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Integrating a Drone-mediated Photogrammetry and Scan-to-BIM Module into an Undergraduate Construction Course

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As technology reshapes the construction industry, the need to equip future professionals with essential digital skills becomes crucial. This study explores the integration of drone-mediated photogrammetry and Scan-to-BIM processes in undergraduate construction management education. The study involved introducing students to drone technology, Structure-from-Motion (SfM) photogrammetry, and Scan-to-BIM processes. Specifically, students were tasked with generating point clouds from drone-captured images, examining the effects of different flight parameters on point cloud accuracy, and then converting point cloud data into building information models (i.e., Scan-to-BIM). Results indicate that students developed a strong understanding of Scan-to-BIM processes and their practical applications, being able to recognize the benefits and potential applications of such processes. By incorporating these advanced digital tools and techniques into construction education, this study contributes to the industry's readiness for the evolving landscape of construction and ensures that future professionals are more competitive and well-prepared for the construction industry's digital transformation.

Key Words: Construction Education, Drone Photogrammetry, Building Information Modeling (BIM), Scan-to-BIM, Point Cloud

Introduction

As technology becomes increasingly integrated into everyday construction practices, construction education programs are proactively adjusting their curricula in collaboration with academic institutions and industry stakeholders. The upcoming generation of the construction workforce needs to be adequately prepared and equipped with the essential skills and tools required for the evolving technology landscape. Notably, drone-mediated photogrammetry technologies has become increasingly adopted in the construction industry thanks to advancements in engineering, robotics, sensors, geomatics, and remote sensing (Colomina and Molina 2014). This technological progress has paved the way for the application of drone-mediated photogrammetry in various construction-related tasks, ranging from site feasibility assessments and planning studies to structural and infrastructure inspections, progress monitoring, safety management, and post-disaster reconnaissance (Albeaino and Gheisari 2021). The construction sector, in particular, stands at the forefront of drone adoption, surpassing all other industries (DroneDeploy 2018), and the construction drone market is anticipated to reach USD 11.9 billion by 2027 (Allied Market Research 2020). Therefore, it is imperative to equip construction management students with essential drone-related skills and tools to ensure their readiness for the future of the construction industry.

Educators have started to actively address this need to prepare the future of the workforce by introducing drones to students (Al-Tahir 2015; Molina et al. 2014; Sharma and Hulsey 2014; Williamson III and Gage 2019; Wlodyka and Dulat 2015). Emerging drone learning interventions provide essential knowledge on different drone vehicle configuration and photogrammetry concepts. In addition, these interventions also familiarize students with contents such as regulatory knowledge from the Federal Aviation Administration (FAA) rules of the Part 107 requirements, multiple applications of drones in construction, and various drone configurations and payloads. Certain institutions have even introduced online drone courses specifically tailored for construction management students, providing them with the opportunity to obtain certifications and acquire essential knowledge in the field of drones (Burgett 2021, 2023). Some other studies have delved into novel training approaches to develop student skills through hands-on interventions. These include the development of virtual reality (VR)-based training environments for drone inspection operations (Albeaino et al. 2022a; Sakib et al. 2021), and assessing the utilization of 2D-based flight visualization platforms to provide novice drone pilots with valuable insights derived from expert pilots' flight patterns (Eiris et al. 2021). Additionally, the effects of drones as a method for attracting K-12 students towards construction disciplines is being explored by researchers (Isingizwe et al. 2023).

At the same time, educators have introduced students to the application of drone-mediated photogrammetry in the construction industry. Drone-mediated photogrammetry, also known as aerial photogrammetry, involves the use of camera-equipped drones to capture aerial images of a target area, which enables the generation of 3D models and maps (Deliry and Avdan 2021). This technique relies on Structure from Motion (SfM), which processes the images acquired by drones. It does so by identifying and matching feature points in the collected images while simultaneously estimating camera positions and the 3D structure of the scene, leading to the generation of 3D models (Deliry and Avdan 2021). The drone-mediated photogrammetry process has gained widespread adoption within the Architecture, Engineering, and Construction (AEC) domain, with applications including structural and infrastructural inspection, safety monitoring, transportation, historic preservation, urban planning, and progress monitoring (Albeaino et al. 2019). In the realm of construction education, Eiris et al. (2018) and Albeaino et al. (2022b) have provided students hands-on experiences in drone photogrammetry. These experiences encompassed the collection of drone images and videos, as well as the processing of this data through the SfM workflow to generate 3D models. Albeaino et al. (2022b) have also focused on exposing students to the effects of different photogrammetric flight parameters on the quality of the resulting point cloud models. However, none of these studies have explored the integration of drone-based photogrammetry with Building Information Modeling (BIM) for the purpose of conducting Scan-to-BIM processes. In the realm of cutting-edge construction methods, Scan-to-BIM stands out as a prominent approach, utilizing 3D point cloud data acquired through various as-built data acquisition tools and techniques, including photogrammetry, videogrammetry, as well as terrestrial and aerial laser scanning, to create or reconstruct accurate as-built building information models (Son et al. 2015). These Scan-to-BIM processes not only facilitate quality assurance/control tasks for construction managers on jobsites but also enable proper design validation, clash detection, progress monitoring, and detailed visual documentation (Son et al. 2015). Recognizing the importance of incorporating Scan-to-BIM into the skill set of construction management students, this advanced technique enhances their ability to conduct vital tasks, such as quality assurance/control, progress monitoring, and facility maintenance. Moreover, this technique fosters a proactive approach toward error prevention, cost reduction, safety enhancement, compliance assurance, and client satisfaction (Rocha and Mateus 2021). This strategic skill development ensures that future construction managers are not only adept at traditional methods but are also at the forefront of technological innovations, equipping them with the necessary skills to navigate the evolving landscape of construction practices and enhance efficiency and competitiveness within the industry.

This study reflects on a recent initiative aimed at incorporating drones and photogrammetry into construction education, specifically focusing on Scan-to-BIM – the process of converting point cloud data into building information models. The study starts by introducing construction management students to the fundamentals of drones in construction and the process of Structure-from-Motion (SfM) photogrammetry. Subsequently, students were tasked with applying their theoretical knowledge to create point clouds using a series of drone-captured images of a real-world building with the aim of understanding the effects of different flight parameters on the resulting point cloud accuracy. They were then provided with drone-generated point cloud data and asked to perform measurements on that 3D model to create a building information model of that facility. This allowed for in-depth analyses of both 3D models, leading to the formulation of conclusions. The subsequent sections of this study elaborate on the methodology adopted, present and discuss the results obtained from students' work and their feedback, and provide insights derived from lessons learned.

Methodology

Course Context and Module Description

The course BCN4252: Introduction to Building Information Modeling is offered to undergraduate construction management students at the M.E. Rinker, Sr. School of Construction Management, University of Florida. This course exposes students to advanced BIM workflows such as model coordination (clash detection), estimating and takeoffs, project visualization, and the utilization of advanced technologies such as virtual reality, augmented reality, mixed reality, 360° photography, light detection and ranging (LiDAR), laser scanning, and drone-mediated photogrammetry. The course is structured into various modules, each dedicated to one of these topics. Each module comprises a theoretical and an applied session.

Within the course, there is a module assigned to the theoretical components of the drone-mediated photogrammetry. This module familiarized undergraduate construction management students in Spring 2023 with fundamental knowledge regarding drones and photogrammetry. It covered FAA Part 107 certificate testing requirements, including topics such as airspace classification, aviation weather reports, as well as operational rules and restrictions. The theoretical components also exposed students to the multiple applications of drones in Architecture, Engineering, and Construction (AEC), as well as various drone types such as rotary-wing quadcopters, hexacopters, octocopters, fixed-wing platforms, and blimps, while highlighting their respective advantages and disadvantages. Additionally, students were introduced to the different software and hardware components mounted on the platforms, as well as the common payloads and autonomous features used by construction professionals for various tasks in construction. A discussion pertaining to the safety hazards related to drone operations on construction sites was also included. The module also covered the entire process of SfM-based photogrammetry, including the process of generating 3D models (e.g., orthophotos, digital elevation models, point clouds) using drone-acquired images as well as the factors (e.g., image overlap percentage, camera angle, elevation) that are known to affect the quality of the generated point cloud models. Lastly, it introduced the different software packages used by construction professionals for point cloud generation. The theoretical and applied sessions were spread over four sessions (2 weeks), totaling six hours. Detailed learning objectives for the theoretical session can be found in (Albeaino et al. 2022b).

The applied component of the drone-mediated photogrammetry module consisted of two parts (Figure 1). Part I involved providing students with a set of drone-acquired images (total of 193 images) of a 924 m^2 building facility located in Gainesville, FL. Students were asked to process these images, which were collected at different drone heights and camera angles (high, low, and oblique), to generate point clouds of the building facility using SfM photogrammetric range imaging technique. DroneDeploy®, a widely adopted web-based SfM processing software in the construction industry (Albeaino and Gheisari 2021), was used to process the drone-acquired images. Students were expected to generate two distinct point clouds as follows: (1) the first point cloud was created using a set of drone-acquired images with a ground sampling distance of 0.05 cm/pixel; (2) the second point cloud was generated using a combination of high, low, and oblique images, each with different ground sampling distances, including 1 cm/pixel (high), 0.05 cm/pixel (low), and oblique images acquired at a 45° angle. The goal was to allow students to explore the impact of different flight parameters (angle, height, image combinations) on the quality of generated point cloud models. Additional details pertaining to the learning objectives of Part I as well as the process used for data collection and point cloud generation can be found in (Albeaino et al. 2022b).

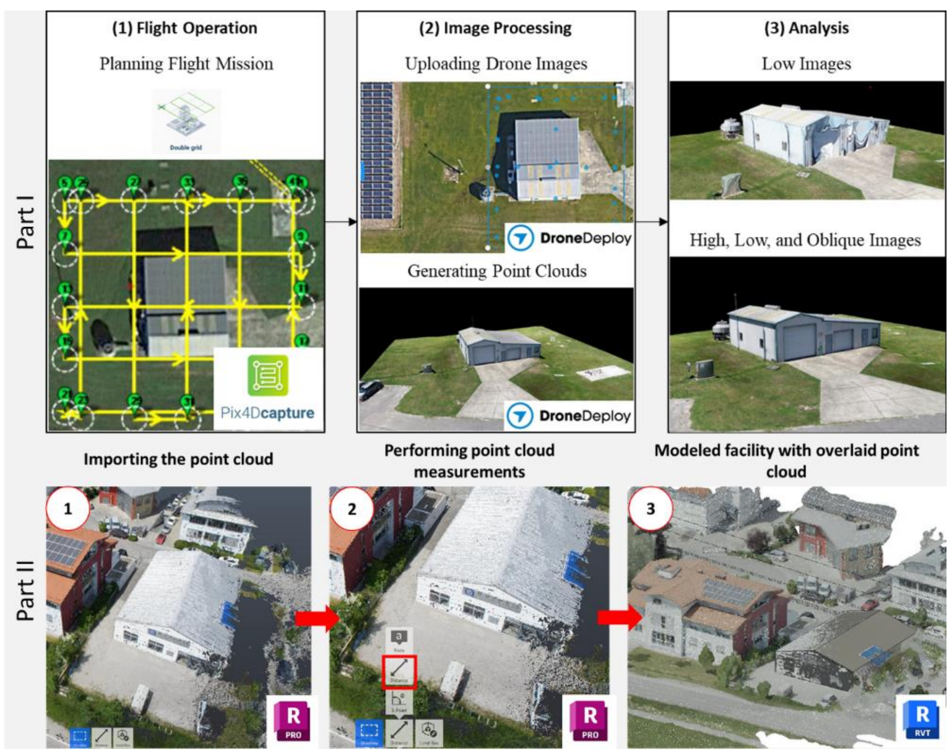

Figure 1. Adopted workflow for parts I and II of the applied drone-mediated photogrammetry module component

Part II of the applied component of the drone-mediated photogrammetry module introduced students to Scan-to-BIM, converting point cloud data from drone images into building information models (Figure 1). The learning objectives of Part II were to: (1) Gain proficiency in the sequential workflow of point cloud data processing, covering importing, filtering, cleaning, and exporting; (2) Learn practical techniques for utilizing point cloud data in BIM models; and (3) Explore the broader role and diverse applications of point cloud data within the context of BIM. Specifically, students downloaded a drone-generated point cloud from the example projects provided by PIX4Dmapper© (Pix4D 2018). Then, students imported the point cloud data into Autodesk ReCap© Pro, enabling them to perform an extensive exploration of the 3D model and subsequently export it in the .rcp format. Following this step, the students imported the point cloud into Autodesk Revit© in .rcp format. Within Autodesk Revit©, the students engaged in the iterative Scan-to-BIM process, conducting measurement of distances within the point cloud using Autodesk ReCap© Pro and relying on this information to model the building structure and its associated roof in Autodesk Revit©.

Scan-to-BIM and Drone-mediated Photogrammetry Module Assessments

To assess the knowledge generated from the Scan-to-BIM applied section of the drone-mediated photogrammetry module, students were provided with a set of questions that asked them to explain the process of Scan-to-BIM, discuss the benefits of using Scan-to-BIM technologies in the AEC domain, and to deliberately provide two examples of Scan-to-BIM applications throughout the pre-construction, construction, and post-construction phases of a project. This assignment was graded over 60. Furthermore, an online adapted version of the module evaluation questionnaire was conducted using Qualtrics (Qualtrics 2021) to collect feedback from the students regarding their satisfaction with the drone-mediated photogrammetry module (Evans 2023). The module evaluation questionnaire provided students with the opportunity to share their perspectives on various aspects, including their engagement levels, their assessment of the module, its learning activities, and its impact on their knowledge, understanding, and skills. Additionally, the module evaluation questionnaire included two open-ended questions, asking students to indicate how the drone-mediated photogrammetry module helped them to improve their knowledge, understanding and skills, in addition to any general comments they would like to make about this module.

Results and Discussion

Eleven students completed the Scan-to-BIM part of the drone-mediated photogrammetry module. Overall, an average overall grade of 53 ± 7 out of 60 on the Scan-to-BIM assignment demonstrates that students acquired a good understanding of Scan-to-BIM processes after completing the 6-hour sessions of the module. They were able to effectively explain the process of Scan-to-BIM and discuss its benefits. For example, students indicated that Scan-to-BIM process is *"particularly useful for renovation or retrofit projects"*, being able to reflect the *"as-is site conditions"* and identify *"changes or damages"*. This allows project stakeholders to *"accurately assess existing conditions and make informed decisions about how to proceed with the project"*, which *"minimizes the need for physical labor and time lost"*, and result in *"increased visualization"* and *"improved collaborations"* by *"reducing human errors and conflicts"* associated with traditional data collection. Students were also able to provide various Scan-to-BIM application examples, ranging from the pre-construction to the post-construction stages of a project. Pre-construction application examples provided by students included designers relying on this technology to *"understand the site conditions better"*, *"conduct site analyses"*, and *"help with planning renovations or extensions for buildings that do not have existing structural and design documentation"*. Construction application examples provided by students included quality assurance/quality control tasks, with some students indicating that Scan-to-

BIM can be used to *"evaluate conformance with designs"*, allowing for *"any conflicts to be rectified and revised in during early stages"* rather than *"making costly change orders on-site"*. Other students indicated that Scan-to-BIM would be useful for progress monitoring, indicating that this technique allows for *"comparison against planned schedule at every stage of a project"*. Post-construction examples included *"facility maintenance operations"*, *"record-keeping"*, and *"digitization purposes"*. By providing students with hands-on knowledge of modern construction technologies, their construction management skills would be improved. This makes them become more prepared for the construction industry by ensuring that they are skilled at utilizing advanced digital tools (i.e., drones) and techniques (i.e., photogrammetry, scan-to-BIM) for planning, quality control, and project monitoring. Such technology-driven skills, combined with their knowledge of traditional construction methods, enable construction management students to be more well-rounded and competitive professionals in the industry.

Table 1

Responses to the module evaluation questionnaire (Evans 2023)

Questions	Ratings	N (%)
On average, what was the total time you spent working on this module per week?	0 – 5 hours	10 (91%)
	6 – 10 hours	1 (9%)
	More than 11 hours	0 (0%)
My attendance for this module was good	Strongly agree	8 (73%)
	Somewhat agree	3 (27%)
	Neither agree nor disagree	0 (0%)
	Somewhat disagree	0 (0%)
	Strongly disagree	0 (0%)
I was well-prepared for the learning activities for this module	Strongly agree	8 (73%)
	Somewhat agree	3 (27%)
	Neither agree nor disagree	0 (0%)
	Somewhat disagree	0 (0%)
	Strongly disagree	0 (0%)
I participated fully in learning activities for this module	Strongly agree	9 (82%)
	Somewhat agree	2 (18%)
	Neither agree nor disagree	0 (0%)
	Somewhat disagree	0 (0%)
	Strongly disagree	0 (0%)
I engaged with the module beyond the minimum guidelines	Strongly agree	4 (36%)
	Somewhat agree	4 (36%)
	Neither agree nor disagree	1 (9%)
	Somewhat disagree	1 (9%)
	Strongly disagree	1 (9%)
Summary: I found the module	Excellent	8 (73%)
	Good	3 (27%)
	Average	0 (0%)
	Below average	0 (0%)
	Poor	0 (0%)
Open-ended question: Please indicate how this module helped you to improve your knowledge, understanding and skills.		
Open-ended question: Please add any general comments you would like to make about this module.		

As for the module evaluation questionnaire, the results revealed that all 11 students found the module to be either excellent (N=8, 73%) or good (N=3, 27%) based on their responses (1= excellent; 5 = poor) to the 'Summary: I found the module' question as shown in Table 1. The majority of the students (N=10, 91%) spent 0-5 hours per week on the module, with only 1 (9%) student spending between 6 and 10 hours. This suggests that the workload associated with the drone-mediated photogrammetry module was manageable for most. Additionally, a substantial percentage of students strongly agreed that their attendance (N=8, 73%), preparedness (N=8, 73%), and active participation (N=9, 82%) in learning activities were positive aspects of the module, reflecting a high level of engagement with the module. However, when it comes to engaging with the module beyond the minimum guidelines, the responses were mixed, with 27% (N=3) expressing some disagreement and/or remaining neutral. This suggests room for improvement in encouraging more students to go beyond the basic requirements. While students generally had a good level of engagement, there is an opportunity to enhance the module's depth of engagement and cater to a wider range of student preferences and learning styles. Students' feedback on the open-ended questions provided valuable insights on the drone-mediated photogrammetry module, with students indicating a significant improvement in their understanding of the subject matter, noting that they "*learned a lot"*, that the module informed them of *"different methods of surveying and capturing data that can be integrated into construction processes"*, that they are *"now much more knowledgeable about drone scanning technology"*, and that they *"liked the module a lot"*. Other students appreciated the module's combination of theoretical and applied knowledge and stated, *"the module helped me understand drone usage in construction"* emphasizing the effectiveness of the course structure and indicating that the module was *"very well organized"*. The hands-on aspect of the module and exposure to various drones and systems on real jobsites were described as enjoyable and informative, with one student expressing, *"I enjoyed learning about different drones and systems and how they are used on a real jobsite"*. The feedback also highlighted the importance of practical activities and more hands-on assignments to apply the newly acquired knowledge. While some students wished for more practical experience, the module was generally seen as engaging and informative.

Conclusion

This study reflected on a recent effort to integrate drone-mediated photogrammetry and Scan-to-BIM processes into an undergraduate construction management course. Increasingly, the construction workforce needs to be adequately prepared and equipped with the essential skills and tools required for the future of technology in the industry. To advance this goal, this study provided construction management students with the opportunity to theoretically and practically explore the fundamentals of drones and SfM-based photogrammetry processes. This was achieved by a set of hands-on activities which included SfM-based point cloud generation and the process of converting drone-acquired point cloud data into building information models, also known as the Scan-to-BIM process. The results showed that the Scan-to-BIM part of the drone-mediated photogrammetry module was highly effective, with students achieving a strong understanding of Scan-to-BIM processes and their practical applications. The module received positive feedback from students, who found it well-organized, informative, and engaging, leading to a significant improvement in their knowledge and skills related to drone technology in construction management. However, there was a potential for further enhancing student engagement and encouraging them to go beyond the minimum requirements in the module, suggesting opportunities for improvement.

As part of future coursework, students in the BCN4252: Introduction to Building Information Modeling course will have the opportunity to develop and enhance their hands-on drone flight operation skills, which are a vital component of the drone-mediated photogrammetry workflow. The images provided to Spring 2023 students were captured by graduate assistants who possess Part 107 certification, a measure taken during the COVID-19 pandemic. This prevented students from engaging in the practical experience of piloting drones, configuring flight parameters, and collecting data by surveying the facility. By operating drones and configuring flight parameters using the ground control station, students will gain comprehensive exposure to the entire drone-mediated photogrammetry process, which encompasses data collection, processing, and analysis. Furthermore, additional Scan-to-BIM hands-on activities will be conducted as part of future work. These activities will include performing quality assurance/control tasks through comparative analyses between as-built (i.e., point cloud data) and as-modeled (i.e., building information model) conditions. Students will also be given the opportunity to compare point clouds generated using Structure-from-Motion (SfM) and drone-acquired images with those generated using laser scanning devices. This comparison will shed light on the accuracy variations in the point clouds and illustrate how these discrepancies can affect the building information model, revealing their direct implications on the representation of the actual real-world facility. Given the small number of students who participated in this module, the insights gained from this study warrant further validation and in-depth analysis in future research with a larger and more diverse sample size. Subsequent studies should explore various parameters, including but not limited to, the effects of varying time commitments on module outcomes. In addition, while this study provided valuable insights into students' overall satisfaction with the drone-mediated photogrammetry module, future research endeavors should delve deeper into specific preferences within the theoretical and applied sessions, providing a more nuanced understanding of the factors contributing to student enjoyment and learning outcomes.

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