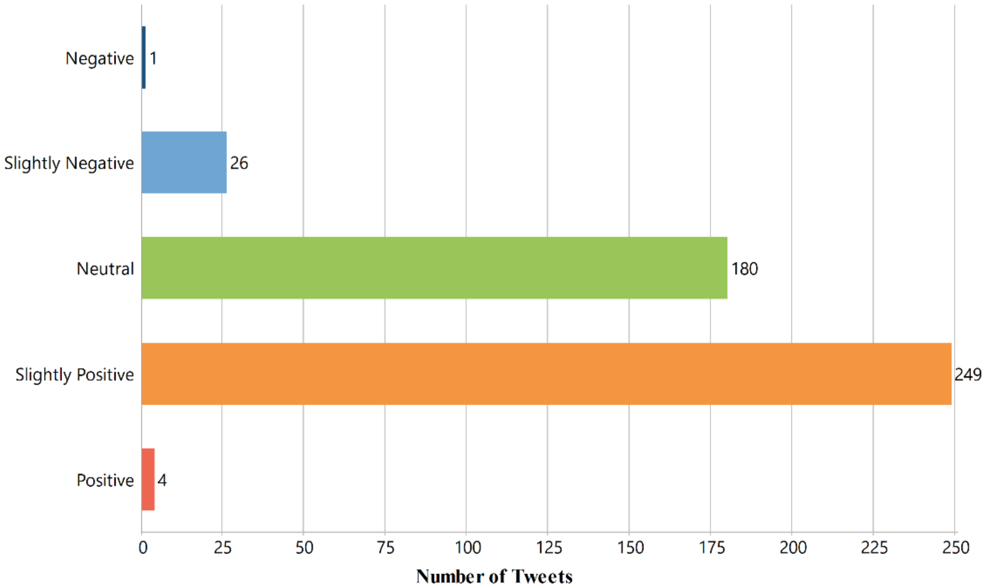

Figure 3. Sentiment analysis results of drone discussions on Twitter.

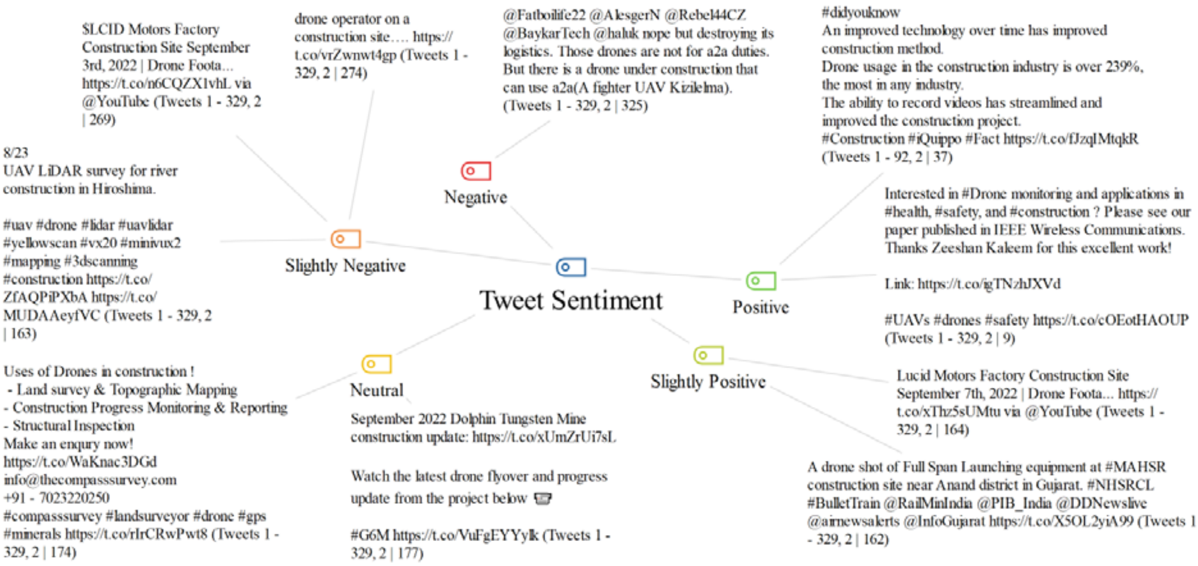

Figure 4. Exemplar tweets illustrating the identified sentiments.

4.2 Discussion

4.2.1. Twitter review and comparison with academic research

By comparing the information collected from Twitter discussion and academic literature, three patterns were deduced: (i) popular application for drones in the AEC industry, (ii) safety challenges/risk, (iii) the sentiment of the Twitter discussion appears to be directed towards use, benefits, and advertisement of service or product, or showcase of projects while opinion about drawbacks of drones are often not discussed.

(i) Popular application for drones in the AEC industry- for both types of analysis, it is deduced that the hotspots or research areas for drone application within the construction industry include inspection and mapping, data processing and management, safety and health management and safety challenges. Unlike discussions in academic research captured by scientometric review, Twitter discussions did not signal drone use for training purposes.

(ii) Safety challenges and risks of drone use - Twitter discussions rarely contained opinions about barriers and/or challenges to drone use. Specifically, Twitter discussions related to safety concerns were by academic researchers "Idris Jeelani" and "Masoud Ghesari".

"While the benefits of drones in construction are always at the forefront, their impact on human workers is seldom discussed. In our new article @MasoudGheisari and me examine the health & safety impacts of drones on construction workers. More at https://authors.elsevier.com/a/1diMW3IVV9nDgV (Tweets 1 - 329, Column: 2 | Row: 19)" "Information on our projects on "Safe Human-Drone Interaction in Construction" can be found at: https://t.co/zU7jVfO2lM Thanks to @NSF @USDOL @CPWR for supporting these projects. @UF @UFdcp @UFRinkerSchool (Tweets 1 - 329, Column: 2 | Row: 62)".

4.2.2 Motivations / enablers for Drone Adoption

The motivations or enablers of drone adoption within the construction industry are numerous. For instance, the virtual reality (VR) immersive experience built with drone-based photogrammetry could improve project communication among stakeholders during project planning, design, and construction phases. Additionally, site images captured from a drone can facilitate claims and legal processes as they can be used for litigation following an accident site (Gheisari and Esmaeili, 2019, Grosso et al., 2020). Other motivations or enablers deduced in academic literature, and Twitter analysis for drone adoption within the construction industry include effective problem identification, reduced inspection cost, accident analysis, and claims and legal. In this study, the motivations or enablers are discussed with respect to the keywords "inspection and mapping", "data processing and management", "safety and health management", and "training aid", as they represent the research focus in the literature.

i) Data processing and management: Photogrammetric models obtained from drones are an alternative to LiDAR scans (Greenwood et al., 2019, Hugenholtz et al., 2013) because drone video images are of high resolution. Thus, they give clarity and characteristics to ground surface features.
ii) Inspection and mapping: With drones, the cost of inspecting high-rise structures such as towers is reduced since the number of workers needed can be reduced (Gheisari and Esmaeili, 2019, Grosso et al., 2020). When aerial photographs are taken using drones, it is easier to identify work progress, problem areas, and maintenance needs on-site (Perez et al., 2015). Thus, time spent on inspection and mapping is reduced, and efficiency is improved.
iii) Safety and health management: It is used for accident analysis and safety performance. Images or videos collected with drones can be used to identify points of accidents. It would enable near-miss analysis, and the findings can be used to provide safety training to personnel (Gheisari and Esmaeili, 2019). When drones inspect hard-to-reach areas which typically pose safety hazards to humans, safety performance can be achieved (Grosso et al., 2020). They also facilitate hazard recognition in site equipment.

(iv) Training aid: Drones are being adopted for training purposes in tertiary institutions (Lobo et al., 2021). With drones, students can securely engage in virtual field trips without real field trips (Hernandez-de-Menendez et al., 2020). It can facilitate the acquisition of technical knowledge, development of skills in spatial visualisation, understanding of abstract things and retention among students. Additionally, drone careers such as drone piloting, software programming, design and fabrication of drones using Computer Aided Design and rapid prototyping are increasing (Lobo et al., 2021, Cañas et al., 2020). Thus, drones as training aid will prepare prospective graduates to occupy such positions.

4.2.3 Challenges to using drones in the construction industry

While there are motivations or enablers to using drones in the construction industry, several drawbacks to using them were deduced. The challenges are related to hardware maintenance, privacy concerns, lighting, regulatory hurdles, liability and legal concerns, safety concerns, technical issues, piloting and training, weather, knowledge and awareness and high capital cost.

(i) Hardware maintenance - short-term scheduled maintenance is required needed, as failure to do so may lead to motor and propeller failure (Greenwood et al., 2019)

(ii) Privacy concerns - drones are equipped with cameras, sensors, and night vision technology that could violate human rights, especially when flown without permission or in prohibited areas which makes privacy a challenge to using them (Jalinoos et al., 2020)

(iii) Lighting – lighting conditions, camera positions, and image acquisition methods limit the use of drones for inspection (Jalinoos et al., 2020). In the US, present rules indicate that drones for work or business-related tasks must be flown only during the daytime; and Part 107 of the US Federal Aviation Administration (FAA) waiver must be gotten for flights at night (Gheisari and Esmaeili, 2019)

(iv) Regulatory hurdles – acquiring proper permissions and understanding flight limitations can span months (Greenwood et al., 2019)

(v) Liability and legal concerns - liability and legal concerns related to using drones arise from personal injury and property damage that error in operation can cause; and invasion of privacy, trespassing, property rights, or insurance issues (Gheisari and Esmaeili, 2019)

(vi) Safety concerns - hazards arise from flying drones over a job site. The hazard may occur if the drone collides with a piece of equipment or birds or falls or due to human errors (Gheisari and Esmaeili, 2019, Greenwood et al., 2019)

(vii) Technical issues - technical challenges range from battery life, radio interference, and sensors to mount on drones that should be clarified before using drones on a construction site (Gheisari and Esmaeili, 2019, Grosso et al., 2020)

(viii) Piloting and training - Based on the FAA requirements in the US, only a certified pilot is required to fly drones in commercial applications (Gheisari and Esmaeili, 2019). Training is necessary to acquire the skills to fly drones safely on construction sites.

(ix) Weather - the operation of commercial drones can be affected by rain, fog, snow, and wind (Gheisari and Esmaeili, 2019, Golizadeh et al., 2019)

(x) High Capital Cost - drone technology requires high capital investment regarding acquisition, maintenance, and cost of personnel training (Adepoju, 2022, Greenwood et al., 2019).

(xi) Knowledge and awareness - Knowledge and awareness about drones and their legal or procedural requirements influences safety and privacy concerns surrounding drone use (Aydin, 2019).

Restrictive regulations regarding flight procedures make using drones a challenging task. The restrictive regulations are due to integrity, privacy concerns about the information collected and public concerns that drones are used for surveillance (Greenwood et al., 2019). The drone policy or regulations mostly discussed in the literature is the US Federal Aviation Administration (FAA) Part 107. Drone regulations have a lot to do with respect to mitigating the challenges and barriers to drone use. The drone-related regulations presently available in countries such as USA, China, and the UK are generalised and could contribute to safety and health challenges. Generalised drone policies (e.g., flight zone restrictions) can heighten unsafe conditions such as distraction and accidents, especially when used on construction projects. Every construction project is one-off as the resources, constraints, and risks are unique and would require unique regulations. For instance, the project site changes rapidly, and the sites are congested, posing unique safety challenges that are heightened when the workers have to share such space with drones (Jeelani and Gheisari, 2021). The regulations for a new site may differ from those for an active construction and engineering site because occupational safety and health risk vary with the nature of the site and type of project. Therefore, there is a need to develop industry regulations that consider the uniqueness of the construction industry and the factors that affect drones' use on construction sites.

The shortcomings or challenges of drone use that pose safety risks on construction sites include noise and accidents. The causes of drone-related accidents include loss of control, pilot error, unplanned landing, system malfunction, flight terminations due to low battery, atmospheric conditions, and collisions with interference (Namian et al., 2021). A suggestion to reduce the probability of incidents on construction sites is that drones are flown during the off-hours or only when the premises are free. However, the suggestion may always be feasible as it defeats the purpose of using drones for some activities, such as real-time monitoring of projects for safety and total quality management. Hence, adopting cutting-edge technologies may be a more viable solution to help keep drone operations safe. In order to improve safety, cutting-edge technologies have been introduced to keep drone operations safe. The technologies include parachute, geofencing, computer vision, and Airsense (Al-Madani et al., 2018, Murison, 2019). Attention has been drawn to pilot error as a recurring reason for drone accidents (Namian et al., 2021, Lu et al., 2019). Thus, it becomes more necessary to mitigate human factors for safety improvement. To achieve this, theories on risk mechanisms, e.g., the Human Factors Analysis and Classification System (HFACS) for analysing accident causality (Lu et al., 2019) and Human Performance Model (Doroftei et al., 2020) used to evaluate the relationship between human factors and the pilot performance, would benefit the construction workplace. With the theories, latent failures that led to an incident can be identified by real-time monitoring of latent failures (Stark et al., 2013).

5 Conclusion and Further Research

This study provides a scientometric and sentiment review of the body of knowledge on drone adoption within the construction industry to deduce the motivators and challenges to drone use in the industry. A total of 128 peer-reviewed articles and 460 tweets related to drone adoption in the construction industry were retrieved from the Scopus and Twitter databases, respectively. The motivators were itemised in relation to inspection and mapping, data processing and management, safety and health management, and training aid. Four motivators and nine challenges to drone application in the construction industry were identified. This study deduced that drone policy or regulation primarily discussed in the literature is the US Federal Aviation Administration (FAA) Part 107. Likewise, the drone-related regulations presently available in countries such as USA, China, and the UK are generalised, which could contribute to safety and health challenges. Therefore, there is a need to develop industry regulations that consider the uniqueness of the construction industry and the factors that affect drones' use on construction sites. Of the identified challenges, knowledge and awareness about drones and their legal or procedural requirements among professionals and the communities over which they fly are relatively less discussed within the construction industry. Understanding the legal requirements to operate drones commercially is an important aspect of drone use (Lobo et al., 2021). Therefore, awareness should be intensified to help drone users and the general public understand drone policies and requirements concerning the type of drone used and the activity to be carried out. More studies focused on safety management strategies, safety knowledge, and training to prevent drone-related accidents are required to identify drone-related hazards and associated safety risks in order to mitigate the safety risk of utilising drones on construction sites. The training will equip operators with hazard recognition and safety risk perception skills to prevent drone collision hazards. More studies in the construction industry focused on human physiological/cognitive responses and their impact on pilot performance are needed to mitigate human factors-related incidents. It is also recommended that researchers involved with drone application should spur more intriguing discussions surrounding drone use in the construction industry on social media, especially Twitter. This could increase the availability of qualitative data about drones' drawbacks, which pose challenges or barriers to use.

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