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Integration of a UAS-Photogrammetry Module in a Technology-based Construction Management Course

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The significantly increased usage of Unmanned Aerial Systems (UASs) and photogrammetry technologies in the construction industry underlines the need to integrate such technologies within the educational curricula. This paper presents the lessons learned from a recent effort to integrate a UAS-Photogrammetry module in a technology-based construction management course. Specifically, the goal was to enable students to better understand the generated point clouds through interpreting and comparing their visual quality differences while studying how common flight parameters [i.e., ground sampling distance (GSD), image angle, image combination] might affect them. This course module consisted of a theoretical knowledge part followed by a hands-on training part. As a part of this module, students generated point clouds, performed photogrammetric measurements, and conducted detailed comparisons based on different flight parameters. The module could provide construction students an opportunity to better understand and assess the effects of different UAS flight parameters on the quality of the generated photogrammetric point clouds.

Key Words: Unmanned Aerial Systems, Surveying, Photogrammetry, Structure-from-Motion (SfM), Construction Education

Introduction

Technological advancements have enabled Unmanned Aerial Systems (UASs) to become more inexpensive and widely used on construction jobsites within the past ten years (Albeaino, Gheisari, & Franz, 2019; Rakha & Gorodetsky, 2018). These aerial vehicles can easily access hard-to-reach locations while safely, cost-efficiently, and timely accomplishing various tasks, including structural and infrastructure inspection, safety management, progress monitoring, and building maintenance (Albeaino & Gheisari, 2021). Such growth in UAS-mediated applications constitutes a driving force for educational construction programs to train and prepare graduating students to use UAS technology in this setting (Albeaino, Eiris, Gheisari, & Issa, 2021; Eiris, Zhou, & Gheisari, 2018). Training future generations of construction professionals is critical, especially with the current lack of skilled UAS pilots and safety managers available on jobsites (Golizadeh et al., 2019; Park, Kim, & Cho, 2017). In fact, while almost all construction companies purchase UAS equipment instead of designing their own aerial platforms, safety managers and UAS operators are needed on every jobsite to ensure the safe deployment of UASs especially over workers and other construction personnel to avoid, for example, struck-by and fall accidents (Martinez, Albeaino, Gheisari, Issa, & Alarcón, 2021). This becomes particularly important with the wide deployment of UAS, the applications of which are expected to expand even more in the future.

Regardless of the construction task type, three steps are required when deploying UASs on jobsites. Step one consists of pre-planning the flight mission(s). Pre-planning tasks include setting flight parameters and navigation style and ensuring that the mission(s) are performed safely and as per the Federal Aviation Administration (FAA) Part 107 requirements (US Department of Transportation, 2016). Step two entails the collection of visual (e.g., images, videos) information of the intended facility. Finally, step three involves post-processing the UAS-acquired visualizations for further analysis and interpretation, depending on the construction task (Albeaino et al., 2019; Rakha & Gorodetsky, 2018). Collected UAS visuals can be: (1) relied upon as standalone images and videos; (2) combined with computer vision and other machine learning techniques; or (3) processed using Structure-from-Motion (SfM) to generate different photogrammetric products (e.g., point clouds, digital surface models, digital elevation models, orthophotos) (Rakha & Gorodetsky, 2018). The latter technique is considered one of the most popular methods for processing UAS-captured data. For this purpose, there is a need to integrate the concepts of UAS-Photogrammetry within construction engineering and management curricula (Albeaino et al., 2021; Eiris et al., 2018).

Multiple studies have focused on the integration of UASs in education. In geomatics and geology, geospatial thinking enabled students to collect UAS images and process them (Al-Tahir, 2015; Jordan, 2015; Sharma & Hulsey, 2014). In engineering, Molina et al. (2014) recruited a team of undergraduate mechanical, electrical and computer engineering students to solve range- and endurance-related issues that quadrotors typically encounter in closed perimeters. Wlodyka & Dulat (2015) asked undergraduate engineering students to design and model different UAS payload configurations before fabricating and installing them on actual aerial platforms. Eiris et al. (2018) and Williamson III and Gage (2019) introduced undergraduate construction students to UASs through course modules and class activities. In both studies, students were exposed to the entire UAS-mediated photogrammetry process, ranging from UAS pre-flight planning and deployment to data collection and processing. Upon processing the UAS-collected data, students also combined photogrammetry with building information modeling (BIM) (Eiris et al., 2018). Recently, Albeaino et al. (2021) developed a virtual reality environment to safely train construction students to perform building inspections using UASs. Many of these studies focused on improving students' UAS piloting skills. Some others have even introduced students to the general processes of SfM and photogrammetry. However, none of these studies had specifically exposed undergraduate students as to how different flight parameters used on site might affect the visual quality of the generated photogrammetric point clouds. Students' abilities to understand how, for example, image angle, image combinations, and ground sampling distance (GSD), affect the resulting visual quality of the point cloud is of particular importance, especially since many UAS applications in construction necessitate generating high-quality 3D point clouds and models to accurately interpret the obtained results and draw meaningful conclusions. These factors – among others – constitute a field of research in geomatics and surveying, and given the increased use of UASs in construction, researchers have recently started to use different combinations to improve the quality of the generated point clouds (Martinez, Albeaino, Gheisari, Volkmann, & Alarcón, 2021). To satisfy this pedagogical need, this study focuses on creating a UAS-Photogrammetry module that provides students with a good understanding of how different flight parameters (i.e., GSD, image angle, image combination) might affect the generated 3D point clouds and models. The module specifically aims at preparing students who can plan UAS flights, operate aerial vehicles, and process corresponding acquired visuals to compare the effects of different flight parameters on the visual quality of the photogrammetrically-generated point clouds. First, details on the UAS-Photogrammetry module in the technology-based course, along with students' learning objectives and expected outcomes, are presented. Details related to the theoretical (lecture-based introduction targeting different UAS-related concepts) and the hands-on (performed flight missions together with collected and SfM-processed UAS data) components constituting the UAS-Photogrammetry module are then provided. Finally, lessons learned from the course module are presented, and future research is proposed.

Methodology

Course Description and UAS-Photogrammetry Module Integration

The UAS-Photogrammetry module, for which four sessions (total of six hours) were dedicated, was integrated into the *BCN4252: Introduction to Building Information Modeling* course offered as an undergraduate-level course at the Rinker School of Construction Management (University of Florida). In this course, construction management students get introduced to BIM-based workflows and advanced technologies such as BIM-based clash detection, BIM-based quantity takeoffs, BIM-based site planning and walkthroughs, mixed/virtual/augmented reality, 360-degree photo/videography, laser scanning, and photogrammetry using UASs. Each module in this course – including the UAS-Photogrammetry module – consists of two parts: theoretical knowledge and hands-on training. The following paragraphs summarize the theoretical knowledge and hands-on training parts of the UAS-Photogrammetry course module, reflecting students' learning objectives and expected outcomes out of these 6-hr sessions (Table 1).

For the UAS-Photogrammetry module, the theoretical knowledge component focused on introducing students to the concepts of point clouds, photogrammetry and laser scanning, which are two data collection methods typically adopted to generate point clouds. The advantages and disadvantages of these data collection methods and their relationship with UASs were also discussed. The theoretical knowledge also introduces students to the concept of UASs and UAVs (Unmanned Aerial Vehicles), their types (e.g., rotary-wing vehicles, fixed-wing vehicles, blimps) along with advantages and disadvantages about each type, their software and hardware components (including common payloads such as GPS, altimeters, inertial measurement units, barometers), technical requirements, and autonomous features (e.g., auto takeoff/landing, waypoint navigation, return home) typically used in construction. Students were also able to recognize current UAS-related FAA Part 107 regulations in addition to the topics that Part 107 covers to obtain a certificate and commercially fly a UAS in the United States. These topics mainly included airspace classification, flight restrictions, operation requirements, as well as aviation weather sources and forecasts. Finally, different UAS-mediated application examples within the AEC domain, the potential safety challenges of UAS flights, and commonly used point cloud generation software were also presented. The hands-on training part consisted of flight operation and visual data collection, followed by point cloud generation. The following sections summarize each of these hands-on training steps in detail.

Table 1. Students' theoretical and hands-on practical knowledge learning objectives

Theoretical Knowledge (two 1-hr sessions)	Hands-on Practical Knowledge (two 2-hr sessions)
Student learning objectives: • Define a point cloud. • Describe photogrammetry and laser scanning. • Identify the advantages and disadvantages of photogrammetry and laser scanning. • Define the concept of UAV/UAS/Drone.	*Student learning objectives:* • Fly a UAS autonomously and manually • Collect different sets of visuals from different angles, heights, and positions. • Use SfM processing software to generate 3D models and orthophotos. • Perform comparative analyses on the visual quality of the generated point clouds.

- Indicate the technical requirements of UASs.
- Recognize the FAA's basic regulations and where to find more information about them.
- Discuss current UAS applications in the Architecture, Engineering, and Construction (AEC) domain.
- Explain safety challenges a UAS might present in a construction jobsite.
- List a few software tools to create point clouds.

Flight Operation and Visual Data Collection

The goal behind performing the hands-on training was to train students on how to (Figure 1): (1) fly using both autonomous (i.e., pre-planned flight missions using flight planning software) and manual control; (2) collect different sets of visuals based on different image combinations (e.g., high, low, and oblique): different angles (i.e., nadir or at a 45° angle) and heights [i.e., ground sampling distances (GSDs): 0.05 cm/px or 1 cm/px]; (3) use structure-from-motion (SfM) processing software to generate three-dimensional (3D) point clouds and orthophotos based on the acquired UAS images; and (4) analyze and compare the effects of image angle, height, and combination on the generated point cloud visual quality.

During the knowledge part discussed in the previous section, students had already been exposed to the entire SfM- and photogrammetry-based point cloud generation workflow process. Due to COVID-19 implications, which forced our course to be instructed online, students could not conduct the planned flight operations in person but were able to perform all other hands-on tasks (Figure 1 – steps 2 and 3). For this reason, graduate assistants who were licensed UAS Part 107 remote pilots performed the data collection and provided the UAS-acquired visuals to students for point cloud generation and data analysis.

Different UAS flights were conducted at a University of Florida building, located at The Energy Research and Education Park in Gainesville, FL (Figure 1). The building has a total surface area of 924 m^2 and was selected based on the following reasons: (1) flying UASs in that location was neither part of any FAA-restricted airspace nor did it need to follow any UAS operational guidelines from the University of Florida's Department of Environmental Health and Safety; (2) the building together with its surrounding area had no vegetation (i.e., trees), metallic structures, and any other facilities that could otherwise negatively affect novice students' piloting judgment and potentially cause unsafe UAS-related situations (e.g., collisions, struck-by accidents).

A total of three flights (two autonomous and one manual) were performed during the data collection to cover all three image combinations (i.e., high, low, and oblique). High images were collected by capturing nadir type of images with a GSD of 1 cm/pixel; low images were also acquired as nadir images, but with a GSD of 0.05 cm/ pixel; and oblique images were captured at a 45° camera angle. Table 2 summarizes different UAS flight parameters adopted during the data collection process. The DJI® Phantom 4 Pro quadcopter was used as the data collection platform due to its popularity and wide usage within the AEC domain (Albeaino et al., 2019). In addition, the Pix4Dcapture® software was relied upon to plan for each of these three flight missions. The platform, which was programmed to fly at a speed of 3 m/s, weighs 1.34 kg (including propellers and batteries), has a camera resolution of 5,472 × 3,648 pixels, and can operate for 25-30 minutes. All three flights were conducted on the same day, between 11:00 and 13:00, to minimize the effect of shadow on acquired images. The following section discusses the data processing workflow, in which students had to use Structure-from-Motion (SfM) and photogrammetry-based image processing software for the point cloud generation.

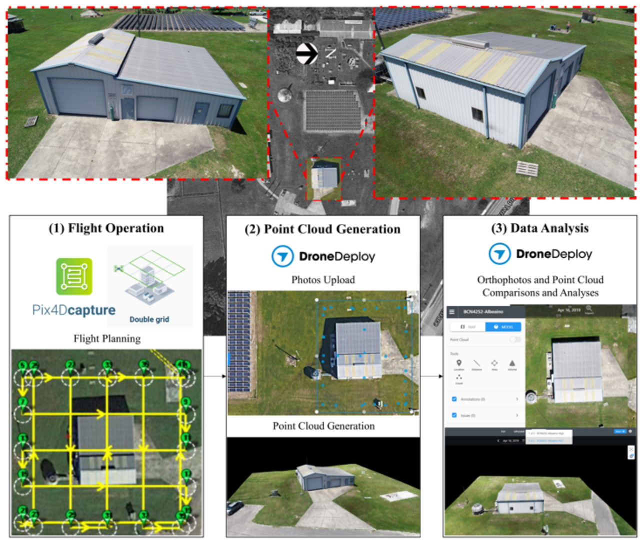

Figure 1. Data collection location and hands-on training workflow

Table 2. UAS flight parameters

Flight* #	Flying style	Image type	Height (in m) AGL*	Front overlap (%)	Side overlap (%)	# of images
1 (Low)	Autonomous	Nadir	18	80%	72%	86
2 (High)	Autonomous	Nadir	36	80%	72%	37
3 (Oblique)	Manual	Oblique (45°)	22	N/A	N/A	70

* *Flight mode: Double-grid,* ** *Above Ground Level*

Point Cloud Generation

Students were provided with detailed instructions on how to process the 193 collected UAS-acquired images using photogrammetry and SfM to generate two different point clouds based on two different image combinations as follows (Figure 2): Point cloud #1 – generated using low (GSD = 0.05 cm/pixel) images only; Point cloud #2 – generated using high (i.e., GSD = 1 cm/pixel), low (GSD = 0.05 cm/pixel), and oblique images (45° angle). The goal behind these two sets of point cloud generation was to help students better understand the effect of different flight parameters on the resulting point cloud visual quality. Students were asked to use DroneDeploy®, one of the most commonly used cloud-based UAS management and point cloud generation software in construction (Albeaino & Gheisari, 2021). First, students were instructed to set up an account, explore different UAS applications examples that the software already provides in the construction domain, and create a new project to upload the UAS-captured images. To create a new project, students were asked to input the project location, which helps accurately position the UAS-acquired images on an actual map. Since these UAS images already contain positioning coordinates, manually geo-locating them on the map was unnecessary, and simply adding the data collection location (i.e., zip code) was sufficient. Upon project creation, students were asked to explore different software capabilities, which range from pre-flight planning (e.g., setting flight parameters such as operation height; programming autonomous flight missions by defining GPS waypoints) to cloud-based post-processing (e.g., point cloud and orthophotos generation) and collaboration (i.e., UAS team members managing and collaborating on generated SfM and photogrammetric solutions). Using the "Create a Map or Model" option, the UAS-acquired images were uploaded, and the corresponding point clouds were generated using cloud-based image processing. This process was repeated twice to generate both point clouds (Figure 2).

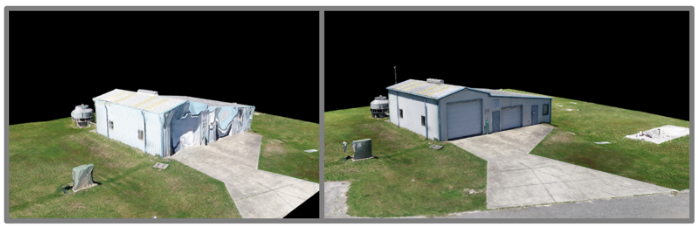

Figure 2. Generated point clouds [left: point cloud #1 (generated using low images); right: point cloud #2 (generated using low, high, and oblique images)]

Module Assessment

Students' theoretical knowledge and material comprehension were evaluated through a knowledge test consisting of 14 questions based on the topics covered in the module. In addition, each student's SfM and photogrammetry knowledge was also assessed using a project interpretation assignment where students had to individually interpret and discuss the differences between the two generated point clouds. Specifically, each student was asked to: (1) submit a screenshot of 3D point clouds generated using both low (i.e., point cloud #1) and low, high, and oblique (i.e., point cloud #2) images; (2) compare both point clouds and describe the visual quality differences between them; (3) justify why the 3D point cloud generated using different image combinations (i.e., low, high, and oblique) was denser and more visually complete compared with the one generated using low images only; and (4) explain the concept of GSD and how it affects the resulting point cloud visual quality. Through these photogrammetry- and SfM-related questions, students would be able to better understand the effect of different flight parameters (i.e., image angle, height or GSD, image combinations) on the resulting point cloud visual quality.

Results

A total of 15 construction management students enrolled in this course module. Overall, the knowledge test results showed that participants had a good understanding of different UAS-related topics (i.e., UASs, UAS components, technical requirements, autonomous features, applications in construction, FAA regulations and weather reports, SfM and Photogrammetry), as evidenced by their high average score (94.3 over 100) on the 14-questions test. Acquiring such knowledge enables students to: (1) have a good understanding of UASs, SfM and Photogrammetry and how these technologies and techniques are being used in construction; (2) meet the needs of the construction industry, which currently relies on UASs to accomplish different tasks; (3) improve their decision-making skills by distinguishing unsafe UAS practices and safety-related challenges that would cause hazardous UAS-related accidents; and (4) understand current FAA regulations for UAS deployment on jobsites. Furthermore, the hands-on practice part of the course module, together with the project interpretation assignment, enabled students to enhance their understanding of UAS-mediated SfM and Photogrammetry in construction. This was evidenced by their high average score (99.46 over 100) obtained on the project interpretation assignment. Such training also helped them generate point clouds, perform different measurements in the models, generate elevation maps, and analyze the effect(s) of image combinations, angle, and height on the resulting point cloud visual quality.

Specifically, almost all students noticed the visual quality differences between both point clouds. For example, one student responded that: *"[…] The 3D point cloud generated using the high, low, and oblique images had a better texture representation compared to the model generated using only the low images. In addition, while exploring the tools and using the distance tool to measure the exact same distance, the measurements were different for the model generated using low vs. high, low, and oblique images. It is also important to note that the model generated using the high, low, and oblique images is more complete and less distorted. There is also a difference in accuracy in the two models with the model generated using only the low images being less accurate. A greater map area of 0.38 acres is also observed in the model generated using high, low, and oblique images as compared to 0.211 acres generated using only low images. […]"*. Another student indicated that the point cloud generated using only low images was *"not crisp at all"*, and that *"much of the building looked deformed and blurry […] edges were rounded and not sharp and it was hard to notice features of the building such as windows, doors and wall patterns."* For the point cloud generated using high, low, and oblique images, students indicated that *"it was the complete opposite"* and that *"the building was clear and very realistic with nothing looking deformed or blurry and edges were sharp and one could easily notice features such as doors and windows of the building."* In addition, the majority of students associated the visual completeness of the 3D models with the camera position (i.e., camera angle), the GSD (camera height), as well as the number of images used during the image processing in their justification on why the low, high, and oblique point cloud was denser and more visually complete compared with the one generated using low images only. As an example, one student indicated that *"[…] the use of more images helps capture many more aspects of the building when compared to the other point cloud […]"*. Other student responses include: *"the high, low, and oblique images can capture more points for the point cloud as it takes pictures from a larger range of angles"* and that the point cloud generated using high, low, and oblique images was more accurate indicating that *"it is easier to calculate points in space if one has multiple different angles of the same point."* Finally, all students were able to define GSD, and successfully relate its effect on the visual quality of the generated point clouds. This was evidenced by participants' responses which include: *"[…] point cloud image quality is directly impacted by ground sampling distance […]"*; *"[…] GSD is related to the flight height, which means the higher the GSD, the higher the altitude of the flight. The higher the GSD value is results in a lower quality resolution of the image […]"*; and *"[…] Lower GSD values produce clearer images […]".*

Conclusion, Limitations, and Future Work

This module provided students with an opportunity to learn more about and apply the entire SfM and Photogrammetry process that construction professionals typically rely on in construction jobsites to analyze UAS-acquired data. They were able to use the provided UAS visuals and generate, using SfM- and Photogrammetry-driven UAS management software, orthophotos, and point clouds before analyzing and comparing the obtained results. Students were also able to qualitatively interpret the visual quality differences between different point clouds while studying how common flight parameters (i.e., GSD, image angle, and image combination) affect the resulting 3D model quality. Because of the COVID public health concerns, students did not have the chance to conduct the planned flight operations in person. Despite exhaustively describing all the steps involved in the data collection process, multiple students expressed interest in performing data collection, and some of them even sent emails requesting permission to have real-world experience with this part of the assignment. For example, two students indicated that *"[…] It is unfortunate that COVID is not allowing us to fly the drones and have a more hands-on experience […]"* and then asked the following *"[…] Is there any chance I could use my own drone, and complete the required flights and image capturing of a building for this assignment? I think it would be a lot of fun to take my drone out with […] and each capture the sets of images ourselves for the assignment and each turn the assignment in […]"*. While using virtual reality training environments allows students (especially novice pilots) to improve their UAS piloting skills (Albeaino et al., 2021), capturing real-world UAS visuals – an essential step in photogrammetry workflow – within a virtual reality environment remains a challenge. Given current pandemic-related relief measures and the expected transition toward normalcy (i.e., pre-pandemic in-person education), construction management students will soon be able to have hands-on UAS flying experience to autonomously and manually collect, process, generate, and analyze UAS-acquired data.

While the advantages of the adopted UAS management software include cloud-based computation which does not require hardware-heavy workstations for image processing, students did not get exposed to other processing parameters that might affect the resulting point cloud accuracy and visual quality. Examples of these processing parameters include aligning images, optimizing the orientation of images, generating dense models and meshes, as well as enabling the rolling shutter compensation option. In future semesters, additional software packages that allow inputting and modifying different flight parameter values will be used to expand students' understanding of the potential effect(s) of different flight and processing parameters on the generated 3D point clouds. Additional UAS-photogrammetry module activities can be created to compare the effect(s) of image combinations, angles, and heights on the positioning and geometric accuracies of the generated point clouds. High-quality and visually complete point clouds provide users with a complete overview of the intended facility and allow for proper interpretation of its different components (i.e., providing aesthetic information and height data, as well as showing details of complicated areas). However, assessing the positioning and geometric accuracies of point clouds might be extremely helpful, especially when performing fenestration measurements, quality control/quality assurance, or surveying types of construction activities. Future work must also focus on improving students' piloting skills by allocating additional training or practice sessions (in both real-world and virtual reality environments) for such course modules. Doing so will help in better preparing construction graduates for the needs of the construction industry and the expected growth in UAS adoption and safe human-UAS interaction within the domain. Future course modules should also introduce mounting UASs with different sensors (e.g., light detection, and imaging devices) to: (1) compare corresponding point cloud visual, positioning, and geometric accuracies; and (2) explore and apply UASs for different types of construction applications (e.g., thermal leakage detection, underground pipeline inspections, bridge inspection). Finally, user-centered within- and between-subject experiments should be conducted to: (1) assess and show the extent of the affect the module had on student learning; and (2) compare differences in learning from using different approaches to teaching the module.

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