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REVIEW ARTICLE

Using drone technologies for construction project management: A narrative review

Serkan Yıldız [1], Serkan Kıvrak [*1], Gökhan Arslan [2]

[1] *Eskişehir Technical University, Department of Civil Engineering, Eskişehir, Turkey*
[2] *Yalova University, Department of Civil Engineering, Yalova, Turkey*

Abstract

The construction sector is one of the sectors where productivity is low compared to other production sectors. Studies have shown that drone technologies can increase productivity in construction. Thus, the use of drones in construction sites has increased in recent years, especially in developed countries. Although drones are technical aerial vehicles, this study focused on non-technical aspects of the use of drone technologies such as current and possible usage areas, advantages and disadvantages of using a drone, issues that should be considered while procuring a drone for a construction site and legal regulations related to the use of drones. In this context, a narrative literature review was conducted and articles examining the use of drones in construction sites were investigated. In addition to the studies in the literature, practical applications were also discussed. The study indicated that drones might make significant contributions to construction management activities. It is expected that this study serves to increase the use of drone technology in construction project management by introducing it in a comprehensive way to the stakeholders.

Keywords

Construction site; Construction management; Drone; Technology; Unmanned aerial vehicle

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1. Introduction

A drone is a recognizable aircraft that has a compact design but is variable in size. Besides images such as video footage and photographs, drones also collect other data and footage to feed directly into other software, such as mapping. There is no pilot or passenger in a drone, and they are either remotely controlled through computer-aided flight routes with the sensors or autonomously [1]. Thus, they are often called UAVs (unmanned aerial vehicles) or UASs (unmanned aerial systems). There has been a tremendous improvement in drone technology in recent years, and civilian use of drones has become very popular. The drone market was estimated to be 11.3 billion USD in 2016, and it is expected to grow to more than 140 billion USD in the next ten years [2]. Civilian drones can be divided into four main types: multi-copters, airships, fixed-wing UAVs and rotary blade UAVs [3]. Their design and usage create the main difference between them. With its aircraft-like design, fixed-wing drones can glide along established routes and reach higher altitudes, thereby effectively drawing topographic maps and measuring longer distances. However, fixed drones can only fly forward. Rotary drones are a better

* Corresponding author
Email: serkankivrak@eskisehir.edu.tr

option for aerial inspection and close-up photography because they are easy to control, and their rotor design allows them to float and remain stable [4].

Some of the significant benefits of drone technology include [5]:

- Reduced processing and analysis times
- Lower risk and therefore lower costs
- More precise digital data for more accurate readings
- Easily accessible via cloud-based integration
- More continuous monitoring of jobsite progress

Typical commercial construction projects are 80% over budget and 20 months behind schedule. Industry leaders are deploying new technologies, such as drones, to reduce costs, increase efficiency in the field, maximize profit potential, and reduce the impact and waste of every project [5]. The rapidly growing drone market has spurred the expansion of its application in various economic sectors, including construction. A report shows that drone technology is expected in the UK to increase the gross domestic product (GDP) of the construction and industrial sectors by £8.6 billion through innovations, productivity and profitability by 2030 [6].

In recent years, drones have become one of the most intriguing trends in the construction sector. A 239% growth, which is higher than any other commercial sector, has been experienced in using drones in the construction sector (Fig. 1). Their aerial vantage point and data collection capabilities made them viable tools, offering benefits ranging from on-site security to remote monitoring [7]. Over the past few years, researchers have explored various drone applications in the construction industry, including site and safety inspection, progress monitoring, damage assessment, and building maintenance [4-7]. Small, inexpensive, remotely controllable commercial drones are advantageous since they can enter spaces inaccessible to personnel or manned aircraft and handle certain construction tasks in less time and at a lower cost. The new generation of drones also requires minimal human involvement, which can reduce risks in the workplace.

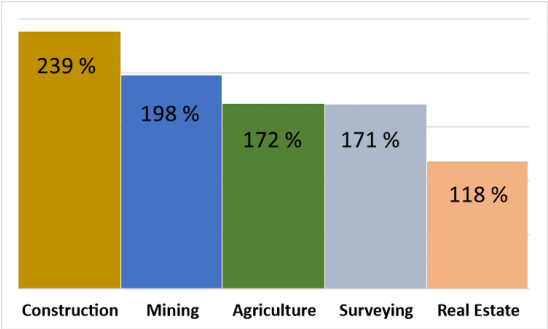

Fig. 1. Growth in the usage of drones in different industries in 2017 [7]

Additionally, advancements in sensors, batteries, and autonomous functions have made drones a more reliable construction application platform. Today's commercial drones can be equipped with a wide variety of sensors, which automatically navigate and collect data and transmit them to a control station in real-time [8].

In particular, the benefits of drone technology have completely changed the entire project life cycle from the start of the project to the end of the project. Photos, videos, and imagery obtained through drones are manipulated to analyze projects, track construction progress, and provide real-time updates. The growth of the industry and the complex nature of construction projects will result in an increase in the usage of drones in construction soon [4].

In particular, drones affected the construction industry by [5]:

- Helping to better monitoring of construction sites
- Calculating the volume of stockpile and types of materials for inventory
- Calculating lengths, widths and elevations of roads and structures
- Annotating images and maps for easier communication
- Calculating overload for an effective removal planning

This study reviewed the literature on the usage of drone technologies in the construction industry. Current and possible usage areas of drones, advantages and disadvantages of adopting drone

technology, factors to be considered while selecting drones, and legal regulations related to drone technology were investigated. This study expected to introduce this technology, which is not widely used in the construction industry in Turkey, to the stakeholders in a comprehensive way and to serve the increase of the usage of drone technologies in construction.

2. Research method

Although there are some review articles in the literature on the use of drones in the construction industry, the researched topics were different from each other since the subject covers a very wide area. For example, besides the applications of UAS in construction, Zhou and Gheisari [8] examined UAS types, on-board sensors in UAS, and styles of UAS control applications. Similarly, Albeaino et al. [9] also investigated the technological components (flying styles, types of platforms, on-board sensors). In contrast, Dastgheibifard and Asnafi [10] only explored the application areas of drones in the construction industry. Unlike other studies in the literature, this study investigated all aspects of the use of drones in the construction sector, from the advantages and disadvantages to the relevant legislation, except their technical specifications. In this way, this study aimed to provide stakeholders with a holistic perspective on using drones in the construction sector.

2.1. Methodology

Literature reviews, which are in different types such as narrative or integrative reviews, systematic reviews, and meta-analysis, are the systematic ways of collecting and synthesizing previous researches. An effective and well-conducted literature review could create a firm foundation for advancing knowledge. In this study, a literature review was conducted according to the narrative or integrative reviews. Narrative reviews are discussions of important topics from a theoretical and contextual point of view, and they are usually used to get an overview of a topic. Compared with systematic reviews, they use less formal methods because they do not need to introduce more rigorous aspects unique to systematic reviews, such as reporting methods, databases used, and inclusion and exclusion criteria [11,12]. This method was preferred because this study aimed to examine generally the effect of drone technology on construction management. While narrative reviews do not aim to seek answers for specific quantitative research questions [12]. This study aimed to answer the following general questions.

RQ1: What are the application areas of drones in construction project management?
RQ2: What are the advantages and disadvantages of using drones in construction project management?
RQ3: What are the issues to be considered while procuring drones for a construction site?
RQ4: What are the regulations related to the use of drones?

2.2. Literature search and selection of the articles

The literature on the subject was researched by using the keywords "Drone," "UAV," "UAS," and "construction sector" on the Web of Science. Since drone technology is a new technology and most of the studies have already been carried out in the last ten years, no date restrictions have been made during the research. The articles were examined primarily through their titles and abstracts. Where necessary, the full texts of the articles were also examined, and more than 50 articles were examined in this study. In addition to the academic articles and references of these articles, internet resources containing up-to-date information were also used within the context of the study.

3. Application areas of drones in construction project management

Drones have brought about many changes in the construction industry. Over the past few years, drones have improved many things in construction, from increasing reporting accuracy to improving safety conditions, reducing costs, and increasing efficiency [13]. This part of the study presents a wide range of drone applications in construction sites.

3.1. Use of drones in the planning stage

Consulting topographic maps is a necessary job when planning large and complex construction works. They can reveal costly mistakes in designs that are not suitable for the terrain. While topographic maps are useful, they are expensive and take a long time to produce. For this reason, the map is not always updated at the start of the job. Due to their ability to map large land areas, drones can dramatically reduce the time it takes to view the topography of a site [4]. Drones are rapidly replacing traditional methods of ground surveillance since they significantly reduce the labor and time required to produce accurate readings. Drones eliminate much of the human error involved in the process and can collect the required data in much less time than traditional methods. Drones integrate the reality of the site into models during the design phase. Their main task is to digitize the landscape of the place in 3D, whether in the design or construction stages. During the design phase, the objective is to integrate the site landscape into the modeling software. Thus, the landscape reality can be taken into account [8-10]. This situation would serve the projects staying on schedule and budget and ensuring accuracy before a project is initiated. Submission of this information can help to determine the feasibility and to aid design. In addition, the high-resolution images generated by the drones can be manipulated into 3D models, allowing precise identification of pre-structural challenges and detection of range errors, saving time and money in the long run [4].

Neitzel and Klonowski [14] used drones to inspect a parking lot and landfill site, and they found that drones can reduce the operating costs related to mapping and surveying on site. Jizhou et al. [15] developed a method that collects surface geometry and texture data to create 3D models based on a single image and a 2D geographic information system (GIS) database. A circular flight path was used by Eisenbeiß [16] to collect terrestrial and drone-based images and to develop a 3D model of a castle. Barazzetti et al. [17] introduced a method that processes close-up images automatically to create 3D models. Bang et al. [18] created a high-resolution two-dimensional map of a road construction site using video obtained by drone, and they concluded that drones could quickly collect multiple images and videos from many different angles. Hudzietz and Saripalli [19] used a drone-mounted camera to collect two-dimensional terrain images and converted the terrain image to a 3D model. Their study indicated that this method could be implemented in a cost and time-efficient manner and was very useful for generating large-scale models. The study in which Siebert and Teizer [20] used drones for the rapid and autonomous collection of mobile 3D map data in large excavation and earthwork sites concluded that drones can offer lower costs, better accessibility and a wider field of view.

3.2. Progress monitoring

Construction projects often involve lots of activities that happen over a large area at the same time. Visual information is the only way to monitor the activities continuing on the site. For project managers, one of the hardest things to maintain on a construction site is real-time project control, which requires real-time data. Typically, data is collected manually by construction workers by walking on a construction site. However, this is a laborious and slow process that makes it impossible for companies to react quickly to changes on the construction site. For example, certain events such as heavy rains, hurricanes, or accidents could considerably change the site, requiring reacting as quickly as possible and collecting new data. Missing a potential problem on the site, even for a few days while waiting for a new manually generated report, can cause significant setbacks that may result in project time and budget overruns.

On the other hand, a 15-minute flight of a drone could create more data that a construction worker will collect with a half-day walk [13]. Another problem is that site progress reports often collected weekly or daily, may lack objectivity or contain errors [21]. Construction workers may sometimes be required to work in unsafe environments [20]. Drones can provide images of entire sites and enable more precise measurements than

assumptions [20,22]. The data collected by the drone will be complete and accurate because the drone can record visual images continuously during the flight. These images can then be processed automatically using software created for this purpose in several types of maps of the entire site [13].

Another advantage of using a drone is that the impressive aerial view created by the drone can give the client a sense of the progress of the project. This situation gives them confidence that their spending is being used effectively. In addition to this, drones can improve the internal collaboration of the team working on site. During a flight, the drone can send information to the software, and designers, engineers, construction managers, workers, and owners can access data simultaneously, monitor the project, and detect any errors that may have occurred [4]. In short, following up the progress on the site becomes fast, easy and cheap through the utilization of drones. They also facilitate the exchange of information between construction companies and their customers, promoting overall efficiency and communication [6].

Producing 3D models is also a commonly discussed method of increasing the reliability and accuracy of progress assessments [20,22]. Comparing as-planned Building Information Models (BIM) with as-built models can help project managers determine if specific milestones have or have not been reached, and to what magnitude of difference, at each location [20,23]; to show progression and when materials or additional resources will be required (potentially improving cost-efficiency) [20,24].

Siebert and Teizer [20] compared UAV and Robotic Total Station (RTS) data for three earth piles using elevation maps generated using points taken from both devices (UAV giving a much larger number of measurement points than RTS). The surveyed volumes for the three earth piles ranged from 8 to 16% [20], indicating that the UAV could achieve a comparable result using more traditional methods. Aerial robots can supply many overlapping images; however, the vast volume of data collected means that currently, the processing time remains a practical challenge that may be partly tackled by various filtering methods [24].

The monitoring framework developed by Lin et al. [25] could superimpose BIM models onto site images captured by drone. Freimuth et al. [26] developed autonomous drone monitoring by defining object boundaries in geo-referenced BIM. Irizarry and Costa [27] evaluated the effectiveness of drone-assisted progress monitoring by using a survey approach. According to Lin et al. [25], the advantages of using drones for following up the progress were lower cost, better accessibility and broader field-of-view. Similarly, Karan et al. [28] pointed out that monitoring tasks were performed in less time, at lower cost and with fewer risks through utilizing drone technology. The framework named D4R [29,30] has a user-friendly tool gathering site information into a 4D BIM, and the framework has been implemented in the Flying Superintendents project [31]. In this project, the whole construction process of the Sacramento Stadium was monitored by a flying drone.

3.3. Occupational health and safety

Even lots of improvements, construction continues to be one of the most dangerous industries in terms of occupational safety. In particular, falls are among the important causes of death among construction workers. There are places on the construction site that are too dangerous for one person to enter. Nevertheless, a construction drone can fly over and record everything that happened in a hazardous area, providing vital information that will help determine how to proceed. Likewise, workers often have to climb to unstable heights and work in unsafe conditions when taking manual measurements. Drones can replace workers in these situations and reduce the risks construction workers face in the field.

Safety managers use drones with high-resolution cameras to monitor the workers' safety compliance. Drones can be used to collect any information related to safety from various angles. Some of them are visual inspection of the use of hardhats and personal protective equipment,

monitoring ongoing operations to prevent hazards, monitoring the situation of workers in the project site, location and orientation of construction equipment. Drones help safety managers to be aware of unsafe situations/locations of the project. Drones may immediately alert the relevant personnel about the accidents and find out the accident location and injured workers. Only in such a case could a safety manager provide immediate feedback and contact the workers [32].

Irizarry et al. [33] used an aerial drone quadrotor helicopter flying all around the construction site and supplied the safety managers with real-time data about what is happening. Irizarry and Costa [27] assessed the feasibility of using drones in safety inspection through interviews with project personnel. De Melo et al. [34] evaluated the applicability of inspecting challenges related to safety using drones in two residential projects in Brazil. They found that detailed information about safety conditions on the field could be collected using drones; thus, safety inspection could be improved. In a similar study conducted by Irizarry et al. [33], a safety check was applied whether the construction workers use their hardhats or not. They found that the construction site could be monitored easily and directly with drones having video cameras and transmitting apparatuses, and thus an immediate interaction with construction workers and safety personnel could be provided. However, they noted that using drones for safety inspection had some challenges, such as the distraction that occurred during the flights and new safety hazards introduced by flying drones.

In the study of Gheisari and Esmaeilli [35], safety managers considered that drones were most helpful for monitoring employees who work near vehicles or cranes with booms and close to edges or openings without protective barriers and for assisting the workers operating in equipment with blind spots. Driverless construction equipment reduces the number of people working on the site, thus the accidents. Drones may be used as the eyes of driverless dozers. The Japanese equipment provider Komatsu and the American drone specialist Skycatch and Caterpillar associated with the French drone provider Redbird are competing to develop these integrated automation solutions [36].

3.4. Infrastructure monitoring and photographing

Monitoring existing infrastructure is vital in determining whether it is safe to continue using them, especially in extreme events [37, 38]. For example, field engineers and technicians conduct regularly scheduled routine inspections of highway bridges or railways to determine the suitability of their physical and functional conditions to continue to use. The most widely used method in regular infrastructure inspections is visual inspection [39,40]. Visual inspection data could be unreliable since the results are based on the inspector's own judgment and experience [13,37,41,42]. On the other hand, cracks observed visually on the surface of structures are often considered a warning of a failure [43], but it is difficult to detect them with the naked eye during inspections [37,44].

Another problem experienced during inspections is the generated safety risks. Inspectors generally need machinery or scaffolding to inspect areas where access is limited [42] and/or hazardous like high-voltage railway cables [45]. Besides auxiliary costs and traffic disruption, this situation creates a health and safety risk [37, 40, 46]. Drones can provide a good inspection without a need for heavy machinery and bulky scaffolding. The stability of structures could be checked by a drone flying around them and taking high-resolution images for analysis. Thermal sensors can be used to detect heat leaks, cold spots, and any electrical issues. Inspections that require an entire team of surveyors to work lots of hours could be completed in a few hours with a drone operator [4].

In short, using drones in infrastructure inspection is very beneficial since it reduces safety risks, environmental impact, facility downtime, and overall maintenance costs. Costs can be reduced since the need for expensive equipment like helicopters will be eliminated. Safety can be improved by limiting the number of dangerous jobs (performed today by, e.g., rope inspectors) and thereby protecting or even saving lives. And third, the environmental impact is reduced since the use

of drones means less CO2 emission than the use of, e.g., a helicopter.

There are several studies in the literature on the use of drones in infrastructure monitoring and taking images. The project of Metni and Hamel [47] aimed to use drones in bridge inspection and traffic surveillance. Rathinam et al. [48] proposed a learning algorithm that minimizes human supervision for drone operations, thus reducing costs and labor requirements. The study conducted by Eschmann et al. [49] indicated that drones could collect data from hard-to-access areas, and the quality of damage detection, damage evaluation and restoration planning could be improved. Huang et al. [50] developed an algorithm for detecting the number and the location of cracks on masonry surfaces by utilizing images collected by drones. Wang et al. [51] utilized drones for detecting faults on power line corridors. Ellenberg et al. [52] showed that measurements would be far more quantitative when drones are utilized in infrastructure inspection. The study, in which Nakagawa et al. [53] utilized drones for inspection of a sediment-retarding basin that consisted of dikes, bridges and debris barriers, concluded that drone is more effective than ground-based scanning.

An autonomous drone Structural Health Monitoring (SHM) system introduced by Kang and Cha [54] was used for crack detection in concrete and coupled with deep learning techniques. Banaszek et al. [55] utilized drones to collect data on various urban structures. Zhang and Elaksher [56] showed that drones could collect images faster, safer, and economical than satellites and manned aircraft in measuring surface distresses of unpaved roads. Drones have also been used in issues related to geotechnical such as geotechnical structure conditions, slope stability assessment, bank erosion monitoring, and lateral scour conditions [57, 58]. Digital Image Correlation has also been used to inspect concrete bridges using images obtained from UAVs [37]. Bolourian and Hammad [41] used drone-mounted light detection and ranging (LiDAR) scanning equipment to inspect bridge defects.

3.5. Damage detection

One of the uses of drones is damage detection. Drones meet the needs for rapid response, access to difficult areas, and on-site information [59]. After a disaster, areas where it may be dangerous for human inspectors to venture, such as flooded areas, buildings damaged by an earthquake, places of potential radiation leakage, and buildings on fire, can be accessed with drones. In these cases, measurements and data that cannot be obtained with more conventional means could be obtained using drones. Drones can rapidly acquire aerial imagery, which can be used to update hazard maps [60, 61]. After a disaster, human teams on the ground can be hampered by dangerous obstacles, which can be avoided with drones [62]. Drones can be used to inspect individual bridges and structures quickly, and the most severely affected access routes and areas can be determined easily with drones. This provides more effective coordination of rescue efforts [61, 63]. Drones are efficient and low-cost data collection tools for assessing flood impact; thus, allocating resources and assistance becomes more effective [64]. Drones are also used for monitoring and inspecting buildings in case of fires [65]. For example, the structural condition of London's Grenfell Tower was assessed with drone images before allowing firefighters to enter the building [66]. In March 2011, an earthquake followed by a tsunami occurred in Fukushima, Japan. The disaster damaged nuclear facilities, and the area had to be evacuated, making reconnaissance extremely difficult [63, 67]. However, surveillance of the facility by drones was possible and, through additional sensors, drones could also collect information on emitted radiation without endangering humans [59].

In the literature, there are studies on the use of drones in damage detection. Ezequiel et al. [68] studied the use of drones to inspect structural damages, damages to crops and vegetation, and the management of water resources after a disaster. Pratt et al. [69] used a tethered drone to assess the damages of a collapsed parking garage since it was impossible to access the best viewing positions with manned helicopters. They cause dust, which

prevents the identification of key features of the damages. In the study of Michael et al. [70], UAVs and ground robots were used to map the layout of an earthquake-damaged building, and the conclusion is that aerial robots can maneuver and collect data from strategic points that ground robots cannot reach; thus, they were well-suited for observation and inspection duties. Yamamoto et al. [61] used drones to evaluate collapsed areas of slopes and river revetments. Drones were used by Kerr et al. [71] to collect data on the damage that occurred on the roof and exterior walls of selected buildings. They concluded that drone-assisted measurement was more controllable and flexible than pictographic measurement systems and required lower costs.

3.6. Other application areas of drones

3.6.1. Maintenance of construction sites

Within the scope of maintenance of construction sites with drones, various activities such as material delivery, creating three-dimensional models of structures and measuring volumes can be listed. Drones can be used in aerial deliveries of equipment, materials and notices. Drones are generally small and have high maneuver capability; thus, they may be fast and safer alternatives to site vehicles in delivering equipment and materials in many cases. This will also make the site safer as one of the primary causes of fatalities on construction sites is being struck by a moving vehicle. Feifei et al. [71] developed three-dimensional building models by using images that were taken by drones. Since observing the whole three-dimensional scene and capturing images of the building from different perspectives is easy with drones, Wefelscheid et al. [72] used drone images to develop building models. Tomita et al. [73] utilized drones to measure the air volume of indoor spaces and stated that higher productivity, lower cost, and better accessibility were possible with drones.

3.6.2. Issues related to traffic

Drones can also be used in traffic operations. Monitoring structures and inspection of bridges mentioned earlier are also important in terms of traffic. Besides these, traffic surveillance, traffic simulation, avalanche control and aerial assessment of road surface condition are some other issues in terms of traffic. Traffic surveillance is monitoring the vehicles in the transportation network. The utilization of drones carrying a video camera and communication sensors provides an opportunity for "bird's eye view" at a low cost. Data obtained easily through drones could be used to give quick responses for transportation operations. Compared to traditional traffic monitoring systems, drones have the advantage of moving at higher speeds and covering large areas. Coifman et al. [74] did four field experiments for intersection movements, network paths, freeway conditions, and parking lot monitoring to reveal the benefits of using drones in traffic surveillance. In the literature, there are also other studies investigating different aspects of drone using in traffic surveillance and indicating its usefulness [25, 75].

Traffic simulation is used to develop models for improving traffic control and doing plan, design and operation of transportation systems better. According to the simulation results, future traffic demand prediction, signal timing optimization, and lane configuration change are some realized issues. Puri et al. [76] proposed to benefit from drone technology to collect real-time data and use this data to generate statistical profiles to improve traffic prediction. Currently, avalanche control involves the use of military equipment, explosives, skiers, and occasionally helicopters. It was studied at Washington University whether drones could be used as a less expensive and safer option for triggering avalanches than using explosives [77]. The development of good repair and maintenance strategies is necessary to preserve the continuity of the transportation network, which requires the assessment of road surface distress. Zhang and Elaksher [56] developed an innovative drone-based digital imaging system for aerial assessment of the surface condition of rural roads.

3.6.3. Enhancing construction site security

Drone surveys may also help to enhance overall security in construction sites. Prevention of

trespasses and thefts; detection of overheating and fire risks by taking thermal images with additional equipment, especially during non-working hours; and audit trails in case of on-site maintenance and security problems are some issues that could be solved with the use of drones [6]. Compared to static cameras, which are expensive and should be installed manually, drones can monitor people entering and leaving the construction site more effectively [78]. According to Capterra, the value of the things stolen from construction sites every year is more than $ 300 million, and only 25% of them can be recovered [4]. Therefore, providing equipment security is a crucial part of construction management. A drone survey can quickly and easily show if the equipment is safe enough and unauthorized persons on the site. This situation provides the prevention of damages or thefts.

4. Advantages and disadvantages or barriers of using drones

4.1. Advantages of using drones

The advantages of drones over traditional methods, which cause them to be used in the listed areas, are as follows [5, 7, 79].

- Drones provide the customer with visual data and additional information about the current state of the building, allowing the customer to better manage and maintain the property after receiving it. Potential conflicts also get easier to resolve.
- Project owners and all other stakeholders can monitor the progress of the work much more easily.
- Drones provide the opportunity to save money thanks to the easy monitoring of the field. These cover many issues such as reducing the need for time-consuming and manpower-requiring monitoring activities, reducing the costs of occupational accidents by increasing occupational safety, identifying idle employees, preventing theft, and better visualizing the quality of work.
- It helps to more effectively control whether occupational health and safety rules are followed on the site.
- In general, it contributes to making site management more effective and efficient by enabling easier and more effective monitoring of the operation at the construction site and by helping to produce data that is difficult and expensive to obtain with classical methods.
- The use of drones helps the company to differentiate and become more competitive with the advantages it provides.

4.2. Disadvantages or barriers of using drones

Besides the advantages of using drones, there are also some challenges to be known in order to use them effectively for construction [79-83]:

- Although it depends on their features and the equipment they carry, the initial costs of drones are high. The cost of drones ranges from US$2,500 for a kit equipped with a small drone with a 20-megapixel camera to US$10,000 to US$15,000 for an industrial drone capable of generating the type of data required by the contractor. Prices of those carrying LiDAR sensors ranges from US$75,000 to US$100,000
- Low battery life is another challenge, such that the flight time of most drones is fewer than 30 min and this restricts operations.
- Using the hardware and software is complex resulting in additional training and costs. Generally, analysis of the data collected by drones should be done by drone service providers.
- Perceiving accuracy levels and tolerances false may cause errors and accidents.
- There are stringent regulations with the use of drones, and this increases the costs. A significant amount of money should be paid by contractors in order to receive an authorization certificate to use the drones for construction.
- The main danger created due to the use of drones is falling drones from heights. This may be due to reckless or amateur control, battery exhaustion, damage caused by weather conditions and obstacles like trees, buildings,

power cable. The fall of drones may result in personal injury and property damage, thereby creating liability. Better insurance is required to help cover these risks and minimize the losses caused by accidents, but this means additional costs.

- The flights attract the attention of workers, and this may cause the disturbance of their work since they tend to stop working to watch the drones flying. This situation may be prevented if sufficient training and knowledge are provided.
- When homes and commercial buildings border a construction site, drones may be able to record video or photos of private properties, which means the violation of the privacy of surrounding residents.

5. Issues to consider while procuring drones for construction sites

Following aspects need to be considered when deciding what type of drone to use on-site [11, 27]:

- Performance: Performance is the most basic element to be considered in drone procurement, according to various factors such as the purpose of use and the characteristics of the construction site. Battery life, flight capability of the drone, properties of the camera, connection with control devices are some of the issues that should be considered under this title. Battery life is important since the current flight time with one battery is around 20 minutes, which sometimes does not meet the needs. Flight capability is critical in relatively difficult flights. The resolution of the camera is important, as some features and software require high-resolution images. Also, the dual-camera embedded in the drone allows monitoring both the front view and the aerial view depending on the situation. It should be noted that there is a possibility that the drone can become disconnected from the smartphone or tablet controlling the system remotely, and this will create a potential danger for the workers.
- Portability: If the drone needs to be used in different construction sites and therefore needs to be transported continuously, it would be appropriate to choose a lighter drone that can be folded down and reduced in size.
- Endurance: Since the construction site is an environment where dirt and dust are intense, the drone must be resistant to these conditions, wear and tear.
- Stability: The wind speed resistance of a drone and its stability when operating in harsh weather conditions with a lot of air movement or rain are extremely important. For this reason, to obtain the desired efficiency and high-quality image from the drone, a drone equipped to operate under these conditions should be selected.
- Ease of Use: Issues such as whether the drone needs mounting, its charge status and the need for a modular camera should be carefully evaluated. It should be noted that some drones are easier to set up and operate than others.

6. Regulations related to using drones

Drones are becoming common on construction sites, so contractors need to understand current drone regulations, potential risks, and best practices to avoid accidents and claims. Operating drones can bring risks, so certain laws are necessary [23]. On the other hand, the use of drones in terms of ethics and privacy can threaten civil liberties, although safety requirements are the top priority of the regulations [84].

Regulations intend to ensure that drone operators are experienced and properly trained and the equipment is certified and properly insured. UAV operators must prove their ability to fly the drones and meet the minimum requirements. Using drones in construction sites may sometimes affect privacy and other civil liberties. However, drones are complex multi-mode surveillance systems that integrate various technologies and capabilities. This results in the current regulatory mechanism not adequately dealing with concerns related to privacy and civil liberties [84].

The Federal Aviation Agency distinguishes between the use of drones for recreational and

commercial purposes. Those for recreational purposes do not require FAA approval, but the drone must be within sight, meet the required safety guidelines, and be 5 miles away from the airport. Besides, its weight can not be more than 55 pounds. The intention to use drones is accepted as commercial in case the operator's occupation is related to the use of drones. It is prohibited to operate drones on moving people and vehicles [85]. In the European Union, the use of more than 150 kg drones is directly regulated by International Civil Aviation Organization (ICAO), and each country regulates the use of those less than 150 kg by itself [86]. These regulations indent supporting drone market development, guaranteeing security, maintaining EU aviation security, providing the protection of personal data, privacy and family, and ensuring the risk fee depending on usage.

In contrast, in the European Union, each country/region can freely determine the regulations. The most important rules to know for flying a drone in France are as follows: [87]:

- All drones of 800g or more must be registered by their owner on AlphaTango, the public portal for users of remotely piloted aircraft.
- Drone pilots must maintain a line of sight with their drones at all times. If a visual observer is tracking the drone, the pilot may fly out of his or her own range of sight.
- Drones may not be flown at night.
- •Drones may not be flown over people, over airports or airfields, over private property.
- Drones may also not be flown over ongoing fires, accident zones, or around emergency services.
- Drones may not be flown above 150 meters.

Compared with global legislation and rules, Turkish regulations are stricter. General Directorate of Civil Aviation issued the latest rules in 2016. Some of these rules are as follows [85]:

- Permission must be obtained from the local authority before flying.
- Operations must be at least 9 kilometers away from the airports.
- It is not allowed to fly around military buildings, defense industrial factories, and prison buildings.
- Drones weighing up to 500 grams can be used for hobby purposes.
- The above rules are not required in search and rescue activities; however, operations require permission from the General Directorate of Civil Aviation.
- Flying all types of drones over private property requires to take permission of the property owner.

7. Conclusion

Drone technology is observed to contribute to increasing productivity in many areas at construction sites. Applications show that this technology facilitates many activities, from planning to monitoring construction work, from increasing occupational health and safety to monitoring infrastructures, making it more efficient and less costly.

While drones facilitate the creation of expensive and time-consuming topographic maps, especially for large construction sites, they also minimize human errors. This saves time and money while creating the maps and prevents possible major negative deviations that occur in the project budget and duration that is caused due to outdated or incorrect maps. One of the most important elements of project management is real-time monitoring of the construction site and timely response to events so that the project is completed within the prescribed budget and time. One of the biggest benefits of drones is that they facilitate progress monitoring in the site and make it efficient. One of the most studied issues in the literature is the effect of drone use on occupational health and safety. Studies have shown that drones are effective tools for monitoring the workers whether they comply with occupational health and safety rules. While drones make monitoring various infrastructures, especially bridges and railways, easier and more efficient, they eliminate both human-induced errors in these activities and the security risks that appear while monitoring the infrastructure with traditional

methods. Drone technology is also crucial in detecting damages due to disasters such as earthquakes and floods and taking necessary precautions quickly and effectively. Apart from these, studies indicated that drones could be used in many other applications, such as ensuring the maintenance of the construction site, taking precautions related to traffic during road constructions and ensuring construction site safety.

All these make construction management easier, more effective and more efficient while making companies using this technology more competitive. Moreover, with the developing technology, drones' application areas are expected to expand much more. Although there are various obstacles to using this technology, which is relatively new, these obstacles are easily overcome with the development of technology and adaptation of the sector to technology.

In conclusion, it could be stated that it is important for construction companies and managers to adopt drone technology to their construction sites to make their operations more efficient. However, being careful in the procurement of drones, which are more technological than other equipment used in construction sites, is important. Another important issue to be considered is that the regulation on using drones. Knowing the related regulations is important since drones pose security risks as they may fall during flight and since people's privacy may be violated due to aerial surveillance of drones.

This review study indicated that using drones in construction sites will be beneficial, especially in completing the construction projects within the determined budget and time. In this respect, sector stakeholders should adopt this technology to their construction sites without hesitation, which will make their company more competitive and ready for the future.

This study only focused on the non-technical aspects of drone technologies. However, the technical aspects of drones should also be discussed in future studies as stakeholders' decisions on the usage of drones might be affected by these aspects.

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