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Drone-Driven Learning: Advancing Construction Education through UAV Integration

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Dr. Hariharan Naganathan, an Assistant Professor of Construction Management at Wentworth Institute of Technology, has made significant contributions to sustainable construction practices through research on energy analytics of buildings and the integration of Augmented Reality (AR) and Virtual Reality (VR) in construction education. As a passionate educator, Dr. Naganathan develops a curriculum that combines theoretical knowledge with hands-on AR/VR experiences, preparing students to design and analyze construction projects. Currently, Dr. Naganathan is working on research projects aimed at improving energy efficiency in existing buildings and exploring the potential of AR/VR in construction education. His dedication to fostering innovation in sustainable construction inspires the next generation of construction managers to create a more energy-efficient built environment.

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Abstract

Recent technological advancements have shifted the construction industry's view toward adopting new technologies to improve their processes. This has led to the utilization of various tools such as aerial photogrammetry, inventory tracking, site logistics, safety inspection, and structural condition inspection. One of the most notable emerging technologies is drones, which were initially developed for military purposes but have since been adopted by the construction industry due to their cost-effectiveness, productivity, safety, and flexibility. However, integrating drones into construction education requires knowledge beyond the traditional topic area of engineering technology. Construction engineering technology educators must use systematic processes and learning tools to introduce drones in the classroom. This paper details the basics of emerging technologies, proposes a preliminary matrix through the learning outcomes from various accreditation bodies, and explains the steps required to implement drones into construction education by reviewing multiple industry case studies. The study also identifies the challenges and effectiveness of utilizing these technologies in classroom education through educators' perspectives.

Keywords: Emerging Construction Technology, UAVs, Student Learning Outcomes

Introduction

In recent years, the construction industry has introduced new advanced emerging technologies such as drones, artificial intelligence (AI), information and communications technology (ICT), sensors, and transportive modality technologies. This study focuses on how to utilize and implement drones, which are an emerging technology in academia. A drone, also known as an unmanned aerial Vehicle (UAV), is a small flying platform capable of carrying a light payload, such as various sensors, cameras, and computer devices. The drone can be operated without a human pilot on board and instead uses a remotely controlled operator at a distant location. The primary advantages of using drones are mobile accessibility within a wireless control signal range, economic affordability, and versatility [1]. Due to continuously advancing technologies, sensors have become smaller, lighter, and more affordable. Digital cameras, LiDAR, and onboard computers with data storage/transmission are integrated with a drone, covering the area with an accurately controlled flying-path system. UAV is a proven technology that keeps growing in its market. According to [7], the UAV industry would generate more than 100,000 new jobs and an economic impact of $82 billion by 2025.

Emerging technologies are constantly improving and expanding their applications in the construction industry. New construction technologies are advancing incredibly, connecting equipment and tools, drones, mobile apps, and autonomous controls worldwide. Some examples of technology implementation in construction include 1) monitoring construction operations to improve productivity, 2) tracking construction material inventories using RFID technology, 3) improving construction safety by detecting hazards on job sites, 4) creating a digital terrain model (DTM) by scanning the topography of the project area, 5) building an as-built visualization model for existing structures, and 6) monitoring structural condition by transmitting sensor data in proximity distance. These technologies continue to advance to overcome challenges, and their financial benefits are impossible to ignore compared to more traditional methods. This paper introduces not only the basics of emerging technologies, including drones, but also the implementation of these technologies to existing construction education programs to improve student learning outcomes (SLOs).

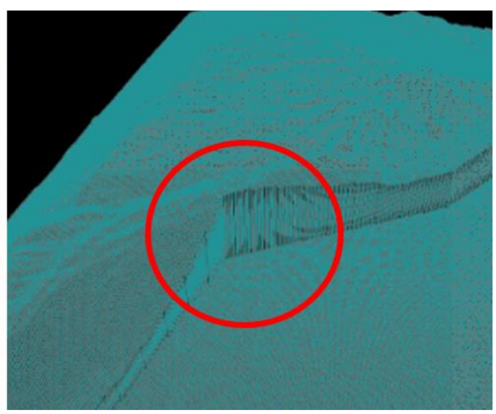
Emerging technology applications for the construction industries

Quantity Photogrammetry for Construction

Drone-based photogrammetry technology is used in construction site management to generate a 3D point cloud model using 2D images taken by the drone's image sensor. The 3D point cloud model measures and verifies the dimensions of targeted objects, such as length and site size, from the built structure components and topographic objects. This information is incredibly useful for verifying the progress visualization of construction work, including earthwork such as cut and fill.

The 3D model volume visualization capability is a powerful tool that allows us to obtain precise and accurate volume measurements of stockpiles. With this feature, we can easily select the stockpile of interest and examine it in the 3D model to generate more accurate volume measurements. To illustrate the process, Figure 1 depicts examples of volume visualization using the 3D model. The polygon tool is utilized to measure the stockpile volume, as shown in Figure 1(a). This tool enables us to define the area of interest and accurately measure the volume of the stockpile. Once the area of interest is defined with the polygon tool, the stockpile is inspected and displayed in the 3D model, as demonstrated in Figure 1(b). This process is a highly effective way to measure the accurate volume of earthwork and trenches, depending on the polygon tool's coverage area. In summary, the volume visualization feature, coupled with the polygon tool, is an excellent way to measure accurate volumes of stockpiles. It is a quick and efficient method that yields precise results, making it an indispensable tool for many applications.

(a) Polygon tool to define an area



(b) Stockpile view in 3D along the defined area

Figure 1 3D Volume Visualization [4]

When it comes to photogrammetry calculations, it is crucial to capture the subject with a 360-degree view. To ensure accuracy, the captured image should be overlapped by 30% to 60% with the adjacent images. Various commercial photogrammetry programs are available, including Pix4D, Context Capture by Bentley, and 123D by Autodesk, which can help generate 3D point clouds. Additionally, open-source tools such as Visual SFM and Open Drone Map can also be used to acquire the 3D point cloud. Figure 2 shows the impressive result of using Pix4D to create a 3D point cloud from the drone images.

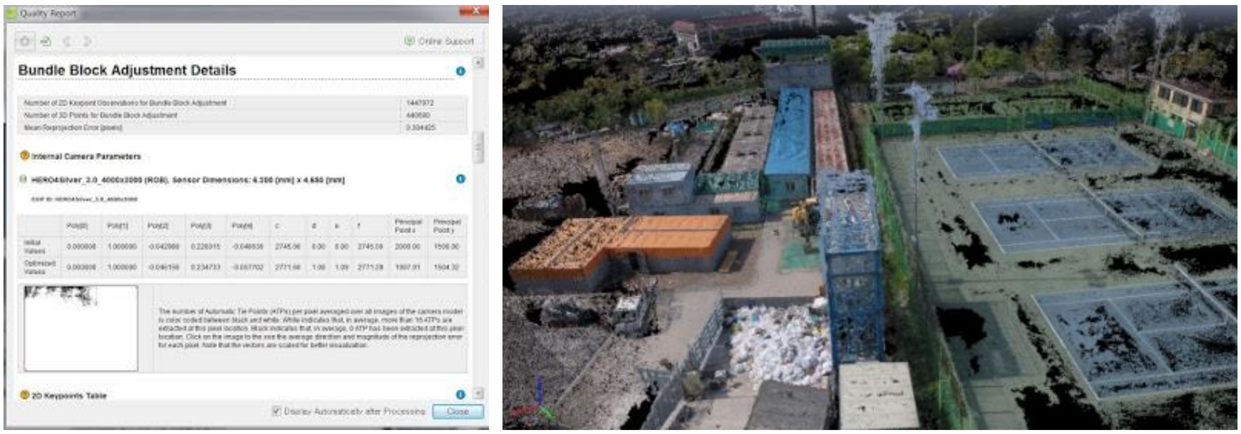


Figure 2 3D point cloud at the Korea Institute of Civil Engineering and Building Technology (KICT) plant facility.

Photogrammetry is a technique for extracting 3D information from 2D images by creating a 3D point cloud. However, this method has some limitations. The process is time-consuming, and achieving real-time processing is challenging. Moreover, the coordinates' accuracy cannot be guaranteed without registration with the reference point in the survey network. Additionally, errors in photogrammetry can range from several tens of centimeters to a few meters, depending on the skill level or technical procedure used.

Project Progress Monitoring with Time Lapse 3D Modeling

Drones have become a popular tool for capturing aerial photos and videos, allowing for convenient tracking and monitoring of project progression. However, it is essential to note that the data received from these captures is in raster imagery format rather than a vector, which can present some limitations for building digital models. To overcome this challenge, it is possible to express the construction sequence in time-lapse as a 3D point cloud collection of coordinate geometry (COGO) points. This approach enables the simulation of 3D model progression in virtual space, offering a more accurate representation of the construction process.

It is worth noting, however, that drone-based 3D point cloud capture is not always accurate in building models. For instance, the building surface color may mismatch due to shadow problems, which can vary depending on weather and sun location. To address this issue points such as unique feature points (invariant edges, color patterns, and matching targets) can be set as references. Despite the challenges, drone-based 3D point cloud capture can be precious in construction projects. For example, the 3D point cloud volume scanned daily can be as much as

1.5 GB, generating an incredible amount of data that can be used to improve project management and decision-making. One such example is the time-lapse case of a 3D point cloud acquired by a drone under a building construction for a roof, which is illustrated in Figure 3.

Figure 3 Example of construction progress in time-lapse [8]

Facility management with Drone

Facility management is a crucial task that involves inspecting and assessing the condition of structures and other elements in a building. With the increasing use of drones in facility management, conducting inspections in areas with limited physical access has become easier. A notable example of this is AkitaBox, a commercial platform that uses drone technology from PrecisionHawk to provide remote sensing and data processing services. This platform combines building management software with drones to create a 'Smart Package' that eliminates the need for manual inspections of the exterior of a complex [5]. Daily drone flights can help monitor site conditions, identify hazards, improve logistics planning, and map assets. The data captured by the drones can be effectively used to manage facilities using Building Information Modeling (BIM) data. Figure 4 illustrates how facility inspection can be automated using this technology.

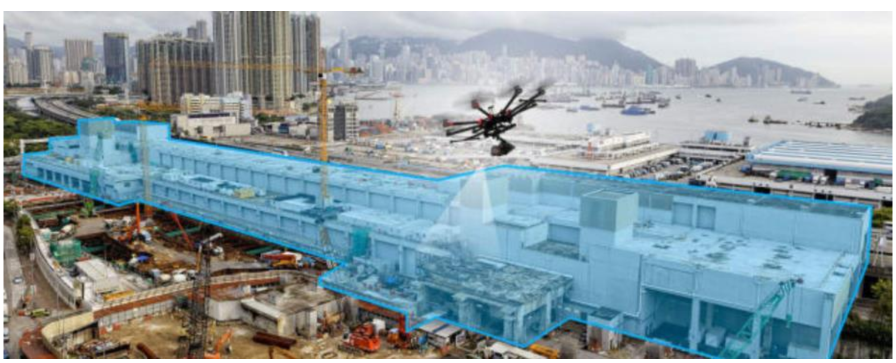


Figure 4 Automating facility inspection with drones [5]

Infrastructure LiDAR Scan

LiDAR and photogrammetry are two technologies commonly used in the construction industry. While photogrammetry measures distances between objects and is a cost-effective method for geometric data assessment, LiDAR uses a laser to collect 3D point data, resulting in accurate and dense vector data. Cloud points generated by drone-based LiDAR produce higher resolution and more precise information than conventional photogrammetry techniques, as the laser can penetrate visual obstructions such as clouds and light vegetation. Reverse engineering applications typically employ the precise information obtained from drone-based LiDAR. Figure 5 is an example of a LiDAR image that scanned highway intersections and ramps [6].

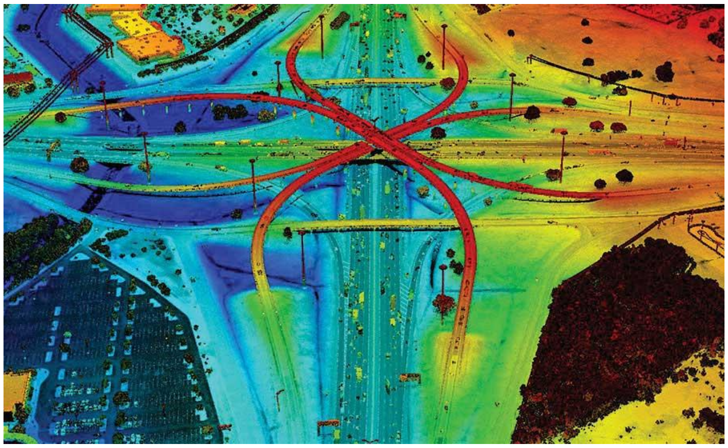


Figure 5 Example of LiDAR scanned Image by Drone [3]

An exciting application of LiDAR technology is digitizing historical sites, which involves creating accurate as-built digital data. One such project that utilized this technology is the ScanPyramids project, which was initiated in 2015. This project aimed to digitize all parts of a pyramid using various reverse engineering techniques and equipment, including drone-based LiDAR laser scanning. The project used the latest scanning and reverse engineering technologies to create a complete digital 3D model of the pyramid. Once the data was obtained, the project team identified the detailed structures of the pyramid, including geometric elements such as levels, slopes, and possible traces of ancient ramps or construction paths. This information was then used for the reconstruction of the pyramids. Overall, the ScanPyramids project is an excellent example of how LiDAR technology can be used to digitize historical sites, enabling researchers to obtain highly accurate data that can be used for various purposes, including reconstruction and preservation. [2].

Learning applications in construction engineering and technology education

The construction industry is continuously evolving, with new technologies being introduced constantly. To keep up with these trends, it is necessary to integrate these new technologies into the current baccalaureate curriculum for construction management education. The construction management curriculum primarily focuses on applying these new technologies rather than creating or developing them. This initiative aims to equip future construction leaders with the necessary skills to lead the industry while maintaining traditional student learning outcomes in the construction management curriculum.

Various technologies utilized in the industry and their applications in different industries necessitate a minimum of four crucial steps: data acquisition, data processing, data application, and execution. The necessary teaching modules that can facilitate the performance of these steps have also been identified. The modules for each of the four application steps are as follows:

1. Data Acquisition:

a. Data Collection: Students should be able to design data collection processes for construction-related projects.

b. Photogrammetry: Students should understand the basic theory of photogrammetry and be able to apply it to the problem.

2. Data Processing:

a. Image recognition: Students should understand the basic concept of image recognition and be able to utilize multiple image recognition techniques and tools.

b. Generate 2D and 3D Data: Students should be able to generate new 2D and 3D data based on the recognized images.

c. Image Data Analysis: Students should understand the basic tools for analyzing images.

3. Data Applications:

a. Implementing Tools: Students should be able to implement tools to apply analysis methods to the collected and processed data.

b. Identify Objectives: Students should be able to define objectives to deduce the useful meaning of data after analyzing it.

4. Execution:

a. Machine Control: Students should be competent to operate and control required machines such as sensors and drones.

b. Monitoring Work Site: Students should understand the concept of operating machines and monitoring worksites to prevent potential risks and/or interrupting any other activities that should be performed simultaneously.

This research study aims to explore the relationship between the implementation of cutting-edge technologies and instructional modules and how they affect learning objectives and outcomes in these programs. The United States has two major accrediting agencies for educational institutions: the Accreditation Board for Engineering and Technology (ABET) and the American Council for Construction Education (ACCE). Both organizations provide comprehensive guidelines for student learning outcomes and coursework. Table 1 details the overview of the student learning outcomes that meet the ABET and ACCE standards. These outcomes are grouped into four primary subject areas: data acquisition, data processing, data application, and execution, and each subject has sub-content. The research aims to provide an in-depth analysis of the correlations between these learning outcomes and the use of innovative technologies in teaching and learning environments, which can help improve the quality of educational programs.

Table 1. The potential use of emerging technologies in construction curriculum based on the student learning outcomes from ABET and ACCE

		Data Acquisition		Data Processing			Data Application		Execution	
	Applications in Curriculum	Collect Data	Photogrammetry	Image Recognition	Generate 2D and 3D Data	Image Data Analysis	Implement tools	Identify objects	Machine Control	Monitoring Work Site
Student Outcomes based on ABET Engineering, Technology and ACCE										
ABET- Engineering	(a) mathematics, science, and engineering knowldege					x			x	
	(b) design and experiments			x						
	(c) design within various constraints									
	(d) multidisciplinary team skill									
	(e) engineering problems									
	(f) professional and ethical responsibility									x
	(g) Effective communication									
	(h) engineering sustinability								x	
	(i) continous education engagement									
	(j) Contemporary issues									
	(k) Modern skills and tools for practice		x		x		x	x		
ABET- Engineering Technology	(a) Knolwege, skill, and tools	x	x	x						
	(b) Application of principles and applied procedures		x	x	x	x	x			
	(c) Standard tests and measurements		x							
	(d)Design systems, components, or processes			x						
	(e) effective technical team									
	(f) Identify, analyze, and solve ET problems;							x		
	(g) Written, oral, and graphical communication									x
	(h) Continuous professional development			x	x				x	
	(i) Professional and ethical responsibilities									
	(j) ET solutions in a societal and global context									
	(k) Continuous improvement		x				x			
ACCE	1) Written communications									
	2) Oral presentations									
	3) Safety plan									
	4) Cost estimates									
	5) Schedules.									
	6) Decisions on ethical principles.									
	7) Documents for planning and management									
	8) Methods, materials, and equipment	x	x	x	x	x	x			
	9) Multidisciplinary team management skill									x
	10) Electronic-based technology		x	x	x	x	x		x	
	11) Surveying techniques									
	12) Project delivery									
	13) Risk management.									
	14) Accounting and cost control.									
	15) Quality assurance and control.	x								x
	16) Project control									x
	17) Legal implications									
	18) Sustainable construction.									
	19) Structural behavior									
	20) Mechanical, electrical and piping systems									

To ensure students have the skills necessary for construction projects, they must have a practical understanding of technical competencies. These competencies include photogrammetry, image recognition, 2D to 3D conversion, and software skills. Evaluating the effectiveness of construction engineering and engineering technology education requires incorporating student outcomes from ABET engineering, ABET Engineering Technology, and ACCE into the curriculum.

Applications of Drone technology in the construction curriculum

Drones can be utilized in the construction management curriculum in several ways:

1. Construction Surveying

Drones have emerged as a valuable tool for site surveys and inspections in construction. They provide an aerial view of construction sites, allowing students to study and analyze the site's layout, topography, and potential challenges. The high-resolution images and videos captured by drones provide students with a bird's eye view of the site, which would not be possible otherwise. By analyzing the images and videos, students can better understand the site's features, such as terrain, elevation, and obstacles. This helps them develop the skills and knowledge needed to plan and execute construction projects more accurately and efficiently. Additionally, using drones for site surveys and inspections is a safer and cost-effective alternative to traditional methods, such as scaffolding and cranes.

2. Construction Analytics

Drones have become an increasingly popular tool for data collection and analysis in construction management. By capturing high-quality aerial imagery and videos, drones can provide valuable documentation, monitor construction progress, and conduct surveys and measurements relatively quickly and efficiently. This data can then be used for detailed analysis and decision-making in various aspects of construction management, such as project planning, monitoring, and quality control. With the help of drones, construction managers can gather accurate and up-to-date information that can help them make informed decisions and improve the overall efficiency and effectiveness of their projects.

3. Construction Visualization

Drones have emerged as a revolutionary tool in education, particularly for construction-related courses. One of the critical benefits of drones is that they can be utilized to create construction simulations and virtual reality experiences. This allows students to virtually explore and interact with construction sites and projects, providing them with a hands-on experience that is both immersive and engaging. By using drones to create virtual environments, students can better understand construction processes and management techniques and develop practical skills that will be useful in their future careers.

4. Construction Operations

Drones are proving to be a valuable tool in the construction industry. In addition to their primary use of surveying and mapping construction sites, they can also be used to teach students about the regulations and guidelines related to drone operations in construction. By incorporating drone technology into the construction management curriculum, students can gain hands-on experience with this emerging tool and develop crucial skills highly sought after in the construction industry. Moreover, drones in the construction management curriculum can provide students with real-world experience in incorporating emerging technologies into construction projects. This experience can help students understand how to apply drone technology in various stages of construction, such as site analysis, design, and construction management. Additionally, it allows them to develop skills critical for future professionals to succeed in the construction industry. This innovative approach to teaching construction management can significantly enhance the learning experience, offering students a unique opportunity to learn about cutting-edge technology and gain practical skills that can be used in their future careers.

Limitations and Challenges

As an educator who wishes to incorporate drones as a pedagogical tool in the construction management curriculum, several challenges must be considered in order to make effective use of this technology.

1. Training and certification:

Educators who wish to operate drones are to undergo thorough training and obtain the necessary certifications and licenses per the aviation regulations. This process can be quite time-consuming and may require additional resources, such as hiring qualified instructors or purchasing training materials. The training program typically covers a range of topics, including drone safety, flight procedures, emergency protocols, and regulatory compliance. Once the faculty members have completed the training and obtained the certifications, they will be well-equipped to operate drones safely and responsibly while adhering to aviation standards.

2. Integration into the existing curriculum:

The integration of drone technology into the construction management curriculum would require a thorough review of the existing courses and the development of new courses that specifically focus on drones. This process would involve detailed planning and coordination to ensure that the use of drones is aligned with the learning objectives and structure of the curriculum. The new courses would need to cover a wide range of topics, including drone operation, data management, and safety regulations. It is also important to consider the availability of necessary resources, such as drones, software, and hardware, to support the new courses. Additionally, the instructors would need to be trained and qualified to teach the new material to students effectively. All of these factors need to be carefully considered and addressed to successfully incorporate drones into the construction management curriculum.

3. Integration with other technologies:

Drones are a vital element of the technology landscape in construction management. However, to ensure students receive a comprehensive understanding of the digital tools utilized in modern construction management, educators should explore the integration of drones with other technologies, such as Building Information Modeling software and virtual reality tools.

4. Logistical considerations:

Incorporating drones into construction management education can be a valuable tool for students to gain hands-on experience with cutting-edge technology. However, implementing a drone program would require several considerations. Firstly, a dedicated space for drone operations is necessary, which should include a secure area for equipment storage. Along with this, faculty would need to establish maintenance and repair protocols to ensure the drones are functioning correctly. Moreover, scheduling drone flights and ensuring the availability of trained operators are additional logistics that need to be considered. It is crucial to have a trained and certified operator to fly the drones, and they must adhere to safety protocols and regulations. Finally, the data collected by drones must be managed and stored securely. The faculty would need to establish a system to store and organize the data obtained from drone flights, as well as ensure that data privacy is maintained.

5. Liability and safety concerns:

Drones have been gaining popularity in various industries, including construction management education. However, the use of drones in this field poses potential risks, both to the operators and to the surrounding environment. As a result, it is crucial to address liability and safety concerns to ensure the safe utilization of drones. In addition to safety concerns, the cost of acquiring and maintaining drones and their associated technologies can be a significant barrier for educational institutions.

Conclusions and Discussion

The construction industry has implemented new technologies that have been proven effective for construction projects. One such technology is drones, rapidly gaining popularity in the industry. These drones have digital cameras and laser scanners that allow for cost-effective and high-productivity digital scans of construction sites. In addition, drones are also used for inventory tracking, safety inspections, automated visualization, and structure condition inspections.

However, many construction engineering, technology, and management programs in U.S. universities are not yet equipped to teach these emerging technologies. Integrating these technologies into the current construction engineering and management curriculum is imperative to bridge the gap between the construction industry and university programs. These technologies are interdisciplinary STEM tools that can inspire students to engage with new technologies and lead technology innovation in the construction industry.

Some of the key challenges that need to be addressed include ensuring that students are properly trained in the safe operation of drones, developing suitable course content that integrates drone technology within the existing curriculum, and identifying suitable locations for conducting drone-based activities. Additionally, it is important to consider the cost of purchasing and maintaining drones, as well as the regulatory compliance requirements that must be met when using drones for educational purposes. The initial cost of acquiring drones and associated technologies can be high, and ongoing maintenance costs can add up quickly. These financial factors must be taken into account when considering the use of drones in construction management education. Addressing these challenges will enable educators to use drones more effectively as a tool to enhance the learning experience in construction management programs.

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