The Use of Drones in the Construction Industry: Applications and Implementation

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Abstract –

In a volatile, uncertain, complex, and ambiguous world, Industry 4.0 can be the silver lining of the construction industry which has been facing daunting chronic problems for decades. The transformative impact of Industry 4.0 which has been well documented in the industrial sector has spurred interested among construction researcher to explore the opportunities Industry 4.0 can have on our industry. Among the various Industry 4.0 technologies, drones have found their way into the construction industry and their use has been on the rise. Building on the existing body of knowledge, this paper summarizes the current state of adoption of drones in the construction industry. To achieve the research objective, the various applications of drones throughout the construction project lifecycle are explored, associated benefits, challenges, and costs are identified, and considerations to be accounted for are discussed. The findings summarize the "5W2H" – or the What, When, Where, Why, Who, how, and How Much – of the use of drones in the construction industry.

Keywords –

Construction 4.0; Technology; Drones; Unmanned Aerial Vehicles; UAV; Unmanned Aerial System; UAS; Remotely Piloted Vehicles; RPV; 5W2H

1 Introduction and Background

The fourth industrial revolution, known as Industry 4.0, has been steadily reshaping industries around the world. With the fast advancement in technological capabilities, industries are continuously adopting technologies into their workplaces. The construction industry is no exception. Despite being a late comer, construction is gradually utilizing the different technologies that Industry 4.0 offers, including augmented and virtual reality, robotics, big data, sensors, and 3D printing [1–4]. Another technology gaining momentum is drones – otherwise known as unmanned aerial vehicles (UAVs), unmanned aerial system (UAS), and remotely piloted vehicles (RPVs).

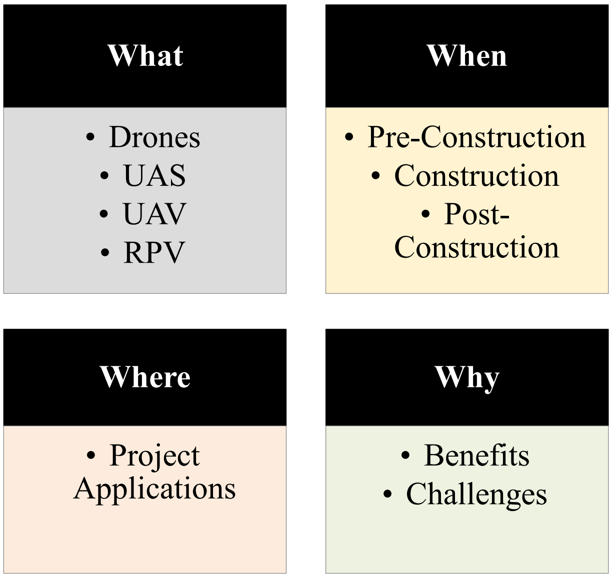
For the past few years, the use of drones in the construction industry has been on the rise, and the global construction drone market size was valued at \$4.8 billion in 2019 [5]. In the United States of America (USA), the use of drones in the construction industry is controlled by the Federal Aviation Administration (FAA) regulations for the commercial use of UAS published in 2016 [6]. The regulations boosted the use of drones in both vertical and horizontal construction projects for both public and private construction sectors, eventually making drones one of the major innovations in the Every Day Counts program conducted by the Federal Highway Administration [7].

Drones were also helpful in the COVID-19 pandemic. With the move to remote working for project stakeholders and safety regulations like social distancing and decreased number of labor, drones played an important role in providing real-time data and allowing work to continue despite restrictions on worksites [8]. Drones were also used for crown surveillance and enforcing social distancing, broadcasting public announcements, spraying disinfectants, and delivery for medical supplies and essentials [9].

2 Objective and Methodology

Following the rise of drones in the construction industry, numerous efforts have been undertaken to investigate the use of this technology and its impact on construction. Using the "5W2H" method, a technique employed to analyze and characterize in a concise and reliable way the most important information about a matter, this paper builds on the existing body of knowledge where academicians and practitioners publications on drones *(what)* were reviewed to (1) explore the applications of drones through the different phases of the lifecycle of the construction project *(when, who, and where),* (2) identify the benefits and challenges associated with those applications *(why)*, (3) provide an overview of the lifecycle cost *(how much)*, and (4) present common practices to implement drones *(how)*. The "5W2H" framework of drones in the construction industry is illustrated in Figure 1 to summarize the state of drones for both academicians and practitioners in the post-pandemic world, especially after drones demonstrated great value before and during the COVID-19 pandemic. The 5W2H method was employed to offer a holistic discussion of drones in the construction industry, a type of discussion that has not been presenting in one single paper yet.

To identify relevant research work, Google Scholar was used to identify articles, journal papers, dissertations, and conference proceedings published between 2017 and 2021. Search filters included various keywords to tackle the two layers, such as ("Drones" OR "UAS" OR "UAV" OR "RPV") AND ("Construction" OR "Construction Industry" OR "Construction Project" OR "Project Lifecyle" OR "Adoption" OR "Implementation" OR "Challenges" OR "Barriers" OR "Benefits" OR "Advantages" Or "Use Case"). The relevant number of papers after scanning titles, abstracts, and the content was 31. In addition to literature, websites for major drone companies that work with construction firms were searched to identify relevant success stories and use-cases, webinars, reports, and publications that can provide insightful observations from the industry perspective. The search resulted in 15 resources which were found relevant to this study.



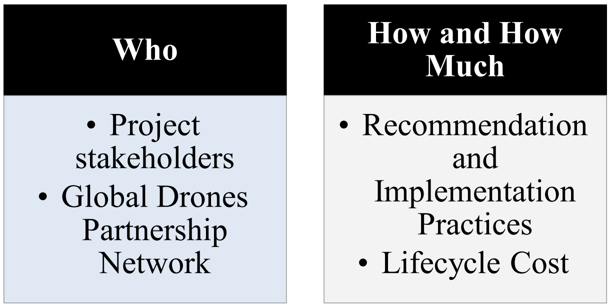


Figure 1. The "5W2H" (what, when, where, why, who, how, and how much) of drones in the construction industry.

3 Applications of Drones Across the Project Lifecycle

Drones can be used across the entire project lifecycle – starting from the early stages of pre-planning and design, passing through the construction stage, to the late stages of asset management, operation, and management. This section elaborates on the major applications for drones across the different phases of a construction project. While there is no single definition of what constitute the lifecycle of a construction project, this paper adopts the following three phases that are commonly referenced in drones related research: pre-construction phase, construction phase, and post-construction phase [10–12].

3.1 Pre-Construction Phase

The pre-construction phase of a construction project includes all stages that are needed before the physical construction starts. During this phase, drones can be used for designing, bidding, and site planning.

In the design stage, the use of drones can provide designers with a good understanding of the project environment. Designers can also benefit from the geometrically accurate 3D scans that drones offer. The 3D scans can be integrated into the modelling software to account for landscape reality when modelling the project [13]. This could help designers and stakeholders visualize the project on its surrounding, and assess how the project could impact its environment from a practical and aesthetic viewpoint [14].

In the bidding stage, drone images can provide contractors with a detailed view of the site location and its surrounding to expose possible risks and hazards that should be accounted for while creating their bid. Moreover, drones can assist in the correction and rendering of terrestrial surveying information to provide geometrically accurate 3D maps for estimating surveying quantities such as earthwork volumes [15]. The accuracy of such measurements can improve the reliability of the bids and decrease possible estimation errors.

As for site planning, the high accuracy of the drone data allows for an accurate identification of site boundaries and presentation of the construction plot area [16,17]. Construction teams can then use this data to plan different site aspects such as entrance and exit points, crane locations, and material storage areas. This becomes especially important when the project is surrounded with restricted areas and no-go zones such as existing utilities and environmentally protected lands [18].

3.2 Construction Phase

The construction phase of a project includes all the physical construction that happens on the construction site. Drones can serve multiple purposes.

To begin with, drones can be used for safety and health purposes. Safety managers can fly drones over the construction site to collect real-time information on hazardous activities, blind spots from moving equipment, and breaches of site parameters and no-go zones [11,19]. Drones can also carry built-in microphones to allow safety managers to contact workers who are in danger and warn them about potential hazards [20]. Successful attempts were also performed on drones to automatically recognize and warn workers who are not wearing personal protective equipment such a hardhats, and detect opening openings and guardrails that do not conform with the Occupational Safety and Health Administration (OSHA) standards [12,21].

Drones can also be used for resource and logistics management. Drones can provide real-time measurement of the volume of materials on site such as soil and aggregates [16]. Drones can also use real-time location systems to detect, identify, and track the movement of materials and equipment tagged by different sensing technologies [22]. Moreover, drones can serve as assistant tools for unmanned equipment, such as excavators with autonomous intelligent control units, to perform earth moving operations [23].

Another use for drones is to track progress on the construction sites. Drones manoeuvring over the jobsite can display the progress happening in real time for stakeholders whether on-site or away [10]. This creates a timeline of information that can be used to control and validate tasks, provide quality control, compare what is built to what was planned to identify differences between plans and real-time progress, and create 3D as-built models [12,18,19,24].

In addition to 3D models and progress reports, footage gathered by drones can prevent a permanent record of the project that can be referred to at any time. Disputes are very common in the construction industry, so stakeholders can refer to the recorded drone footage when problems arise for a comprehensive understanding of the situation [25]. Drone footage can also be useful evidence to resolve litigation since they “can clarify or explain oral testimony or documentary narrative in concrete terms” [18,26].

Other uses of drones on the construction project include transporting and installing construction materials like bricks, foam blocks, and steel elements [27–29]; transporting labour tools [23]; illuminating dark areas in the construction site and providing lighting for night works [23]; finishing and painting walls and vertical slopes [30]; monitoring dust and quality of air and detecting environmental violations [23]; inspecting existing structures before repairs or remodelling [12]; and managing demolitions or destruction of structures [31].

3.3 Post-Construction Phase

The post-construction phase of a construction project includes all stages happening after the physical construction ends. During this phase, drones can be used for different mapping, marketing, monitoring, and inspecting purposes.

Drones can be used to map inaccessible and hazardous areas, especially with their ability to enter areas and reach certain heights that can be hard to capture manually or by laser scanners [32]. Thus, the bird’s eye view that drones can provide, when integrated with advanced scanning technology, allows stakeholders to create 3D models of existing structures such as historic landmarks [32]. Moreover, the unique viewpoint that drones provide allow project owners and real estate agents to create unique videos for their constructed projects for marketing purposes, sales, and promotions, especially for commercial projects [33].

Drones can also play a vital role in monitoring and inspecting structures. For example, drones can be used for inspecting and cleaning facades of skyscrapers, detecting corrosion in dam slopes, inspecting hazardous roofs such as those made with slate or clay tile and steep-slope roofs, and identifying roof leaks or electrical hot spots on transformer installations that are not ground-visible to detect inefficiencies in energy usage and develop thermal maps [23]. Moreover, [34] identified several studies that investigated the use of drones in highway infrastructure management, both bridges and roads. For bridges, the use of drones can enhance monitoring and inspecting bridges due to the drones’ ability to manoeuvre above, under, and around bridges without the need of heavy equipment or traffic control. As for roads, drones can enhance the periodic basement of pavement conditions and distress monitoring by reducing the man-hours needed or visual inspection and conducting in-situ tests to measure different aspects such as distress, unevenness, rutting and cracks [34]. Asphalt 3D printing technologies could also be installed on drones to fill cracks in pavements [35].

Another major use-case for drones is post-disaster reconnaissance. Fires, explosions, and natural disasters such as earthquakes, floods, hurricanes, tornadoes, and landslides can cause unavoidable damage to buildings and infrastructure. Drones can be used to perform comprehensive damage assessment through identifying damage evidence ranging from cracks to complete collapses, and enhance the processes of rescuing, cleaning, rehabilitation, and retrofitting [12,23]. Damage evidence can also be helpful when filing for post-disaster insurance compensations [36].

4 IMPLEMENTATION OF DRONES IN CONSTRUCTION PROJECTS

4.1 Benefits

The different applications of drones across the construction project lifecycle discussed earlier highlight major social, economic, and environmental benefits.

From the social perspective, the ability of the drone to manoeuvre over hazardous areas and dangerous heights for important tasks like inspection or surveying makes the technology a safer alternative than human labour. Land surveyors and inspectors can fly drones over their areas of interest instead of performing their surveying or inspection tasks physically and getting exposed to risks [12]. Drones can also add an extra layer of security to the job site through identifying breaching of parameters or entrances to no-go zones faster [19]. This becomes especially important for site visitors and pedestrians commuting around the jobsite. Moreover, the use of drones for inspecting highway infrastructure such as bridges, roads, and tunnels, can decrease the hardships of traffic control [37].

From an economic perspective, the different use-cases of drones – discussed in the applications section above – show that drones can (1) simplify reporting through capturing and footage in real time for project stakeholders present inside and outside the job site, (2) enhance decision making through remote site access, (3) provide accurate calculation tasks such as earthwork volumes, (4) track progress on construction site with high accuracy and compare it to design to develop as-built statuses, (5) track the movement of materials and resources anywhere on the job site, (6) replace the need for heavy equipment and truck cranes or elevating platforms to inspect hazardous area, and (7) reduce liability through resolving disputes faster [16,18,21,23,32]. All those benefits translate into productive job sites with efficient communication and collaboration among stakeholders, and significant time and cost savings in a construction project [12]. Moreover, the use of drones allows companies to gain competitive advantage whether when bidding on projects or seeking new clients.

From an environmental perspective, drones do not rely on fossil fuels and are mostly electric-motor driven. Thus, drones release significantly lower levels of carbon dioxide emissions when compared to construction equipment, making them an environmentally friendly alternative for aerial work – i.e. land mapping, photography, and surveying [12]. Further environmental benefits are also perceived through reducing congestion, for drones will decrease the number of human labour and equipment needed to perform critical tasks [28]. Moreover, the use of drones can contribute to sustainable development and construction when monitoring energy projects like pipelines, wind turbines, or solar farms [12].

4.2 Challenges

Despite the different benefits perceived from the use of drones, several challenges remain at the technical, social, and legal standpoints.

From a technical standpoint, technological constraints such as the limits on the battery life can shorten the time of flights and operations [38]. Battery life is affected by factors such as the take-off weight, which in turns affects the types of cameras and sensors that can be used [34]. Another technical constraint is the effect of environmental factors like severe weather conditions and rough terrains; terrains like mountains and hills or underground tunnels and severe weather conditions like extreme temperatures, accumulation of ice, high wind speeds, and heavy rains may hinder signals and connectivity [34,38]. Moreover, drone take-off location and flight paths should be away from large metal objects or heavily reinforced concrete structures since electrical sensors like gyroscope and magnetometer can be affected by communication interference if there are magnetic sources around the drone [39]. Furthermore, even though researchers are studying the ability of drones to perform aerial drone-based construction tasks, material such as bricks or blocks or voxels might require to be altered to meet the drones capabilities [40]. Finally, while drones excel at outdoor environments. Several limitations remain for using drone in indoor environments with the absence of GPS and lack of predefined parameters necessitate more intricate sensing abilities and sophisticated supporting algorithms [38]. To overcome such technical issues, cross-industry cooperation is required between the manufacturer and client to enhance product research and development and improve the capabilities of drones for the construction industry [23].

From a social standpoint, operating drones comes with the risk of collisions with people, objects, and other aerial vehicles [34]. Many reasons can cause the drone to malfunction such as the sudden discharge of the battery, unpredicted weather occurrences like unknown winds aloft, unexpected hazard events like forest fires or earthquakes, loss of command and control link, loss of visual contact with the drone, and loss of navigation control [37]. Even though the probability of such risks may be low, they become more possible when using drones on large scale entails [41]. Noting the labour intensive nature of the construction industry and the critical location of many construction sites in populated areas, drone malfunctions may lead to crashes crash into on-site personnel, pedestrians, vehicles, or structures resulting in bodily injuries and/or property damages [38]. Other social challenges include security and privacy concerns. Drones are equipped with cameras, night vision device, and various sensors that give it the ability to track objects and observe them in different perspectives. Such capabilities can facilitate snooping and capturing unauthorized images of persons or private property, which in turn raises privacy concerns from citizens [38,41]. Moreover, many law enforcement agencies have voiced security concerns on the use of drones since drone operations can be vulnerable for GPS jamming and hacking, making drones prospect for malicious users to conduct cyberterrorism and other unlawful activities [9]. Such social challenges may be maintained by strong security firewall systems and ethical guidelines for drone operations to clearly define the objectives of the flight, the data that should be gathered for analysis, time of data residentials, possible privacy violations, and proper risk and safety mitigation plans and strategies [23].

From a legal standpoint, different aviation rules may restrict the potential of drones. For example, in USA, while the FAA regulations are important to guarantee the safety of people and property, other regulations may cause operation restrictions. Examples of restricting regulations include: the weight of the drone including payload at take-off should not cross 25 kilogram (55 pounds), flying at or under 120 meters (400 feet), flying at or under 160 kilometres per hour (100 miles per hour), staying 8 kilometres (5 miles) away from airports, remaining in Class G airspace, keeping the drone within the visual line of sight of the operator, and yielding the right of way to other aircrafts. It is worth to note that restrictions, aside staying in Class G and the take-off weight of the drone – may be waived by the FAA upon submitting a waiver. It is also worth to note that the restrictions of flying over moving vehicles, flying over people who are not protected by a shield and/or part of the operation, and flying at night were lifted by the FAA as of April 2021 [6]. Other legal challenges come in the form of liabilities [26]. The absence of common industry standards for risk allocation and mitigation may cause potential liabilities on who might be responsible for the incurred injuries or property damages in the case of a drone malfunction [26]. This becomes especially important because the FAA does not mandate insurance for drone operations, but requires operators to report all drone incidents, which may lead to revoking licenses and jeopardizing the company from using drones in their operations [26]. Thus, insurance companies should develop policies to clearly define and integrate drone usage into the insurance coverage of construction projects and create ideal insurance cost models that account for the accident rates and safety risks for drone operations [23].

4.3 Lifecyle Cost

The lifecycle cost of implementing drones can be broken down into three phases: procurement and acquisition, operations and management, and retirement and disposal [42]. The procurement and acquisition phase is related to the permits needed to buy and operate the drones, and the cost of purchase. Factors that affect the cost of the purchase include the drone's weight (i.e. battery, propellers, motors, controllers, frame, take-off elements), its payload capacity (i.e. gimbles, cameras, sensors), and endurance (i.e. battery service) [42]. Other cost factors include the required software for navigation and flightpath automation, to control, monitor, communicate, and navigate the drone, in addition to gathering, storing, and sharing data [42]. The operation and management phase is associated with incurred costs to operate the drones at regular intervals of time. Examples of operation costs include the lifespan of propellers and batteries, software adaptability, insurance, and operating crew [42]. As for the retirement and disposal phase, it is derived from the recuperated capital at the end of the drone's lifespan [42].

5 Implementation Practices and Recommendations

Several companies have published success stories of the use of drones in the construction industry, whether through webinars, academic papers, or blogs. A number of those resources were reviewed to comprehensively compile a list of common practices needed for implementing drones [12,36–38,43–48,50]. It is worth to note that the practices should be treated as guidelines instead of an official standard for implementing drones.

To begin with, construction companies should understand the need for drones before starting the implementation process. As seen in the applications section, drones have multiple purposes across the entire lifecycle of a project. Thus, it is important for companies to communicate with project stakeholders and assign one or more champions to define the areas of interests, the type of data needed, the timelines of acquiring and analysing the data, the proper methods to share the data, and the expected deliverables. Another reason for including multiple stakeholders is that one drone flight may serve multiple teams. Thus, understanding the needs of every team helps better understand the use-cases that drones can fulfil. For example, images can be shared with superintendents to note and understand

Since the construction industry is resistive to change, a transition to implement drones in construction processes may not be easy. Thus, it is important for champions to highlight the value of using drones by sending newsletters, conducting webinars, and sharing videos with those who are hesitant to change. Return on Investment (ROI) is also a common practice to show value; champions can perform preliminary analysis by comparing the current incurred costs (such as the current-state labour wages and equipment needed to collect the data and perform analysis) to the drone investment cost (i.e. the Lifecyle cost explained before) and the expected savings (both tangible such as the equipment's replaced by drones, and intangible such as the dollar value of the time savings). Another way to show value is to conduct different pilot test on a small-scale construction product with the help of a third party and gather feedback from involved personnel.

Another important practice is to review the regulations and necessary authorizations to operate drones. While the FAA is responsible to regulate the operations of drones in USA, several states and cities have created their own rules and regulations, with some imposing regulations limitations that are stricter than others. Thus, a company should invest time in understanding the local and federal rules and regulations in their areas of operation.

As discussed in the challenges section, the drone operations are associated with serious safety risks. Thus, it is important for companies to develop risk assessment pans and standardize checklists for drone operators and on-site personnel to use before, during, and after the flight operation. Such practices are also valuable for the involved lawyers and insurance companies.

Finally, the global drone market is increasing and currently involves a growing number of hardware, software, pilot, training, insurance, and distribution partners. With such a strong global partnership network, and with drones successfully exceeding their expectations on construction projects, companies have the support that they need to confidently start their drone initiatives.

6 CONCLUSIONS

This paper recapped the use of drones in the construction industry. Using the 5W2H method, the paper presented the different applications of drones across the lifecycle of a construction project, discussed the benefits of using drones and elaborated on the challenges, and provided an overview of the lifecycle costs. The paper also presented a comprehensive assessment of common practices derived from several successful implementations of drones in the construction industry. Findings in this paper can set a baseline for both construction academicians and practitioners for the state of drones in the industry. Further studies can build on this study by providing industry use-cases and elaborating on other Industry 4.0 technologies that can be integrated with drones to maximize its use.

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