Integrating the Use of UAVs and Photogrammetry into a Construction Management Course: Lessons Learned.

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Abstract –

Unmanned aerial vehicles (UAV) have gained tremendous interest in the construction management domain as a platform for progress monitoring, safety supervision, quality inspections, and overall job site logistics. With the continued growth of UAV application within construction domain, it is essential for construction program graduates to develop a general understanding of UAV operations, regulations, and integration with other technologies as a part of their construction curriculum. This document presents an exploratory case study to identify the potential opportunities and challenges of integrating a UAV and photogrammetry module into a building information modeling (BIM) undergraduate-level course. Photogrammetry and BIM integration with UAV have been selected as the use case because of their widely-used applications in construction domain. The module learning objectives as well as the technical components of flight operations, knowledge tests, and photogrammetry workflow integration are discussed in detail. This module provided an opportunity for students to obtain hands-on experience on both software and hardware sides of the UAV, Photogrammetry, and BIM integration. This allowed the students to successfully assess and implement these technologies in a realistic practice exercise. Challenges were found with the time required for student to be sufficiently effective pilots to perform the UAV flight operations under the hardware limitations of the study. Additional blockades were recognized during the integration of federal aviation administration (FAA) UAV regulations within the module. The contribution of this case study is to provide a better understanding of integrating the use of UAV and photogrammetry within an undergraduate construction curriculum.

Keywords –

UAV, Photogrammetry, Education

1 Introduction

The use of Unmanned Aerial Vehicle (UAV) technologies in the construction domain has been continuously growing over the past decade. Academicians and industry professionals have presented tremendous interest in this technology as new technological advancements have decreased the cost, and increased the reliability, flight time, and manoeuvrability of UAVs. Construction professionals seek for safer and more efficient means for conducting their construction management operations and UAVs might be a platform to facilitate them with their tasks [1].

Some recent applications of UAV technology include: building or safety inspection [2,3], progress monitoring [4,5], damage assessment [6], site mapping and surveying [7, 8], building maintenance [9], among others. Most studies consist of two basic steps: UAV data acquisition, and data processing and analysis. UAVs equipped with various sensors have been used to capture visual, thermal or geographical data, then make use of the data to evaluate the condition of target structures or sites. Photo-/video-grammetry has become a widespread technique employed to process and analyze aerial photographs or videos. In such photo-/video-grammetry techniques, the data captured by UAVs has been mainly used to generate point cloud data for applications such three-dimensional modeling [10] or distance measurement [11].

As these applications become more generally employed in practice, a need has arisen for university-level courses that integrate them as part of their curriculum. Efforts have been done in STEM fields to integrate these technologies in their curricula. Mechanical, electrical, and computer engineering, have concentrated on the hardware and software design of the aircraft [12, 13]. In geomatics, the educational aspect of UAVs has focused in geospatial thinking, where the students collect aerial images for remote sensing and image processing purposes [14-16]. Nevertheless, UAV and photogrammetry technology integration in construction management education remains largely unexplored in the construction literature. This paper investigates this integration by using a case study where these technologies are integrated into an undergraduate-level course as a hands-on module.

2 Research Motivation and Scope

The construction management domain is currently undergoing a vast technological and institutional transformation with the adoption of visualization tools such as BIM, and virtual reality (VR) [17, 18]. In the educational context, these innovative technologies have been successfully integrated into several program curriculums using various teaching modules that follow core construction concepts [19]. UAVs offer reductions in work load, risk, and overall cost of some construction operations [3, 20] and over the last few years, this technology has become very popular in the construction domain. Although UAV technologies might have been used by various construction management programs, there are no publications in the construction literature that addresses the pedagogical challenges and opportunities present in the implementation of these technologies in construction management education.

This study discusses a hands-on module aimed to enhance students learning about UAV technology for reality capturing purposes and how it can be used for building information modeling. Without this type of hands-on learning experience, students would have to gain these skills during their internships or after graduation. In this paper, an analysis of the module components (flight evaluations, knowledge tests, and photogrammetry workflow integration) are discussed. Additionally, the pedagogical opportunities and challenges would be explained.

3 Module Design

The module has been designed for the undergraduate-level course BCN4252: Introduction to Building Information Modeling at the University of Florida based on empirical experience of current construction practices in the United States. The course focuses on advance BIM (Clash Detection, Quantity Takeoff, Site Development, Walkthroughs) and related construction technologies (VR, AR, 360-degree photography, UAVs, Photogrammetry). In the course, 7 sessions are dedicated to UAVs and Photogrammetry. These sessions are divided into two major components: knowledge development and hands-on training. During knowledge development sessions, the basic concepts relating to the UAV applications, operations, regulation are introduced. The relationship between UAV and photogrammetry is described by providing practical examples of the integration of these techniques in the BIM methodology (e.g. surveying, mapping, inspection, progress monitoring, and clash detection). Additionally, software and techniques used to generate these point clouds are discussed within the construction domain. In the hands-on training, student perform UAV flight operations using a UAV to generate point clouds through the employment of software workflows. These actives have several learning objectives and expected outcomes that would be discussed in this section.

3.1 Learning Objectives and Expected Outcomes

In the knowledge development sessions of the module, students are expected to understand the definition of UAV, differences between fixed-wing and rotary-wing UAV, key components on a rotary-wing UAV, description and advantages of UAV autonomy features such as waypoint navigation, obstacle avoidance, auto-takeoff and return home. The students are also expected to gain basic understating of UAV regulation in relation to airspace classification, operation requirements and flight restrictions. In addition, students should have been able to define photogrammetry, identify their advantages and shortcomings, and evaluate the incorporation of these techniques into construction-related applications.

In the hands-on training part of the module, students are expected to perform various UAV flight operation tasks and understand the fundamentals of UAV safe flight. Students are also instructed to generate three-dimensional models using recorded photographic data obtained from UAVs, integrating a photogrammetry software workflow.

3.2 Flight Operations

This section of the module evaluates the students' UAV flight skills. The evaluation consists of three different flying tasks, where the students fly the aircrafts above a linear path with three stops – two on each end, one in the middle as shown Figure 1. Stops are marked as numbered circles. A mannequin head is placed in between each of the paths and elevated to a height of four feet by a platform. The students exercise ascend, descend, yaw, roll, and capture pictures or videos using UAV during the flight operation.

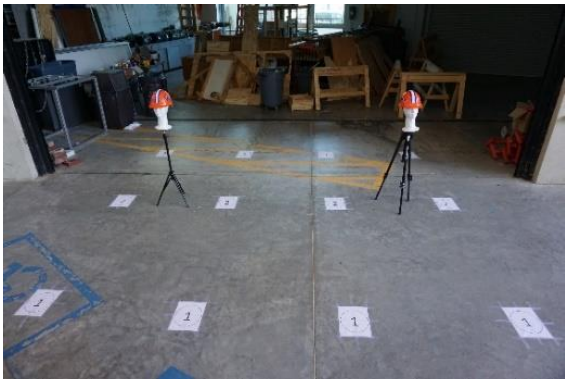

Figure 1. Flight Operation Exercise Area

The difficulty of maneuver in each task increases progressively from beginning to end, which simulates a typical flying session on construction site. Takeoff and landing are included in all tasks as they are critical every time a UAV is flown. To perform the tasks, students use the Syma 5X aircraft, which is equipped with a Full HD camera sensor. The selection of this aircraft was mainly driven by the cost, but other factors such as reliability and maneuverability were considered. Figure 2 displays each task to be performed by the pilots. Initially, task 1 requires the pilot to controls the UAV to take off, ascend, then land on the same location. During task 2, the pilot controls the UAV to take off, ascend, yaw 360 degrees, then land the UAV on the same location. In task 3, the pilot controls the UAV to take off, ascend, yaw 90 degrees then roll to the next stop and land UAS on the circle. Then, the student control the UAV to take off and ascend again, direct the camera to the object, capture a video, roll to circle 3, then land UAV.

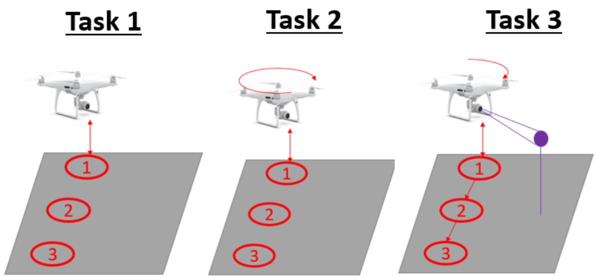

Figure 2. Flight Operation Tasks

Before the test, an ungraded preliminary practice session is provided for the students to familiarize themselves with the operational characteristics of the aircraft selected for the study. Students are divided into four groups, each corresponds to a path within the testing area. Each path is dedicated to two students, who share one UAV and six batteries. Each student at each path has approximately 10 minutes to practice each flight task.

During the test, the students are divided into four groups. Each group is assigned to one path and had one visual observer that evaluates their flight performance. Students pilot the UAV employing the techniques acquired during the preliminary session and are graded by the visual observers based on a Likert scale that measures the performance of each task in a five-point scale, ranging from poor (1) to excellent (5). The students also provide open-ended comments on each task during the evaluation session.

3.3 Knowledge Test

In the United States, the regulatory agency Federal Aviation Administration (FAA) is responsible for setting the standards for commercial aerial operations throughout the country [21]. During 2016, the FAA set in place a standard for commercial operations of UAVs. Commercial pilots must obtain a certification to perform aerial operations, including those performed in the construction industry. The FAA requires for pilots to pass an evaluation regarding UAV regulations, airspace, weather, loading, performance, and operations to get accredited. Analogously, the European Aviation Safety Agency (EASA) have proposed a framework for the operation of UAVs under the A-NPA-2015 [22], classifying the UAV operations as "*Low-risk operation – 'open' category*" which encompasses "*small drones under direct visual line of sight operated within safe distance from persons on the ground and separated from other airspace users*" [22]. Nevertheless, the EASA is still under review and has not presented a final publication with the general ruling as December of 2017. The knowledge section of the module is created to discuss UAVs, these regulations, and their previous applications.

Throughout this part of the module, students are expected to gain a basic understanding of concepts relating UAVs, their applications, safety challenges, and regulations. To evaluate their comprehension of the material, a knowledge test is designed, containing 14 questions in all these topics. The test has five categories as follows:

- The concept of UAV
- UAV technical requirements
- FAA basic regulation and how it might relate to construction domain
- Current applications of UAVs in Architecture, Construction, and Engineering domain
- Safety challenges of using UAVs onsite

3.4 Photogrammetry Integration

For this study, a three-step photogrammetry workflow is used to help the students in their point cloud generation process (Figure 3). The initial step (1) of the workflow requires the extraction of the keyframes for the videographic data captured with the Syma 5X aircrafts that contain the mannequin head. To achieve this, the VLC media player (free and open-source) software is employed to attain screen captures of the keyframes in the video files. On the second step (2), Autodesk Recap® is used to generate the point cloud. The extracted keyframe images are imported into Autodesk ReCap® cloud-based software. An RCS (Point Clouds) file is obtained after processing, containing the mannequin head and the surrounding environment. Using the Autodesk ReCap® desktop software, the point cloud is cleaned with the objective of separating the surrounding environment and targeted object (mannequin head). In the last step (3), the cleaned RCS file is imported into Autodesk Revit ®, where it is scaled relative to the model, and positioned for display in an RVT (Revit Project) file.

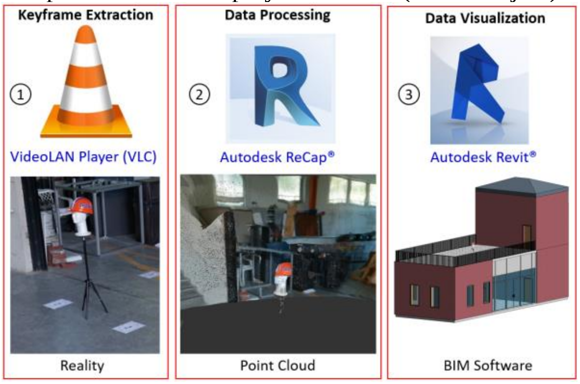

Figure 3. Photogrammetry Workflow

3.5 Data Sampling and Collection

For each section of the module data was collected from the students taking the course. In total, 11 students took part in this part of the module, performing all the tasks corresponding to each section. The data collection was done using the following criteria:

- Flight Operations: The students were evaluated by an observer based on their UAV flight performance using a five-level Likert scale: poor, fair, average, good, excellent. The evaluator graded the students' performance according to the tasks defined on section 3.2.
- Knowledge Test: The number of correct answers were collected from the quiz to evaluate the understanding of the participants regarding UAVs in the construction domain, its usage, and the FAA regulations.
- Photogrammetry Integration: In this section of the module, keyframe images obtained and RCS and RVT files were collected from the students. Each component was evaluated according to its completion and representation accurateness.

4 Results and Discussion

4.1 Participant Demographics

In the sample data collected for the study, it was found that subjects were mostly male (91%), with a minority of female (9%). The average age of the participants was 22 years, with a maximum of 24 years and a minimum of 21 years. All the students (100%) were in the senior year (4th year) of their university education. Generally, the students (82%) reported to have between one and five years of work experience in construction management, and the remainder (18%) informed less than one year of experience. Most of the students stated to have excellent or good eyesight (73%).

Overall, most of the participants did not have any experience with radio controlled (RC) cars, boats, or airplanes (64%) with none of them having any experience. with operating UAVs either in their personal time or at work. Many of the students also had an average knowledge of UAVs in construction (73%) and understanding of FAA regulation (55%).

Figure 4: Students performing flight operations

4.2 Flight Operation

The data collected from the flight operation performed by the students reveal that overall, as the difficulty of the maneuvers increase, the performance decreased (Figure 3). Task #1 - *UAV to take-off, ascend, and land*, was the highest scoring task on average, rating above "*average*" in the Likert scale, but it presented a wide dispersion (Mean: 3.2, Median: 4.0, IQR Low Bound: 1.0, IQR High Bound: 5.0). The evaluators noted that several of the participants experienced issues performing the maneuver as the UAVs "*do not go straight up and down*". Moreover, the evaluators also noticed that if "*the UAV [front] is facing the user, the maneuver difficulty may increase*", which indicates that it was challenging for the participants to identify the front side of the UAS in relation to their positions.

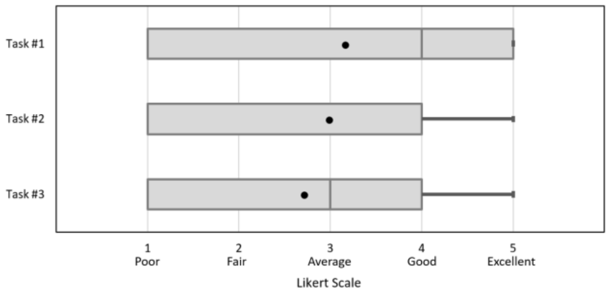

Figure 3. UAS Fly Tasks Grading

Task #2 - *UAV to take-off, ascend, yaw 360 degrees, then land*, was rated "*average*", displaying a wide distribution of scores, and leaned towards the lower end of the scale (3.0, 4.0, 1.0, 4.0). The evaluators commented that most students "*could not perform the 360-degree rotation*", as the UAV was "*hard to control*". Task #3 - *UAV to take-off, ascend, yaw 90 degrees, then* *rolls, captures a video, and land*, presented below "*average*" scores (2.7, 3.0, 1.0, 4.0), with a wide distribution leaning towards the low end of the spectrum. This was the most challenging task in the set of flight manoeuvres. The evaluators commented that the UAVs were "*drifting all over the place*". Additional comments were provided that identified issues with the recording of the video, as the UAV recoding light indicator would "*flash red light [recoding on] and then immediately go back to green light [recoding off]*"

Additional comments were provided by the evaluator immediately after the flight maneuvers were done, reporting hardware issues such as "*had to reset the UAV several times to reestablish the control link*", "*the UAV is very hard to keep steady*", and "*batteries change interrupted the UAV flight*". Additionally, the evaluators observed that "*more time practicing would be beneficial*" and that the participants that did not attended the practices session before the evaluation session had a lower overall performance.

Following the UAV flight operations, the participants reported the total workload required to perform the tasks using the NASA TLX [23] assessment tool (Figure 4). The participants indicated that the mental demand required for the flight tasks was above average (Mean: 11.5, Median: 14, IQR Low Bound: 6, IQR High Bound: 16) with high variability. It was observed during the flight maneuvers, that the participants required their full attention on the task to perform them according to the prescribed requirements. The physical demand reported by the participants was well below average (4.9, 5.0, 2.0, 7.0) with a narrow distribution of responses. The UAV operation required minor physical effort as there are radio controlled aircrafts. The only physical effort required was the manual set-up of the aircraft on the markers. The participants expressed that the temporal demand was below average (8.0, 8.0, 6.0, 11.0) with a narrow distribution. This indicates that the participants did not felt highly pressured in terms of the time or pace required for the tasks.

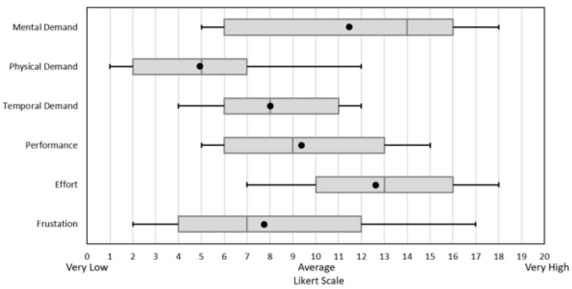

Figure 4. NASA TLX Grading

The participants reported that their overall performance of the task neighbored the average score, but this measurement present a wide distribution of responses (9.4, 9.0, 6.0, 13.0). This indicates that the average participant perceived to be successful in their task performance. Moreover, the participants indicated that the effort required to perform the task was above average (12.6, 13.0, 10.0, 16.0) with a narrow scoring distribution. Finally, the participants indicated a below average level of frustration (7.7, 7.0, 4.0, 12.0) with respect to the tasks. This suggests most of the participants did not felt irritated, stressed, or annoyed during the UAV flight maneuvers.

4.3 Knowledge Test

The knowledge test that the study participants took after the flight maneuvers, revealed that in average participant scored 18.2 out of 20 points with a standard deviation of 1.74. As shown on Figure 5., 45% received the maximum score for the evaluation. Overall, the questions that most participants answered erroneously were related to UAV and its flight height under the FAA regulations. This indicates that the participants had some difficulties understanding basic FAA regulations and their significance in the construction domain. Other questions that were incorrectly answered by the participants were mainly related to the concept of UAV and its application in the construction domain.

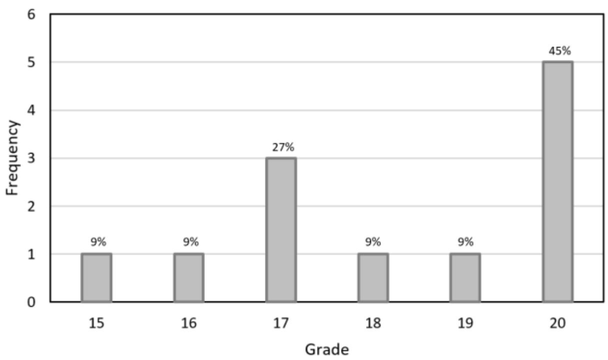

Figure 5. Knowledge Test Results

4.4 Photogrammetry Integration

After the participants concluded the flight operations, the videographic information was extracted from the UAVs, for posterior analysis using the workflow established on section 3.4 The video was successfully split into pictures by the participants using VLC MediaPlayer®, creating an average of 186 keyframe images in JPEG format.

The images were input into Autodesk ReCap® for processing, obtaining RCS format point cloud as a result. Within the same software, the participants cleaned the point cloud as contained the environment surrounding the target object, so that only the desired object remained. The resulting RCS file then was imported into an

Autodesk Revit® architectural model, where the point cloud was scaled to proportional measures to the model. The key issues reported by the participants related to the software the cloud-based software Autodesk ReCap®. Multiple uploading and processing errors of the images were found, mainly caused by the number of input images into the platform.

5 Research Limitations

This research has three major sources of limitations: (1) sample size, (2) participant experience-based limitations, and (3) hardware limitations. (1) The sample size for this study was very limited, containing only 11 participants analysed in the results. This implies that the observations presented in this study cannot be used to generalize beyond the sample population. As this is an exploratory study, the focus aimed to provide general overview of the variables and factors affecting the topic by directly reporting the lessons from the teachers, evaluators, and participants. Consequently, these lessons may not be representative for all instances or conditions in construction management UAV and photogrammetry education.

(2) The participants of the study did not have any experience flying UAVs excepting the preliminary practice session. The flying operation were directly affected by the deficient piloting skills of the participants during the evaluation session. This presented difficulties to obtain usable footage for photogrammetry application. (3) The UAV hardware used for the operation does not provide in-flight stabilization of the aircraft, which requires constant user input to maintain a leveled aircraft. Moreover, the UAV is equipped with a low-end camera without a gimbal, producing photos and videos only up to Full HD resolution. This introduces additional complications for inexperienced pilots to keep a fixed target focused for a reasonable amount of time, and further limits the quality of the 3D models to be produced from the photogrammetry process. With the intention of simplifying the flight operations to control for these variables, the UAV were flown in low altitude without any obstruction, wind or precipitation, (reducing the risk of losing control and crash), which is not representative of real-world fly conditions. With the same intention, the participants monitored the UAS closely in distance, making the tasks less challenging.

6 Opportunities and Challenges

The integration of UAV and photogrammetry in a BIM course module presented insightful pedagogical opportunities and challenges for undergraduate construction management education. The hands-on approach presented on this module enabled students to experience the common hardware and software-related problems professionals might encounter during the application of UAVs for generating point cloud data. The flight operations of the UAV provided a method for the students to experience the problem-solving skills necessary for a pilot to successfully obtain aerial imagery. Establishing a control link, battery life time constraints, and spatial awareness for UAV control were some of the identified factors that affected the students flight operations. Moreover, students understood BIM software interoperability limitations, as they were required to recognize the appropriate file formats for the manipulation of point clouds. Overall, students recognized the necessity for general troubleshooting knowledge in relation to the hardware and software involved in the technical workflow.

The challenges observed in the integration of these technologies into the module related to the UAV (flight, hardware, knowledge) and the photogrammetry software utilized for this study. This module comprised only twelve hours of lecture and lab time, which limited the time needed for the students to practice their flight skills. Only a two-hour session was employed for the students to physically perform the UAV manoeuvres, followed by the evaluation session. Another crucial factor that reduced the efficacy of the students' performance was the UAV hardware. The Syma 5X aircraft used in this study do not possess an automatic hovering feature, increasing the difficulty of any operation that requires steady image capturing. Moreover, constant supervision of the flight operations by the instructors is required, which effectively limits the number of students that can simultaneously fly the UAVs while achieving the learning objectives of the module. This level of supervision could be lowered by providing UAVs with more automated features, simplifying the flight tasks the students are required to learn. Nevertheless, the understanding of the image collection workflow still requires instructor guidance.

The UAV FAA content for the module was also hard to be integrated as this module did not aim to provide an exhaustive overview of regulations and pilot certification. Nevertheless, this module attempted to provide sufficient information to create awareness regarding UAV operations to the students. Only the three major topics that comprised the FAA Part 107 certification were covered at a basic level (regulations, airspace & requirements, and weather), but many other topics were left out. Finally, the software utilized to create the point clouds also generated challenging situations. ReCap® has the advantage of allowing cloud-based processing of the images, reducing the computational power required from the students' computers, but makes difficult the evaluation of errors that might occur during the point cloud creation process due to the limited feedback provided by the platform. Additionally, this software limits the number of images that can be uploaded to the platform, allow a maximum of 250 images.

7 Conclusions and Further Study

The use of UAVs and photogrammetry techniques within the BIM context has become generalized in the construction industry during the recent years. This has generated a necessity for program graduates to have a practical understanding of UAV operations, regulations, and integration with other technologies. This paper describes the opportunities and challenges observed in the implementation of UAVs and photogrammetry module in an undergraduate-level course. During the flight operations, knowledge tests, and photogrammetry workflow integration, data was collected to obtain insight on the design of the module. From the analysis of the data, it was found that the students had an overall "*average*" performance flying the UAVs, while they were highly constrained by the UAV hardware used in the module and the limited amount of piloting experience. Additionally, the photogrammetry workflow presented challenges during the point cloud generation due to limited amount of control and input that students and teachers had on the photogrammetry process.

Further investigation must be done to validate the findings of this study. Data sampling over various semesters is recommended to obtain generalizable results. Moreover, in the subsequent data collections, the hardware of the UAVs should also be improved to remove some of the limiting factors presented on this study. Additional practice sessions are recommended to improve the mastery of the students piloting the UAVs. Future research should explore the effects of the introduction of UAV/Photogrammetry module in program graduate education by assessing how valuable the skills obtained on the course are in relation to industry practice.

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