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Unmanned Aerial Systems in the U.S. Construction Industry: Exploratory Study on Current State of Practice

Spoorthy Prakash, M.S., and Caroline Clevenger, Ph.D.
University of Colorado
Denver, CO

Manideep Tummalapudi, M.S.
Colorado State University
Fort Collins, CO

Recent advancements in the construction industry include the expanding application of Unmanned Aerial Systems (UASs) throughout the lifecycle of construction projects. These advancements result in significant increases in technical capabilities within construction as well as time and money-savings. Despite their abilities to improve efficiency by enhancing construction processes and practices, little is known about the current state of applications and the barriers to UASs successful adoption. The purpose of this exploratory study is to investigate the current state of UASs practice for various applications within the construction industry by providing a literature review and a series of interviews with construction professionals and UAS pilots. The outcome identifies key UASs applications including pre-construction, surveying, project progress monitoring, safety management, and quality management. In addition, the study documents low awareness of UASs applications among construction professionals, and outlines professional training requirements, Federal Aviation Administration (FAA) licensing requirements, capital requirements, and a range of implementation challenges. Understanding the applications of UASs in construction supports construction firms to achieve improved efficiencies in various construction activities where UASs can be deployed.

Keywords: Unmanned Aerial Systems in Construction, UAS in Construction, UAV in Construction, Drones in Construction.

Introduction & Literature Review

Recent construction technological advances introduce smart solutions to solve real-world problems. They help increase productivity, improve collaboration, and enable industry to tackle more complex projects (Tummalapudi et al, 2021). One such technological advancement that has been lately disrupting the construction industry is Unmanned Aircraft System (UAS).

An UAS consists of a remotely piloted flying asset equipped with several sensors through a control system. The Federal Aviation Administration (FAA) requires a UAS operator, or drone pilot, to operate it. UASs have quickly risen to provide a competitive advantage for a wide variety of industrial applications such as agriculture, infrastructure, oil and gas, traffic surveillance, and military. The market size for UASs is expected to exceed $30 billion in the United States by 2026 (Mc Kinsey, 2017).

UASs have opened a wide range of opportunities and applications in the Architecture, Engineering, and Construction (AEC) industry such as landslide monitoring (Yeh and Chuang, 2020), bridge inspections (Hiasa et al 2018), traffic surveillance (Barmpounakis and Geroliminis 2020), historical preservation (Enriquez et al. 2020), to name a few. In construction, UASs are used in a variety of ways- from site progress tracking, to overseeing subcontractors, to keeping stakeholders informed (Albeaino and Gheisari, 2021) and applications are rapidly expanding. It is estimated that the construction industry will invest more than $11 billion in UASs in the next few years (Goldman Sachs, 2017) and extract a $45 billion market value usage (Shakhatreh et al, 2019). Previous studies have reported that implementing UASs have had several advantages with regard to time and cost-saving in surveying activities, obtaining access to difficult-to-access spaces, and improving quality and reducing safety concerns of certain construction tasks (Gheisari and Esmaeili, 2018). This paper aims to further illuminate the current state of practice of the adoption and the barriers for construction firms to implement the adoption of UASs.

Research Methodology

With an objective to synthesize and understand the current state of practice as well as future applications of UASs in the construction industry, the authors designed a study consisting of a literature review and semi-structured qualitative interviews with experienced professionals and drone pilots working in the construction industry. To begin, the authors conducted a literature review of research regarding UASs and their construction applications over the last five years (2017-2021). Building upon these findings, a second phase of the research was to develop a short questionnaire and exploratory interview protocol that focuses on identifying the current state of practice of UASs in construction. The open-ended interview questions mainly focused on current applications, challenges and barriers, future applications, and implications of UASs in the construction industry, as shown in Table 1. Follow-up questions were based on the response of the participants, and are also shown below.

Table 1

Open-Ended Interview questionnaire

Applications of UASs in Construction:

1) What are the different operations/activities your construction firm uses UASs for? Please describe them.
2) Please describe the different types of UASs you use for these operations (Follow up: type, brand, capacity, deliverables produced, software used to convert deliverables)
3) What are the expenses related to using UASs? (Follow up: costs related to UASs purchase, UAV operator, software, conversion charges, operations, and maintenance expenses)
4) What are different construction tasks you're collaborating UASs with other emerging technologies? Please describe how you do that?
5) What are some challenges you experience in using UASs within your construction firm?

The development of interview questions follows DiCicco-Bloom and Crabtree's (2006) recommendations to include experience questions and knowledge questions. To recruit participants for the study, the authors adopted a snowball sampling approach. The authors initially extended invitations to a few known construction professionals using UASs to participate in the research. Each willing interviewee was then asked for further contacts and introductions. This led to introductions to several construction professionals that use UASs as a part of their daily work and eight of them were selected

to be a part of the interviews. All participants of the study work in Colorado, and also fit the following criteria:

1) Currently employed in the construction industry;
2) A minimum of 3 years of experience in the construction industry; and
   a) Use UASs as a part of their daily responsibilities; or
   b) Lead UASs (and other emerging technology) initiatives for a construction firm that has been implementing UASs for at least 2 years.

Eligible participants were sent emails containing the interview protocol and consent letter explaining the aims of this research and requesting a probable time slot for the interview. The interviews were conducted synchronously either via Microsoft Teams, Zoom, or phone, depending on the preference of the participant. The interviews were semi-structured, and the purpose of using this approach was to initiate each interview with a set of open-ended questions that would lead to a thoughtful discussion while providing the flexibility to pursue appropriate follow-up probing questions. Table 2 shows the experience levels of participants (ranging from 7 and 28 years). With permission, all interviews were recorded and transcribed for data analysis purposes. Manual thematic coding was used by the authors to analyze the collected data to identify patterns and themes in the qualitative responses. The analysis primarily focused on the trends of different applications of UASs in the construction industry.

Table 2

Participant Information

Participant	Experience(yrs.)	Company Size(employees)	Markets
Participant 1	20	224	Commercial
Participant 2	7	803	Commercial
Participant 3	22	22,000	Heavy Civil
Participant 4	28	700	Commercial
Participant 5	19	172	Commercial
Participant 6	25	3,100	Commercial
Participant 7	13	25	Commercial
Participant 8	15	292	Commercial

While eight interviews is a small sample, according to Mason (2010), the size of the sample in qualitative studies is irrelevant because the value of the study is based on the quality of data. The primary reason for recruiting these eight participants was their experience, expertise, and willingness to participate in the study. Implementing such a strategy, according to Simms and Rogers (2006), increases the richness of data due to the commitment of the interviewees.

Results and Discussion

This study utilized expert interviews to obtain information regarding the current state of practice and barriers to implementing UASs in the construction industry. The expert interviews were conducted during February and April of 2020, and each interview on average took between 40 and 60 minutes.

Current State of Practice

This section presents different types of UASs that are employed, and various construction-related applications the UASs are used for by the participating construction firms.

Types of UASs used in Construction

The construction firms that participated in this research study used four different types of UASs, namely multi-rotor drones, fixed-wing drones, single-rotor drones, and fixed-wing hybrid drones. These different types of drones are shown in Figure 1. (Images Source: Google)

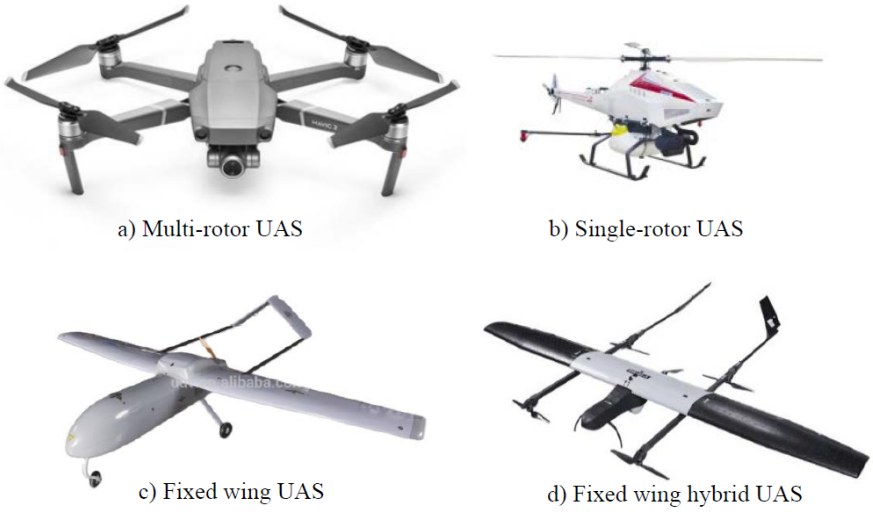

Figure 1. Types of UASs used by participant construction firms

Some firms possess multiple types of these UASs, whereas some firms possess only a single type. The participants mentioned that they select UASs based on needs and applications. It is observed that construction firms predominantly prefer multi-rotor UASs over other types as multi-rotor UASs are cost-friendly and sufficiently powerful as they are flexible and able to vertically take off and land. One participant mentioned, "The multi-rotors have exceptional hovering capabilities, this type of UASs is suitable for both vertical and horizontal constructions" indicating the suitability of multi-rotors across construction sectors. The software applications that are compatible with UASs and used for construction applications, according to research participants include DroneDeploy, Pix4D, Propeller, Ark Aerial, Reality Capture, and UgCS. DroneDeploy was the most frequently mentioned by participants, and one participant explained that "DroneDeploy is a comprehensive application that simplifies, supports, collaborates data collection and processes image/video data collected via UAS for surveying and mapping solutions" indicating its wide usage for surveying operations by construction firms. The initial capital investment to obtain the UASs, annual operation, service, and maintenance cost including software costs for various construction applications ranges between $ 4,000 and $ 35,000 per UAS based on the type and its construction-related applications. One participant mentioned, "Despite high initial costs of UASs, our firm noticed 9X time saving and 4X cost saving in tasks UASs could perform when compared to traditional methods", indicating how construction firms weigh the cost-benefits of UASs for various applications.

Applications of UASs in Construction

This preliminary study identified various applications of UASs in construction such as aerial photography, photogrammetry, surveying, inspections, cut-fill estimations, quality checks, safety monitoring, among several other applications. Table 2 presents the current state of practice of the participants. To organize these various applications, the authors categorized these applications into four major categories namely

1) Pre-construction Management
2) Quality Management
3) Safety Management
4) Construction Surveying
5) Project Progress Monitoring

Pre-construction management

All participants of this study mentioned that they use UASs the most during preconstruction activities namely site mapping and site layout planning. To develop an effective site layout, the construction team needs to know information such as current site conditions, location, and surrounding constraints. To do this, the project managers usually walk the job site and collect information. The research participants informed that, with the advent of UASs, now they fly a UAS over the job site during the job site walks to collect every minute site detail, thereby making their site layout planning very efficient. "For one of the jobs we bid a few weeks ago, certain areas of the job site were inaccessible, and our drone (aka UAS) collected critical visual information from the inaccessible areas that assisted us plan site logistics very efficiently", quipped a participant informing the practical applications of UASs in site logistics and planning activities. Jiang (2020) reported similar applications of using UASs to improve the efficiency of site layout planning. The next most important application of UAS in pre-construction, as informed by the participants, specifically the Heavy civil construction firms in the calculation of cut/fill volumes for earthwork. "The UAS we have is equipped with a laser scanner, it collects the photogrammetry site data, through which we generate 3D models of the areas, and then by using some software applications, we can calculate accurate cut/fill volumes which we use in our estimates. This has saved us a lot of time as well as effort while being very accurate", informed a participant indicating how UASs improve accuracy in addition to their applications. This is in line with Wang's (2017) findings related to applications of UASs for earthwork calculations.

Quality management

The UASs combined with other latest technologies such as LIDAR and Building Information Modelling (BIM) is used for quality control and management by the contractors interviewed. Approximately 50% of the interviewed contractors explained different ways they use UASs for quality management. "We use UAS for quality management in various ways. For a project in which we had a BIM model, we flew a UAS to collect point cloud of the 'as-is' construction to compare it with the 'as-planned" BIM model to assess quality deviations, if any" informing one of the quality control applications of UAS in construction. This corresponds with Kielhauser's (2020) study that identified various quality control applications of UASs in the construction industry.

Safety management

Some of the participant firms (25%) informed that UASs are used for safety inspections and training at the job sites. "We run UAS safety flights regularly at our job sites to inspect if all employees are following safety standards, and if all required safety measures are taken", specified a participant. These

findings corroborate with de Melo's (2017) study that used data collected through UAS for safety inspections to conform with safety standards at the job sites.

Project progress monitoring

About 80% of the participants mentioned using UASs for tracking the daily/weekly construction progress of the job sites. "We collect real-time visual construction progress data of our projects by flying UASs. This information is useful to assess site progress against planned progress. Our project owners and other stakeholders now have progress updates and key milestones frequently without even visiting the site due to UASs. This also helps to document site progress for future purposes", mentioned a participant informing how UASs are applied for progress monitoring and their advantages.

Table 3

Summarized Results on Current State of Practice of UASs in Construction

Participant	**Type of UAS used**	**Total No. of UASs**	**Company Size (employees)**	**Annual Expenses ($) per UAS***	**Functional Applications**
Participant 1	Multi-rotor	3	224	$ 6,000	Earthwork Site progress Photogrammetry
Participant 2	Multi-rotor	1	803	NA	Survey Site logistics Cut-fill logs Safety Inspection
Participant 3	Multi-rotor, Fixed wing, hybrid	30	22, 000	$ 35,000	Quantity control & Inspections Project progress Photogrammetry Safety
Participant 4	Multi-rotor	Confidential	700	$ 5,000	Project progress Communication Quality control Productivity
Participant 5	Multi-rotor	Confidential	172	$ 12,000	Photogrammetry Thermal scanning Building envelope Aerial Imaging
Participant 6	Multi-rotor, fixed wing, hybrid	7	3, 100	$ 14,000	Photogrammetry Quality control Rockfall mitigation Soil erosion
Participant 7	Multi-rotor	1	25	$ 10,000	Photogrammetry Safety Inspections

Participant 8	Multi-rotor	5	292	$ 4,000	Marketing Survey Quality control Site progress check

*UAS costs include equipment and accessories and can vary significantly depending on quality.

Construction surveying

The UASs are widely for site surveying applications in the construction industry. Every participant of this study indicated that they collect aerial photography data of job sites for surveying and layout purposes. “Traditional techniques such as total station takes us a lot of time, effort, and money. While UASs provide faster and less costly construction land surveys as they can collect data and process it much quickly”, informed a participant regarding the efficiency of using UASs for surveying. “Earlier, for an 80-acre job site survey that requires at least 1600 GPS points, we spent 80 hrs. (3 min/point) for data collection, $12,000 for surveyor costs, and waited about 2 weeks for processing. Now, by using UASs, we collect about 1 million GPS points in 2 hours and have the processing done in less than 24 hours, all for $1500”, indicating how adopting UASs for surveying purposes saves time and money.

Barriers for Implementing UASs in Construction

Despite the literature identifying several benefits, the current state of practice suggests that construction firms use UASs for limited applications. To increase mobility and further improve the integration of UASs in the construction industry, it is critical that research investigate the barriers to the wider adoption of UASs in construction. This section of the paper identifies numerous barriers that impede the implementation of UASs in the construction industry. Barriers mentioned by participants included lack of contractor awareness regarding advantages and applications of UASs in construction, lack of technical know-how regarding extraction and processing of UASs data, lack of training, extensive certification and licensing requirements, flying in congested spaces, flying in varying weather conditions, and large initial capital requirements to acquire UASs among several other factors. “The costs associated with starting a UAS program within a construction firm are huge and some contractors are reluctant to make that investment. They have to buy the equipment, purchase the relevant software packages to process the data, train the personnel to use UASs to collect and handle data, obtain licenses and certifications for them. This is a lot of initial investment, which drives away several contractors,” opined a participant informing the costs associated with implementing UAS programs. Another participant mentioned, “UASs are easily affected by tough weather conditions, such as heavy rain, snow or wind. Weather conditions like heavy wind or thick cloud cover can prevent a UAS from flying safely and can stop the right and clear images from being taken. Operating UAS under these kinds of conditions can cause delays and might eventually lead to a collection of wrong data,” indicating limited operability as one of the major barriers for contractors to consider implementing UASs. The general trend of responses from the participants was that the UASs are upgrading the technical capabilities was rapidly making them well suited for construction applications. “I started using UASs 3 years ago, the kind of technical abilities UASs have today, the way they fly longer, and process data accurately are way ahead and different from what I’ve seen in 2018. I am confident this will improve much faster and help construction tasks much better in 2024 or 2025”, said a participant indicating an optimistic outlook regarding overcoming the hurdles to implement UASs as well as the growth of UASs could experience in the construction industry.

Conclusions and Limitations

The objective of this research study was to identify the current state of practice, and barriers for using UASs in the construction industry based on a literature review and interviews with construction professionals and drone experts who use UASs for various construction tasks. The study provided a list of UASs applications, which includes surveying, project progress monitoring, safety management, and quality management. The construction firms that participated in this study used different varieties of UASs such as single rotor, multi-rotor, fixed-wing, and fixed-wing hybrid, while multi-rotor UAS is the most predominan9xtly used among construction firms. The initial investment costs, and annual maintenance expenses for UASs range from $4,000 to $35,000 per UAS based on the different applications the firms use. Noted barriers to using UASs in construction included low awareness of UASs applications among construction professionals, professional training requirements, large initial capital requirements, and issues related to flying in congested areas, night times, and different weather conditions. In the future, UASs can be expanded to integrate with other technological advancements to further improve construction operational efficiency.

The limitations of this study include a small sample size and that all participants were from the same region. Future research is recommended to explore a mixed-methods study to collect data from across the U.S. regarding the current state of practice and will perform a cost-benefit analysis of using UASs in construction. This study contributes to the body of knowledge by identifying application areas, the current state of practice, and barriers to implementing UASs in construction. This information can be utilized by prospective construction firms that want to implement UASs to take informed decision-making regarding the implementation of UASs within their firms.

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